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ON DECOMPRESSION SICKNESS IN DIVERS: SOME OBSERVATIONS MADE DURING TRIALS FOR THE ROYAL NAVY

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SUMMARY

Diving is an ancient activity and its main complication, decompression sickness, has been described for at least a century. Theoretically treatment of this injury should present no problems other than those of technique. In practice there are many unexplained points which cast doubt on the efficiency of current methods of treatment. Diving trials using air, or oxygen and helium breathing mixtures are described as well as submarine escape training without the use of self-contained breathing apparatus. Cases of decompression sickness occurring during the trials are described and classified as major or minor depending on the therapy used. It is suggested that this classification is less confusing than others as there is no implication of aetiological factors other than decompression. "Pulmonary Barotrauma" develops by a different mechanism and is considered separately from "Decompression Sickness". The progression from dissatisfaction with recommended therapeutic routines to the development of complementary ones is shown. The application of basic principles to cases arising under conditions not previously encountered, is described. Case notes of 136 cases treated by recompression are given as well as comments on 261 other cases. Proposed therapeutic routines and illustrated records of some of the very deep therapies are included in the Appendices.

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CHAPTER I

INTRODUCTION

Scope of Diving

For more than two centuries diving has been carried on mainly for the purpose of salvage. For two thousand years there has been a military fringe benefit in damaging ships of the enemy. This military application was widened considerably in scope during the 1939 - 1945 war to include such activities as pre-invasion beach reconnaisance and attack on land-based installations, as well as being developed in its original role against shipping. The effect of this expansion was a great increase in the demand for knowledge of the effect on man of this underwater environment and in the number of trained men who were thrilled by the adventure. Technical advances led to the establishment, in the last two decades, of a new sport which now numbers its participants in hundreds of thousands. Thus an activity which 25 years ago affected perhaps 500 people in Great Britain, now involves over 1,000 in the Royal Navy alone and probably one quarter of a million in this country. At the present time breathing equipment has such a short endurance that the risk of decompression injury is slight for sportsmen, but with continuing advances in material, engineering, and design problems, breathing sets are becoming available that will place the divers using them at greater risk of specific injury due to diving. These cases may occur near coastal towns or inland villages, where water more than 20 feet deep is available for diving. This work will cover some aspects of cases at decompression sickness found in divers doing experimental work and in men undergoing submarine escape training, and more commonly known as "bends".

<u>Effects of Pressure</u>

Any reduction in the ambient pressure of man is a decompression. By physical laws the gases that such a man had been breathing must have been in solution in his tissue fluids as well as filling his air-containing cavities. The main physical laws observed are those concerning the solubility of a gas in a fluid; the concept of partial pressures; the relationship of volume and pressure; and the process of diffusion. A man at 33 feet in water breathing air from an adequate supply, is breathing at a pressure equal to the weight of 33 feet of water plus the whole height of the atmosphere which is equivalent to another 33 feet of water - in this case therefore the pressure is equivalent to 2 atmospheres absolute or twice the pressure exerted on a man at sea level. In response to laws of physics as the environmental pressure round the subject is reduced, i.e. as the man returns to the surface, the excess gases absorbed must either expand or come out of solution. This problem is magnified with increasing depth as the total pressure is increased by 1 atmosphere absolute for every 33 feet of water. If these expanding or evolving gases cannot reach the external environment, an injurious situation may arise and any detectable ill-effects are called decompression sickness.

Decompression Injury

Decompression Sickness is a term which appears self-explanatory and by implication suggests a condition which should respond to the straightforward application of the physical principles involved. Through the years and with the use of several therapeutic or preventive measures for ailments involving the teeth, the paranasal sinuses, and the middle ear space to name a few, the term decompression sickness now tends to be limited to conditions where gas bubbles are presumed to be present in the tissues of the body rather than in the body air spaces. Such bubbles may arise in situ or they may be introduced into the body accidentally. One important effect arising from the aetiology of the bubble is that the gas in the bubble introduced accidentally into the tissues is more likely to dissolve in the tissue fluids as these fluids usually do not contain as much gas in solution as those tissues in which the bubbles develop from supersaturation. In diving most bubbles introduced into the body arise from damage to the lung and as such the conditions thus produced are probably better grouped under the title "pulmonary barotrauma". The term "decompression sickness" would then be kept for those conditions presumed to be due to the evolution of gas from tissue fluids. The treatment is based on similar principles for both conditions. There have been very many communications on the ailment and related matters - more than enough to fill three large volumes of a bibliography. (85. 86. 87) However, surprisingly few accounts of the treatment of disease as seen in divers have been published compared with the numerous papers published dealing with the conditions as it occurs in tunnel workers, caisson workers, and in aviation.

<u>Pattern of Trials Work</u>

The majority of the cases described in this paper occurred in the course of work associated with the development of safe diving routines for men. The trials followed experimental work on animals, which was designed to test the theoretical calculations, and consisted of simulated dives in compression chambers followed by actual dives in water. The success or failure of the routine depended on the number of cases of decompression sickness that developed; too many cases meant that the routine was too dangerous while no cases meant that too many safety factors had been included. Once a routine had an incidence of 1 - 2% cases, standard safety factors would be added and the routine promulgated for general use. The trials medical officer was responsible for assessing each dive and for carrying out any examination or treatment. He was concerned in all matters that affected the divers and gave his advice in the planning stages of each trial as well as giving his opinion on progress.

<u>Types of Diving Considered</u>

Five types of diving will be discussed. Firstly in the normal dive the diver descends breathing the appropriate mixture to his depth, carries out his task, and ascends carrying out a decompression routine at various stages in the shallower part of his ascent. In a second type, after carrying out his task the diver ascends directly to the surface and enters a compression chamber where the pressure is increased and then released in a pre-determined pattern - this routine is called "surface decompression". Combined diving is a third variant and consists of a dive followed after a short interval at atmospheric pressure by another dive but the ascent from this second (or any subsequent dive) is so made that any remaining excess gas still present in the diver's tissues from the preceeding dive is taken into consideration. The fourth type of diving is known as "deep diving" and, while the exposure to pressure and time follows the normal descent, work, and then ascent pattern, the depth of such dives means that air cannot be used as the breathing medium by the divers. The fifth type, "submarine escape" dives are those in which the escaper or "diver" is exposed to rapid increases in pressure and after a minimal time at maximum depth, he carries out his ascent without breathing equipment. Circumstances have led to the problem being studied by the general practitioner away from skilled ancillary help, and in the nature of the activity producing the injury, this will almost invariably be the situation in which the doctor has to treat his patient. Pol and Watelle (124) in their paper which is commonly considered the first serious study of caisson workers apologised for their work as it had been done "sans plan, sans programme, sans ordre" as there had been no intention of publishing it. Over a century later, their sentiments are echoed.

CHAPTER II

COMMON TERMS USED IN DIVING

In very general terms a "diver" carries out a "dive" when a man, suitably equipped, goes under pressure greater than atmosphere for a time. This dive has three phases, one of increase of pressure, or "compression", one of duration at maximum pressure or "bottom time" and one of return to atmospheric pressure. Usually the first two are together called, "the dive" and the last is the "decompression". From the point of view of the diver, the most important pressure is that of the depth at which he is working. This pressure is related to atmospheric pressure at sea level which is treated as unity or "1 atmosphere absolute". Atmospheric pressure at sea level varies with weather conditions and latitude but these fluctuations are small relative to the large pressures involved in diving and may be ignored. It is convenient to express this unit in round figures as 15 pounds per square inch, 1 Kilogram per square centimetre or 33 feet of water and such values can be referred to as "an atmosphere". It follows that a diver at 33 feet in the sea is subjected to an ambient pressure of 2 atmospheres absolute, and at 100 feet, to an ambient pressure of 4 atmospheres absolute. In most pressure work, gauges read zero at sea level so that gauge readings are always 1 atmosphere or its equivalent less than the absolute pressure, thus the above diver is subject to a pressure of one atmosphere and 3 atmospheres gauge respectively. For convenience, the pressures in diving tend to be expressed as x feet of water (gauge understood) or y atmospheres (absolute understood) whereas compressed air working pressures tend to be described in pounds per square inch (gauge understood).

The situation is rapidly reached where it is injurious to return directly to atmospheric pressure because of the onset of symptoms and signs of "decompression sickness". To avoid this the diver follows a "decompression routine" described in "decompression tables". (Table II.1). Decompression tables are lists arranged in increasing order of depth in 10 feet intervals; in each interval, the duration of dives are arranged in lengthening order of time and usually in multiples of 5 minutes. Opposite a depth-time combination a row of figures gives the shallowest depth the diver may reach after a dive of this combination and the minimum time he must spend there to prevent the onset of decompression sickness before proceeding to his next depth/time pause; such depth/time pauses are "decompression stops" or "stages". The details for this "stage" decompression routine for a dive of a particular depth and a particular duration is referred to as a "schedule". If the decompression is carried out continuously the decompression routine is known as a "bleed" of so many units of pressure per minute. Decompression sickness has various synonyms such as "caisson disease", "bends" or "compressed air illness" in such industries as tunnel building and marine salvage and such as "aero-embolism" and "barotrauma" in aviation.

AIR DECOMPRESSION

Depth not exceeding (ft.)	Duration Time leaving surface to beginning of ascent not exceeding (minutes)		Stoppages at different depths (minutes)					Total Time for Decompression (minutes)
			50'	40'	30'	20'	10'	
80		30	-	-	-	-	-	-
		40	-	-	-	-	5	5
		50	-	-	-	5	5	10
		55	-	-	-	5	10	15
		60	-	-	-	5	15	20
		70	-	-	-	5	20	25
	Limiting	75	-	-	-	5	25	30
	Line	80	-	-	5	5	30	40
		90	-	-	5	10	35	50
		105	-	-	5	20	40	65
		120	-	5	5	30	45	85
		140	-	5	10	35	50	100
		160	-	10	30	40	50	130
90		25	-	-	-	-	-	-
		30	-	-	-	-	5	5
		40	-	-	-	5	5	10
		45	-	-	-	5	10	15
		50	-	-	-	5	15	20
		55	-	-	-	5	20	25
		60	-	-	5	5	20	30
	Limiting	65	-	-	5	5	25	35
	Line	70	-	-	5	10	30	45
		75	-	-	5	15	30	50
		80	-	-	5	20	35	60
		90	-	-	5	25	40	70
		100	-	-	5	30	45	80
		110	-	5	15	35	45	100
		120	-	5	20	35	50	110
		135	5	5	25	40	50	125
		150	5	10	35	40	50	140

Table II.1

Decompression Table

Extract from R.N. Diving Manual (133) showing schedules for dives to 80 and 90 feet. Dives below the limiting line should only be done in exceptional circumstances. In a previous edition (132) all dives above the limiting line were grouped in Diving Table I and those below the limiting line in Diving Table II.

When a dive is carried out in the sea it is known as a "sea dive" or "wet dive" and the expression of the pressure as depth in feet of water is logical. Certain pressure vessels are made in which the diver may carry out a dive where the increase in pressure is obtained by supplying gas, usually air, from a system of compressors and storage cylinders. For convenience in diving research, the pressure is often also expressed as depth in feet of water. Such vessels are known as "compression chambers" or"pots" and the diver carries out a "chamber" or "pot" or "dry dive". In commercial work the terms "caisson" or "tank" may be used for such vessels. The primary function of these chambers in naval work is the treatment of decompression sickness for which the patient is placed inside the "pot" and "recompressed". After relief of his injury the patient returns to the surface in a decompression routine intended to prevent reappearance of his signs and symptoms and generally referred to as a "therapeutic decompression".

When the decompression tables in general use are those for diving no deeper than 200 feet, they are called the "standard air tables" as air will be the breathing mixture used by the diver to sustain his life while underwater. If a diver carries out first one dive and later more dives, he is said to carry out "combined diving" or "repeated diving" or"multiple diving". Various instructions exist for discovering the decompression routine for such dives and an important point is the "surface interval" or time spent at atmospheric pressure between two dives. If for some reason the diver cannot carry out the appropriate decompression for his dive and is forced to return to atmospheric pressure he must be recompressed in a chamber within a very short time to carry out an appropriate decompression routine and this manoeuvre is referred to as "surface decompression".

"Deep diving" generally refers to all dives deeper than 200 feet and is so distinguished because air is unsatisfactory as the breathing medium for the diver. This is due to the amount of nitrogen present which causes "narcosis" and the danger from the amount of oxygen present of "oxygen poisoning". As a result the proportion of oxygen is reduced and the required bulk of the breathing gas usually then consists of helium. Such diving in the sea may involve the use of a chamber which can be lowered into the water and which can be kept empty of water but, because it can also be closed with the diver inside and he can carry out his decompression routine while so confined, it is called a "submersible decompression chamber". In two ships, one British and one Swedish, this submersible decompression chamber can be placed on top of a compression chamber and, once the pressure is equalised, the diver may "transfer under pressure" from relatively cramped to more comfortable surroundings to continue his decompression. If a diver is required at any time to vary the gas mixture that he breathes, for example if he breathes 100% oxygen during the final stages, he is said to be carrying out "oxygen decompression". In experimental work "oxy-helium" is the colloquial term for respirable oxygen and helium mixtures and is only qualified by the percentage of oxygen e.g. 5% oxy-helium. In such work also the depths may be as shallow as 35 feet but as the aim is to dive to great depths, all oxy-helium dives are considered "deep dives".

Once a technique of diving has been tried under very close supervision and in controlled conditions, it is taught in the training schools and can be used by men on their tasks. Thus it is changed from an "experimental technique" to an "operational routine". Certain modifications may be made to decrease risks. For example in looking up decompression tables for a dive, if the man has reached an exact depth or an exact duration, it is customary to use the decompression schedule for the next greater depth or longer duration. The operational teams consist of "Clearance Divers" who are highly trained volunteers. They have been taught to use self-contained breathing apparatus which is complete with its own gas supply whether it be air, or oxygen, or oxygen and nitrogen mixtures and which may be open circuit (i.e. exhaling into the water) or closed circuit or semi closed circuit. In addition they can use equipment, usually open circuit, where the gas, usually air, is supplied from the surface thus avoiding the problems of endurance. These men are popularly known as "Frogmen" and are full-time divers. Other naval ratings carry out their own various duties such as mechanics, storemen, communicators and cooks and dive as a part-time activity. Such divers are usually limited to self-contained or surface-supplied air equipment and are "Ship's Divers". The classical or"Standard Diver" with helmet and heavy boots has become redundant in the Royal Navy but he was used in most of the trials described here because of the ease with which his depth could be controlled.

The ease of a diver's progress under water is affected by his buoyancy which can be increased as "positive" buoyancy by his equipment and gas contained deliberately or accidentally in his clothing. It is customary to have the diver and his gear slightly "negative" or "neutrally" buoyant by making him initially "positively" buoyant and then adding lead weights to over-compensate or balance this. These weights can be "ditched" or rapidly released as a safety measure so that the restoration of his positive buoyancy will bring the diver back to the surface. The importance of buoyancy in this work is the effect on the effort required by the diver to carry out his descent and ascent as well as on his ability to keep a constant depth during his dive.

CHAPTER III

HISTORICAL REVIEW

It is a matter for surprise that a subject which is normally dismissed in most medical test books in a paragraph should have an extensive bibliography. Most of this literature is contained in the three volumes of the "Bibliographical Sourcebook of Compressed Air, Diving, and Submarine Medicine" which lists more than 10,000 references up to 1963 (85.86.87). Even at that, it is stated by the compiler (85) that the list is not comprehensive as papers of the last century and the early part of this one are inserted as much for their own lists of references as for their intrinsic merits.

Man has long wished to study the response of his kin to exposure to altered environment - particularly when the reaction was not a simple reversible one as superficial study suggested. When the problems started to involve thousands of people where previously the victims had been numbered in tens, as happened when civil engineers started tunnelling and when aviation soared towards space, the stimulus to study was great. This meant that the physiology, toxicology and traumatic possibilites of atmospheric pressure, oxygen, nitrogen and carbon dioxide when altered from normal values, came under the scrutiny of men in several disciplines of research and clinical work both for the study of avoidance of the problems as well as for the potential benefits to the individual, his well-being and his occupation. Behnke (18) considered that the nascent bubble had replaced the spirochaete as the great impersonator and the bulk of the literature describes the effects of the presumed attacker on the various systems of the body, rather than on the whole individual.

Very rarely is there one single paper which is a milestone; in this field more often a series of articles is collected in one volume either by one author or on one topic. Pride of place must go to Boyle (23), who in the course of studies on respirable atmospheres in evacuated chambers, recorded, in passing, the appearance of a gas bubble in the eye of a viper. While it may be true that this bubble was due to vaporisation (2), rather than to supersaturation of the aqueous humour, it is the first recorded observation of a bubble caused by reducing the ambient pressure. Injuries, including decompression sickness, must have occurred in sponge and pearl divers throughout the ages but the records are vague and more suggestive of the effects of unbalanced excess external ambient pressure at depth crushing the air-containing body cavities, especially the thorax and commonly known as "squeeze", than of decompression sickness. Triger (144), who developed the first practical caisson, is credited in an annotation of an address he gave in 1845, with the first description of a case of caisson disease. Pol and Watelle (124) in 1854 described their experience with commercial caisson workers in which they took advantage of the workers' own comments, deliberately to re-introduce a patient into compressed air as treatment for his condition - the first therapeutic compression - as well as recommending a period of half-an-hour for return to surface for all workers the first decompression routine. Many observers in this field produced concepts of the causation of decompression sickness which varied from the mechanical effects of high pressure and dense gas on circulation and respiration to more basic physical effects due to solution and evolution of gas in fluids. Hoppe-Seyler (88) in 1857 is credited by Hill (84) with being the first to point out that death occurred because of obstruction of the circulation by bubbles and to explain that this sort of condition was due to inadequate time for gas to escape from venous blood during its passage through the lungs. It is difficult to ascertain the order of priority of the many workers, mainly French and Central Europeans, in the various steps taken as often the vital point is obscured by the literary style as well as by the vast amount of speculation on the topic. However Paul Bert's work culminating in the publication of his book "La Pression Barometrique" in 1878 (18) stands out like a lighthouse in that his experiments established beyond argument that decompression sickness was due to gas absorbed during exposure to raised pressures and then released during the return to atmospheric pressure. His most practical point was his suggestion for a steady rate of decompression from the working pressure so that the decompression time was related to the working pressure instead of being a fixed duration. These principles were gradually accepted and work by various groups has been directed to establishing the various durations of exposure and total decompression and the rates of pressure change as modified by exercise, by temperature, by ventilation, by the respired gases (from pure oxygen to oxygen and helium mixtures) and by environment from sea as in diving, to air, as in commercial works such as tunnelling.

The aetiology of decompression sickness is the formation of intra and extravascular bubbles as described by Gersh and Harvey and their co-workers (30, 60, 61, 62, 63, 68, 69, 90). The only recent query of the bubble aetiology has been raised by End (58) who considered that high pressures led to intravascular sludging of the red corpuscles which blocked the circulation and led to the secondary appearance of bubbles as suggested by Swindle (143) but this work has not been confirmed nor does it appear to have been followed up.

On decompression theory, several groups have made major contributions the earliest being Heller, Mager and Von Schotter (71) who as a result of experiments and a review of the past in their exhaustive volumes recommended a decompression time of 20 minutes for exposure to each atmosphere greater than atmospheric pressure. Haldane with his co-workers, especially Boycott and Damant (22), reconsidered the stage method already touched on and discarded by Bert (18) and produced the first really practical diving tables based on work which showed that it was always safe to bring a man to half his absolute pressure if he had been saturated at that pressure - the 2 : 1 ratio concept. This meant that a diver could be raised to a depth for a period during which the excess gas would be evolved from his body thus enabling him to proceed to a shallower depth. It was far more practical to raise a diver through the water in steps than to provide a constant rate of travel. Hill carried out a considerable amount of work on decompression especially with Macleod which he gathered together in his book "Caisson Sickness" (84) but his work was more valuable for his confirmatory experiments than for any original concepts, he being a proponent of the bleed rather than the stage method. As a result of his work with Haldane, Damant (39) produced therapeutic decompression tables for compressed air workers suffering from caisson disease which introduced a decreasing rate of bleed. Smith (139) had previously suggested that a special treatment chamber be provided at compressed air workings but it seems that Moir (120) of Great Britain as a member of the consulting engineering firm supervising the work on the Hudson tunnel in New York, was actually the first man to have such a chamber provided and he claimed a dramatic reduction in fatal cases of decompression sickness once its use was established. That there was a need for such measures is shown by the many series including both fatal and non-fatal cases reported which ranged from the 63 cases by Pol and Watelle (124), in 1854 25 cases by Littleton (99), 119 by Woodward (151), 3,692 by Keays (90) to 689 by Campbell Golding et al (28) in 1960. Steadily since 1854, prodded perhaps by compensation claims for death and disability, industry has gradually increased the decompression time from a fixed 30 minutes irrespective of pressure to the varying scale of the current Compressed Air Special Regulations (119) with its varying rates to a slowest of $9\frac{3}{5}$ minutes per pound per square inch (usually regarded as 10 minutes per pound in practice)

In the Haldanian theory it was postulated that there were hypothetical tissues of various half-times to saturation from which it was possible to calculate diving tables on the assumption that each tissue could tolerate a supersaturation equivalent to double that of saturation at ambient pressure. Through the years this concept has been elaborated by many workers who, as a result of experience, have increased the number of tissues, and varied the ratio for each tissue; nowadays some workers have a multi-tissue model each tissue having a different half-time with its own ratio which varies with the absolute pressure and with the inert gas being breathed. Hempleman and Rashbass and their colleagues (34. 35. 36. 37. 38. 54. 73. 74. 75. 76. 78. 126. 127) showed that Haldane's assumption (22) did not hold at greater pressures than 2 atmospheres absolute and they tried to simplify the procedure by treating the diver as if he was composed of one homogenous fluid which could safely tolerate a constant excess gas tissue tension. These two approaches led to the introduction of diving tables based on the ratio concept by Van der Aue et al (147) and by Dwyer (52) in 1957 into the United States Navy (145) and thence in most navies, and tables based on the single tissue idea by Crocker (35) into the Royal Navy in 1958 (132). (A comparison of these tables is part of this work). A Swiss mathematician and diver, Hannes Keller, startled the diving world in the early 1960's with his spectacular dives to various depths to 1,000 feet (91); his calculations seemed to be based on a 3 tissue model instead of the multiple tissue idea and on the use of maximal quantities of oxygen in his breathing mixtures to produce maximal gradients for elimination of absorbed inert gas. Regrettably he has endeavoured to keep the details of his ideas secret for commercial reasons but it is generally felt that there is no real new principle involved but rather a difference in technique and acceptable safety standards.

The treatment of decompression sickness in divers continued along the lines suggested by Damant (39). Shilling (137) collected a large number of reports of cases occurring in divers and compressed air workers and he produced a classification, based on the system of the body apparently affected, which has stood the test of time. Erdman (57) had preceded him with a similar but less comprehensive classification limited to tunnel workers. Behnke joined the team working on these problems in the United States Navy and has taken part in very many studies over the past 30 years. On the problem of decompression sickness his most lasting work may well be his share of the project that led to the production of a new therapeutic routine for divers (51), later evaluated by treatment of 113 cases; -- this work was so impressive it led to the adoption of the recommended tables with few modifications by almost every Navy in the world including the Royal Navy. (See Appendix II) (Behnke incidentally in the 1940's visualised the use some day of a compression chamber for the treatment of aviators' decompression sickness (6) but this was not done till reports of dramatic successes in the late 1950's led to a drastic re-assessment of this form of therapy by aviation medicine experts). The subject was surveyed and brought up-to-date in 1954 in the book "Decompression Sickness" (59) where the emphasis was more on the condition as met at low pressures by aviation personnel but Behnke (5) contributed his experiences with high pressure work.

Dudley (48) had summarised the basic principles of therapeutic recompression as follows: "The treatment of compressed air illness is immediate recompression. Recompression is preferably done in a chamber especially designed for the purpose into which air can be pumped rapidly up to any required pressure and in which the rate of decompression is under exact control". In the 30 years since that passage was written, the main changes are that one would now talk of "decompression sickness" to include those cases arising while diving with breathing gases other than air and one would add to the requirements of the chamber the facility of access by a medical attendant as needed, i.e. the chamber must have an access lock large enough to take a man. That recompression, when adequate, is the right treatment when treating cases of recent onset, is dramatically obvious to anyone who has worked in this field; as exemplified by the late Sir Robert Davis (42) who wrote "No one who has seen a victim of compressed air illness, gravely ill or unconscious, put into a chamber and brought back to life in a few minutes by the application of air pressure will forget the extraordinary efficiency of recompression or be backward in applying it to a subsequent case of illness". This can be contrasted with the inexperience shown in a recent report by Brunner et al (24) who treated cases of neurocirculatory collapse in decompression sickness by infusions and pressor drugs although a compression chamber was available in the same building.

The four variables of treatment are the pressure required, the stay at that pressure, the manner of the subsequent decompression, and the gas mixture breathed during the decompression. Any other treatment given in addition to recompression is ancillary and is more akin to good nursing with its benefits than to specific therapy. Keays, for example, in his large series (90) followed the practice of some predecessors and recommended that the pressure be raised to that at which the tunnel worker had been exposed during his shift - i.e. the working pressure. Damant (39. 40) recommended that the pressure be raised to that level at which the signs and symptoms disappeared - i.e. minimum effective pressure or depth of relief. The subsequent decompression was a steady bleed in Keay's routine and an increasingly slow "bleed-off" of pressure in Damant's method. In both methods air was breathed during the entire procedure. Griffiths (28) used to recompress his pain cases - which he called Type I Decompression Sickness - to 2 pounds per square inch above working pressure which he maintained for a period of 15 minutes after the disappearance of all signs and symptoms. If there was no relief, he then increased the pressure by 2 pounds per square inch every 15 minutes till relief occurred. He then decompressed fairly quickly to half the absolute pressure or 12 pounds per square inch (gauge) which ever was the greater and then continued decompression by reducing the pressure by 1 p.s.i. during 15 minutes. However he now uses the minimum effective pressure for relief waiting there for half-an-hour after relief of symptoms before decompressing in the same manner (67); this routine has led to fewer recurrences. In more gravely ill patients - Type II - he still returns to working pressure or higher if needed, and again after the disappearance of signs and symptoms (which may be several hours in clearing), decompression is started at 15 minutes per pound pressure to 15 p.s.i.g. and then 30 minutes per pound pressure to atmospheric pressure with a 4-hour pause at 12 p.s.i.g. and 2-hour pauses at 8, 4, and 2 p.s.i.g. In essence these routines started as "working pressure" methods but have been converted to "minimum effective pressure" methods.

In contrast the U.S. Navy Therapeutic tables (145) use the "minimum effective pressure" approach but once this has been found this is used to select an increment of pressure where the man is kept for half-an-hour before commencing decompression in stages gradually increasing in duration towards the surface. In addition, the use of 100% oxygen by the patient is optional although strongly recommended. These tables were based on decompression schedules devised to prevent the appearance of decompression sickness after a deliberate injury-producing routine, it being assumed that if signs and symptoms did not develop, then the table would probably be effective as a therapeutic regime in actual cases. The maximum pressure required was fixed at 165 feet (6 Ats.Abs.) as it was calculated that a further increase of 1 atmosphere or so would not have an appreciable effect and higher pressures introduced other complications as well as delaying the time when 100% oxygen could be used (7). (An experienced medical officer could vary these limits if he felt the case needed such increases). During the treatment of the more seriously ill cases, periods of continued exposure to certain pressures for 12 hours and 6 hours were introduced to try and saturate the patient at that pressure and reduce recurrence by allowing time for elimination of the bubble. (The Haldanian concept of ratio was modified in this work). Henderson (82) had foreseen the possibility of decompression sickness in aviators in 1917 but Boothby and Lovelace in 1938 (21) were the first to attribute a case to decompression sickness rather than to anoxia or some other diagnosis. Armstrong (2) described the similarity of the condition in aviators and divers but he was satisfied that the return to lower heights or ground level was adequate therapy. Due to his work attention was drawn to the problem during the war when bombers could not descend while over hostile territory to ease afflicted aircrew. Amongst the possible solutions Lawrence et al (97) reported on a "bends bag" into which the injured man could be placed and the pressure raised to 3.5 pound per square inch (equivalent to an altitude of 22,000 feet). This latter approach is an example of the use of the minimum effective pressure technique while the former methods can be considered as examples of the maximum available pressure routines. Behnke's suggestion (6) for compression of certain cases of aviation decompression sickness to pressures greater than atmospheric was a reasonable extension of the minimum effective pressure technique.

Several other matters affect the therapeutic decompression. The use of 100% oxygen has been investigated by several people (89. 157. 100) the most comprehensive work being by Behnke who believed it encouraged elimination of the inert gas in the noxious bubble (9). Donald (46) among others (122. 130. 158) believed in the occurrence of decompression sickness under certain circumstances when the diver was breathing only 100% oxygen. Oxygen and helium mixtures have been recommended (134. 135. 145) but the main use is for the comfort of the patient as difficulties in pulmonary ventilation are thought to be eased and the abolition of inert gas narcosis leads to a better attitude by the victim. Exercise during decompression has been the subject of controversy, being recommended by the Haldane group (22) and the Hill group (84) among others (10). Van der Aue with his group (146) conclusively showed that exercise increased the incidence of decompression sickness. It would appear that quiet movements to keep the circulation moving in all parts of the body is preferable to stagnation but that it is easy to overdo it and make an attack of decompression sickness more probable. Thus exercise during a treatment routine would also seem to be contra-indicated.

Eventually, the collected experience of several years of treating decompression sickness in divers was analysed by Slark (138) and by Mackay (106) in Britain and by Rivera (131) in America. In essence these papers showed how errors in application of the tables could be made as detailed by Behnke (5) and the opinions on need for future work were similar. The most startling finding was that the treatment routine for a gravely ill person could on occasion produce decompression sickness in an attendant who had been with the patient throughout but who had not had a pressure exposure before treatment started, i.e. the routine not only did not prevent the occurrence of decompression sickness in a man who had not dived but an overt attack could be produced. In the meantime experimental work on deep diving was restarting in several countries and other ideas on therapy were developing. For example Erde (56) has investigated the use of hypothermia combined with high pressure for neurological cases of decompression sickness with delayed treatment with inconclusive results and Barthelmy (3) in France has investigated the use of Heparin which he has shown has a protective effect on onset in dogs but no real effect on treatment in man. The use of glucose saline infusion or plasma was recommended by Behnke (6) and used in a very difficult case by Cockett and Nakamura (31). Nicotinic acid has been tried with doubtful effect (153) Eaton (53) has published his experience on the treatment of goats with decompression sickness in experimental work. His method depends on the minimum effective pressure which he maintains for a few minutes followed by decompression by a slow bleed until the animal becomes restless. The decompression is then stopped till the goat settles down when the bleed restarts; occasionally animals with spinal cord lesions do not respond and have to be destroyed. Although the indications would be less definite as divers tend to conceal the restlessness due to recurrence of symptoms till they are unbearable, his approach is worthy of attention. During current work in the U.S.N. Workman and Goodman (156) have produced a routine using minimal effective pressures, work matched by Barnard and Mackay (108) in the R.N. Both groups use much lower pressures for selected cases than the official tables and take much shorter times to carry out the subsequent decompression.

There are two main problems of decompression sickness in experimental work; first the possibility of the injury arising at greater pressures than published routines envisage; and second, the pulmonary irritant (45. 140) effect of dry gas containing high partial pressures of oxygen on the divers in the consequent prolonged decompression. The section on deep diving will exemplify the trial and error routines developed along the lines of minimum effective pressure, high oxygen levels, bleed-offs and prolonged pauses based on the experience of the past.

At this point it is worth considering the special problems that arise in diving to depths greater than 300 feet as far as physiology is concerned. The fact that oxygen at a partial pressure of 2 atmospheres in the sea could be acutely toxic was described during the Second World War in the work of Donald (44. 45). At 300 feet, or 10 Ats.Abs. the oxygen, in the 20% oxygen, 80% nitrogen mixture that is air, reaches toxic levels so that it is necessary to reduce the oxygen content of respired gases at this and greater depths. In addition, the nitrogen content has an effect; whether direct, or indirect this effect is narcotic in nature and has been a highly controversial subject among research workers over the past 30 years. The current main protagonists are Bennett (13) in Great Britain and Carpenter (29) in the U.S.A. on the side of a direct effect on cerebral cells and Seusing (136) in Germany and Buhlmann (25) in Switzerland who prefer the theory that the effect is due to disturbed elimination of carbon dioxide. As result of recent work by Bennett (14. 15. 16) and further consideration by Buhlmann (26) it seems that there are effects not entirely attributable to high carbon dioxide levels and that nitrogen may exert its effect by impeding carbon dioxide elimination in brain stem cells. Kiessling and Maag (93) showed that this effect was detectable in impaired performance at 100 feet while Bennett and Glass (17) found E.E.G. changes at very shallow depths. Miles and Mackay (117) showed that the impairment was not so great as to endanger the life of the self-contained diver at 180 feet. These findings had confirmed the experience of deep divers of the past who had limited the normal maximum diving depth on air to 250 feet. When End (55) introduced helium as the gas to supply the volume required for respiration on the suggestions of Hildebrand et al (83. 134. 135) mental clarity and manual dexterity returned to the deep diver and it was reasonably straightforward to produce oxygen and helium mixtures which would not be toxic. Helium had different solubility and diffusion co-efficients to nitrogen (12) which meant that values already found for nitrogen decompression had to be the subject of much experimental work but the principles remained. Reasons of supply of the quantities needed meant that the field was investigated mainly by groups in the United States of America. The other noble gases, xenon, krypton, argon and neon (14. 15. 16) have also been investigated and have been found to be more narcotic than nitrogen and as such impracticable. Hydrogen has many attractive qualities and Zetterstrom (19. 159) in Sweden carried out several successful dives before he lost his life through the inexperience in diving techniques of his surface attendants. The explosive properties of hydrogen entail certain precautions, and tedious procedures during the dive so that little interest has persisted in this cheaper gas. The use of mixtures containing oxygen, nitrogen, and helium has been suggested (149. 155) but so far no reports of practical experience with such multiple gas mixtures are available. The effect of the use of helium on decompression time has generally been, that as saturation occurs more quickly with helium than nitrogen, short duration dives have a longer decompression time than an equivalent dive on air but that longer dives reach a stage where an increase in duration does not lead to much increase in decompression time (121. 132). This concept was challenged (49. 50) and the results were available at the start of the deep diving trials. The trials described in this thesis in the section on deep diving show that helium dives tend to have more severe symptoms than air dives (79. 80. 81. 103. 104. 105). It is difficult to be precise on the cause of this because of the other factors of total duration of the dive and the high pressures of exposure of the diver.

So far the term decompression sickness has covered cases arising during a reduction in pressure when it is presumed gas appears in various tissues by evolving from supersaturated solutions although the reasons and mechanism for this process are not precisely known. Gas may also be introduced to the tissues directly without the intermediate stage of solution and evolution, as happens occasionally in clinical manoeuvres at atmospheric pressure. For many years it has been generally accepted that restriction of free expansion of gas in the lungs may lead to general or local high pressures with consequent rupture of lung tissue and spread of gas intravascularly or interstitially (4. 28. 33. 47. 95. 98. 123. 125). The practical importance of this point may be that as the tissues are relatively unsaturated in most cases compared with a diver it should be possible to effect the disappearance of the bubbles more rapidly by recompression and so reduce the secondary damage due to hypoxia or oedema. Behnke's first publication was in this field and many authors such as Alvis (123), Crocker (32), Burnett (27) and Schaeffer (98) have described cases sometimes demonstrating the lesion which led to the pocketing or trapping of gas at higher pressure. The signs and symptoms are similar to decompression sickness and,usually, develop rapidly. Of course, such cases may occur after any period of compression so that the diagnosis of decompression sickness may not be differentiated from pulmonary barotrauma. The question is raised whether cases of decompression sickness in which lesions such as lung cysts are described are due to an inadequate decompression routine or to inadequate pulmonary ventilation (28). Wright (109. 110. 118) has carried out many experiments on cadavers and animals which show the range of pressures required to lead to pulmonary damage as well as the fact that the damage starts on release of pressure. He has not yet succeeded in demonstrating histologically the actual passage of the gas through the pulmonary lining but this fits the observed cases in which the gas entry is not persistent so presumably the interruption of tissue continuity disappears on equalisation of pressures. Walder (148) has reported animal experiments with drugs causing bronchospasm leading to pulmonary barotrauma which may be interpreted as showing that a clinically demonstrable lesion is not always present or persistent in man which again fits observations in such cases. The treatment in any event is recompression as often recommended. It is of interest that Lundin and Lundgren (100) have described the use of recompression therapy after several days delay in the case of a woman who had had a large air embolism during a thoracic operation and that while there was no dramatic response, all attendants were convinced that her eventual complete recovery started while at high pressure in spite of the delay.

Finally some mention must be made of the bone lesions seen in compressed air workers. The causation mechanism is still uncertain. The best survey is that of Davidson (41) in tunnel workers and he found several reported cases of the aseptic necrotic lesions in divers. Preliminary studies have been carried out in the Royal (112 . 115) and United States Navies (20) suggesting that diving under their respective regulations does not lead to this sequel but that commercial undertakings are somehow responsible. Whether this is due to the longer time at pressure, the frequency of shifts, the abuse of decompression routines, the ignoring of minor signs and symptoms or in the inadequacy of recompression therapy, all these points have been discussed in extenso wherever men concerned with this field have met. Due to the time lag of development of the radiological abnormalities and the recent awareness of the problem, it has not been possible to make any deductions on this matter in the various trials recorded here. However all men now taking part in experimental work have a survey carried out as recommended by Davidson (41) so that in the future some information may be gained, especially as the deep dives are now longer in duration and at higher pressures than commercial work.

CHAPTER IV

PRINCIPLES OF A DIVING TRIAL

Ethics

In a disciplined service, there must be constant awareness of the possibility of a clash on some aspects of human experimentation. Where such experimentation is intended to lead to greater safety for or higher efficiency by the combatant, it is easy to gloss over the problem of the means to the end. The general guide used in this field is embodied in the Declaration of Helsinki (72). In a diving trial, the man is exposed to a probability of injury where the severity cannot be predicted. Ideally such trials divers would be volunteers with the best of motives and fully informed on all the risks - an impossible situation where the risks are not fully known. In practice incentives were provided; formerly these had been of a financial nature then purely one of prestige but latterly they were both financial and endowing prestige. Opportunities were regularly available for men to volunteer for such work. Any man who is sent to any diving team has the right to refuse to dive - at the risk of losing his qualifications if his refusal is considered unreasonable with the financial and posting consequences. The problem of "free choice" lies not only in such direct after effects but also with the indirect pressures that are brought to bear on a man by his colleagues as members of a select group, by the attraction of a shore posting in the base area, or by the possible comments in his record sheet. The statement by the Medical Research Council (111) clearly delineated the problem in the case of procedures not of direct benefit to the individual.

There is no doubt that the discovery of a diving routine which will reduce the toll of injury and permanent disablement due to an activity which is carried on for military, commercial, and leisure purposes is a laudable end. With the co-operation of the responsible officers the ethical difficulties of the participation of the men were safeguarded by the adoption of the following routine. When the individual is nominated for a trials team or he volunteers for such a posting, he joins the team temporarily to learn about the work involved. After an interview he may decide against such work and an alternative draft to a similar billet for sea or shore service is found; if he wishes to continue and he is considered suitable, he carries out a short probation period and only after mutual agreement is his posting confirmed. At a later date he may change his mind - or he may become unsuitable for reasons other than his own fault - and in that case, strenuous efforts are made to transfer him to a suitable posting. This possibility is explained to him initially but no guarantee is given other than that attempts to find such a position will be made. (He may also leave the team for disciplinary or other administrative reasons). When a man leaves the team his record is marked to the effect that he took part in such work - and especially in any notable event - but no mention is made of any reasons other than disciplinary for his departure unless there is an enforced limitation on his future diving employment. In this way an acceptable method is provided where the diver may "contract out" with minimal indirect pressure whether he was a volunteer or selected instead of the ideal routine of "contracting in" with full knowledge.

In reaching his decision the prospective subject must have confidence first that the trial is worth doing; second that adequate preliminary work has been done; third that the control is adequate; fourth that he will be given the best available treatment if he is afflicted; and fifth that in the worst possible outcome of serious disability he and his dependents will be treated humanely. The first three points are essential to the performance of the work in any case and the fourth is satisfied by the services of experienced medical officers and attendants backed up by consultants. The traditional outlook on the fifth point is changing. In his training the characteristics of initiative, a sense of responsibility, and self-reliance are developed in divers and these attributes cannot be ignored in experimental work however less troublesome blind obedience might be. In this day and age these qualities have led to domestic arrangements such that the previous compensation of appropriate pensions is usually inadequate. While death of the diver may lead to his debts being paid, a disability pension is often insufficient to maintain hire-purchase payments. Some form of insurance to cover the outstanding debts either as a lump sum or as a regular supplement of income must be considered as part of the expense of an experiment where reduced earning capacity may occur however unlikely such an event may be. It is worthy of note that there has been no lack of volunteers although it has not always been possible to arrange their release from their current tasks and that a few men who were drafted exercised their right not to take part.

Selection

Having laid down the conditions on which men may be found for trials work, the next problem is how to discover their suitability. As knowledge of diving physiology is still relatively limited, the problems of selection are relatively simple. The men obviously must be competent at their job and this means that they must be fully trained and experienced. Miles (114) has carried out a survey of some physical characteristics in divers and found no point in which they differed from national service men after initial entry training. Wise (150), in the light of work done with aircrew on susceptibility to decompression sickness (58. 66), found no predisposing factor in 1,003 divers examined for age, height, weight, and body type. A general clinical interview and examination and an X-ray examination of the chest are required in each man to confirm his state of health and his general attitude. (In deep diving work E.E.G. and skeletal X-rays are now being taken as control examinations for future checking). The testing time is the first dive when the new man has to entrust himself to routines that have not been proved safe. For this reason, it is essential that one at least of those responsible for the trial should be in the actual diving team and in particular it is of value if the doctor can be this man; another good choice is the senior diving officer responsible for the carrying out of the programme; the designer of the diving equipment should also dive. No doctor can be as well trained as the divers but as long as he is known to be willing and actually does dive at some opportunity the divers will be satisfied. In deep diving he may be permitted to dive under very closely supervised conditions at a later date - even if it is only the very last dive on a routine already accepted on the basis that they want to make sure he is always fit enough to treat them. Once a trial has been under way for some time, less experienced divers may take part if it is clear that a lower state of training is acceptable, and some such divers did take part in two of the trials discussed in this work.

As each diving trial is intended eventually as a working routine, the divers in the experimental team should be representative of an operational unit. In fact a case might be made for selecting divers known to be susceptible to the risks involved, so that the worst possible results are obtained.

Number of Dives and Divers

It has long been known that divers vary both between themselves and, for any one person, from day to day (44), in their susceptibility to diving injuries of various kinds. There is at present, no criterion for the safety of a routine other than the incidence of decompression sickness, in spite of attempts to prepare scales based on severity of signs and symptoms (141. 142) or special post-dive tests (92) to assess dives in a quantitative manner. Superficially there is a 50/50 chance because of the case/no case outcome of each dive but experience has modified this situation by excluding the extreme situations of all injured or none injured without however defining the variables concerned. This makes any attempt at applying sophisticated statistical rules a pointless pastime. Some decision had to be made on the number of dives that must be done before a particular routine can be considered as tested, as neither unlimited time or unlimited numbers of men, - or unlimited money - were available. In the past up to 5 dives was considered sufficient to check a routine for any one combination of depth and duration. Most of the trials here reported, were carried out with a target of 10 dives by 10 different individuals for each step; this was not always achieved. This number was selected on an arbitrary and intuitive basis and was accepted by various authorities with little discussion (101). Because more dives were done by a greater number of individuals, these trials are more acceptable than previous work of a similar nature, nut no pretence is made that a satisfactory solution has been found to the question of what is a well-planned decompression trial. A trials team has varied from 8 to 22 individuals at any one time but the inevitable spread of each trial over a period of time has meant that many more men have usually taken part in any one trial.

Assessment of Cases of Decompression Sickness

The actual dive routine and various matters of equipment and decompression tables vary with each trial but a constant need is the assessment of the condition of each man during, and after, the decompression of his dive. Almost every diver at the start of his experimental experience finds that questions about his bodily reactions result in sensations he had not previously noted; this response is complicated as he does not know what sensations he would have if he had developed decompression sickness and he has heard many bar room tales about the disabilities in undiagnosed or mistreated cases. Where a physical sign is present, there is little difficulty; usually the complaints are subjective and experience is required both by the diver and the doctor in ascertaining the cause and the severity before appropriate treatment may be given. At one time some naval divers suggested that all senior divers undergo an attack of decompression sickness to gain experience, so that trainee divers would learn directly from one with experience but this proposition was rejected out of hand by those divers and doctors with experience of the variability of individual susceptibility and case severity.

Once symptoms and signs have been accepted as due to decompression, the dive in question can be considered risky. However individual variability is such that an adequate routine may still be possible and the diagnosis could be wrong. Although all such cases should be diagnosed as decompression sickness, which is a serious condition, a further empirical classification is carried out into major and minor attacks. It is realised that this may be interpreted as an indication of a disease which has a steady progression in severity proportional to the inadequacy of decompression, but this attitude would be as wrong as a claim that there was no such progression. Experience shows that if decompre ion sickness occurs after a dive it may be of any severity; it is more likely to occur in minor forms rather than major if the decompression is barely sufficient and conversely if the decompression is grossly inadequate.

Problems of Treatment

There are several practical reasons for using severity as a guide but the main one is the therapy required. Once a man has carried out a standard therapeutic recompression regime, he is reluctant ever to carry out another unless he feels, in himself, that it is essential. If the medical adviser treats all cases by recompression, the diver tries to assess his own condition; if he considers it trivial he will not report his symptoms and signs and he will try his own remedies. Decompression sickness is an injury that may become symptomless fairly quickly without specific therapy; or it may be eased by such home remedies as a bath, analgesics and rest; or it may be quiescent for some hours and then return with increased severity. In the first two situations, no harm may be done to the victim but assessment of the decompression routine may be erroneous, while in the third situation, the condition may become very difficult to treat. If the doctor treats his patient as well as the injury and uses symptomatic palliatives when indicated as well as specific treatment, he has the advantages of co-operation, surveillance, and information to assist him in his task of assessment and therapy. This point may seem to have been laboured but from personal experience men will forego financial recompense of sums of £20 and over for a treatment of 10 hours duration or so rather than report sick if a therapeutic recompression was probable. Men have also been known to tell several days later of symptoms that had occurred but which had since disappeared, this inspite of a flexible approach to treatment by the attending doctor. (The problem of bone damage is very worrying when dealing with men who have concealed their injury.)

Classification of Cases

A preference for dividing cases into major and minor categories rather than by system involved has already been mentioned. Such a division has two practical advantages. First any illness not due to the decompression, such as a simple bruise can be considered as a minor case and there is no indication to underestimate signs and symptoms. Secondly, the classification helps in determining the rest period of a diver after an incident as in a minor case a "lay-off" of 24 - 48 hours is adequate but a period of 5 - 7 days is prudent after recovery from a major incident. The difference between the two grades rests on one factor - whether the diver required to be recompressed for therapy or not. Thus a major case is one where the diver had to be recompressed for the relief of his signs and symptoms. All other cases are minor ones.

Major cases have signs and symptoms which range from aching pain to cardiovascular and neurological involvement of various types. The amount of compression required depends more on the speed of development of the condition and rapidity of therapy than on system or systems involved so that further sub-divisions of assessment are not worthwhile; any recompression is enough to classify the attack as major. A minor case may present, as localised pruritus, or erythema or mild aches round joints which respond to mild analgesics or to heat therapy in the form of deep hot water baths or to simple rest. The possibility of recompression may arise if signs and symptoms progress and these indicate that this would be better therapy - in fact a hot bath may sometimes be provocative in cases of doubt as to the best treatment for a particular case - and such cases would be reclassified as major ones. Often in cases where aching pains are the only symptoms, errors can be made by underestimating the severity first by the diver and then by his medical attendants. In such cases only knowledge of the individual will reduce the possibility of error. A period of several hours of persistent mild aches is an indication of error in assessment and such cases should then be considered as major even if recompression therapy has not been used.

Assessment of Trials

It is admitted that the standards of assessment are arbitrary but successful operational routines have been evolved. It is considered that in trial dives an overall incidence of major cases of 2% is acceptable (101) as the addition of safety factors for operational use would reduce this considerably. No comparable standard is available for an emergency or an exceptional routine but adequate treatment facilities are required (132. 133) wherever and whenever such a situation might arise - and the risk of decompression sickness as found at the trials assessment is one of the factors taken into account before an exceptional dive may be permitted.

Where decompression theories are being tested the assessments are easier. One major case means the schedule is unacceptably dangerous as does the occurrence of more than two minor cases. The occurrence of one or two minor cases out of the group of ten dives on a particular routine would mean that the next step in the programme would be carried out very cautiously but not necessarily after any alterations in the plan.

CHAPTER V

PERSONNEL AND MATERIALS IN THE DIVING TRIALS

Background

Diving qualifications in the Royal Navy are usually awarded after appropriate courses have been successfully completed. Naval equipment is designed for specific tasks such as salvage and mine clearance. Very few divers have experience of all types of diving equipment although the great majority have had an occasional dive in equipment other than that of their speciality. For example a Clearance Diver, normally a self-contained swimmer, is not always able to move with comparable speed and economy of effort to that of his Standard Diver colleague when wearing the latters' traditional surface supplied helmet and other equipment.

A change has been taking place in naval diving however and although three of the trials described here were carried out by men in standard equipment - although the run down in the Standard Diving branch led to some of the trials divers being Clearance Divers by basic training - the fourth trial was carried out by swimmers in a role that had been exclusively the preserve of the helmeted man. The fifth trial described deals with submarine escape training in which equipment was used to provide buoyancy only.

Personnel Qualifications

It is much to the credit of Diving Officers and men that the rivalry of those trained differently always led to friendly banter and

and competition rather than to bickering and lack of teamwork. This was helped by those few divers who had transferred from Standard to Clearance Diving. The experience in diving varied from men with 20 years service in standard equipment, - that is before self-contained diving had been instituted in the Navy, - to men with a 3 weeks course completed some months before. The qualifications ranged from officers, qualified as Clearance Diving Officers or as Qualified Deep Divers, and ratings, of the three grades in each of the Clearance Diving and Standard Diving branches, who were all full time divers, to men who had qualified in one of the two Ships' Diver's grades and who were part-time divers as they had other qualifications such as Mechanical Engineer, Stores Assistant, Sick Berth Attendant, or Seaman.

Personnel: Physical Factors

The men varied considerably in respect of such characteristics as age, height and build but all were still apparently healthy enough to remain on active duty in Pulheems category P2. Age varied from 18 to 48; weight from 9 stone to over 15 stone; height from the minimum standard of 62 inches to 74 inches; and body build from extremely thin to obese (i.e. waist measurement much greater than chest measurement)

Equipment

The equipment that was used varied with each trial and with the phase of the trial. These phases fall naturally into those where simulated dives were carried out in compression chambers and those where the dives were carried out in the sea.

a) Compression Chambers

During a compression chamber dive the man is exposed to an ambient air pressure of his simulated dive but does not have the hydrostatic effect of pressure difference between head and feet. If he is carrying out a dive with air or some mixture of oxygen and helium as his breathing medium, the dynamics of his respiration is unencumbered by breathing equipment as he normally breathes chamber atmosphere. The energy he expends is less than on a comparable sea dive unless he deliberately exercises on a rowing machine or other work device. The diver is under constant observation through the port holes and he is in communication both by voice and coded signals so that a feeling of isolation is absent and rarely does he have any apprehensive feeling of failure of equipment. If he is one of a group diving, he may be particularly affected by the feeling of general hilarity and irresponsibility engendered by inert gas narcosis. He can wrap up in blankets to be warm and comfortable during decompression (Fig.15) and he may even have a nap.

Altogether 7 different compression chambers were used in two establishments and one ship (Fig. 1 and Fig. 2). There were no differences in principle in the operation of the chambers but there were many minor differences of construction all of which had some bearing on the trials; all but two of these differences affected the comfort of the diver (Fig. 3). When it is realised that these chambers were also used for therapeutic compressions which sometimes took up to 5 days, it can be appreciated that the comfort of the available chambers was relevant to the disclosure of signs and symptoms of decompression sickness and to the decision as to the best treatment in a particular case. Any dogmatic instructions for therapy under all circumstances could be cruel to men liable to be under therapeutic conditions frequently either as a patient or as attendant to a patient, however valuable such instructions might be for the rare occurrence in an operational team.

The two differences of operation of the chambers concerned the accessibility of the patient and the equipment for administering alternative breathing mixtures to that of the chamber atmosphere. All chambers have small compartments, commonly referred to as medical hand locks, through which small items such as food and drink, recreational matter, drugs, and for hygienic needs, could be passed. However if skilled medical attention was required for the patient - for examination, passive physiotherapy, attention to pressure points, catheterisation and blood sampling to mention a few actual requirements of the past, - unless a suitably trained person had accompanied the patient into the chamber at the onset, a very difficult situation could arise. For this reason chambers should have at least two large communicating compartments one of which could be used as a man-lock. Once such a lock is available, opportunity can be taken to relieve the attendants, or to introduce another patient if such a need arises. One of the chambers on this trial was of single compartment construction with small hand locks; two chambers had a large lock on each side of the main compartment; and the remaining four had the common large lock and main compartment construction.

Breathing the chamber atmosphere is the simplest arrangement for the occupants. The carbon dioxide concentration in the closed compartment will rise but frequent ventilation by flushing gas through the chamber will avoid any danger from this cause. At times it may be desirable for the men to breathe a different oxygen and helium mixture or pure oxygen for part of a simulated dive, or of a recompression therapy. (Problems of chronic exposure risks and the fire hazard put the possibility of making pure oxygen the chamber atmosphere out of practical consideration). The solution must be some form of breathing equipment. In these trials several types were used either fitted to the chambers or portable to be taken into a chamber. The most popular consisted of storage cylinders of the appropriate gas outside the chamber fed through a control panel to a main pipe inside the chamber, the men being able to connect simple demand valves with mouthpieces to this pipe (Fig. 4). Such a system kept bulky equipment out of the chamber leaving a maximum amount of room for the occupants but it wasted gas and caused a steady pressure rise in the chamber. Alternatively the control panel could be installed inside the chamber and the demand valves connected directly to it thus saving structural modifications but decreasing the available space and still leading to a pressure rise from exhaled gas. The popular system was permanently fitted in one chamber and the internal panel was used in two others most of the time. All chambers were fitted with a system which had the supply cylinders externally connected to reducers inside the chamber and the gas was then led to closed circuit breathing apparatus. This system had the advantages of room and gas economy but the breathing equipment was heavy, and was only tolerable for short spells mainly because the gases became uncomfortably warm from the absorbent; generally it was unpopular and had a detrimental effect on the morale of any invalid. In fact a fourth method was preferable and this was to move cylinders, control panel and demand valves as one unit into the chamber in spite of the disadvantages of bulk and weight.

Other differences that existed between chambers were not important in the routine but were of importance to the divers. The length and diameter were the most obvious as the dimensions determined such points as ability to sleep stretched out, ability to sit upright, and ability to stand. Small chambers had to be ventilated much more frequently to remove carbon dioxide and replenish oxygen when the chamber atmosphere was being breathed.

During this process, noise was troublesome, especially if treatment was being undertaken; the noise of compression and decompression from stage to stage might be acceptable but the unavoidable insistent sound of release of compressed gas during ventilation prevented normal sleep and caused fatigue. (Silencers were tried but were relatively ineffective).

Wide bench seats and folding chairs were desirable where they could be fitted as some dives took up to 22 hours in the chambers and some therapies were much longer. Eventually foam rubber seat cushions and floor and bench mattresses were provided.

Communications were either by use of coded knocks with a mallett or by means of a sound-powered telephone initially. Later four chambers were fitted internally with two-way microphone and loudspeaker fitting so that the occupants were always overheard by the outer attendants. Later still the system was modified to receive music and the occupants once more had to knock to draw attention to their wish to transmit a message and the music was then turned off!

The final significant difference between the chambers concerned the thermal insulation. It was found to be nearly impossible to keep the inhabitants warm in a steel chamber in the open air during a British Winter while a light alloy chamber in a warm foreign summer needed ice blocks on top to maintain a comfortable internal temperature. Swings of up to 30 degrees Centigrade (55 degrees Fahrenheit) were recorded on several occasions during such simulated dives. More stable conditions were obtained where the chamber was kept under cover in an even temperature and such conditions applied to 5 of the chambers, 2 of which were on board ship.

b) Submersible Chambers

As a link between equipment on land and equipment in the sea, a brief description of submersible chambers is relevant (Fig. 5). Two such chambers were used. The principle is that of a diving bell which, with its occupants, is raised and lowered in the sea rather like a lift.

The water level is kept down by gas supplied from the floating base or ship so that the occupants are exposed to the ambient pressure in air. The chamber is lowered either to a point where the diver then sallies forth and returns or else to a point where the diver, already started his ascent meets and enters it to complete his decompression. The chamber is then hoisted as required and when instructed the occupants can close a hatch to seal the mouth of the bell thus converting it into a pressure retaining vessel. The divers may either breathe the atmosphere of the bell or they may use breathing equipment. This chamber is then hoisted inboard where the pressure is released as planned while it rests on the deck; in the case of the newer bell it is hoisted on top of a compression chamber into which, once the pressure is raised to match that in the upper chamber, the divers transfer, (43. Fig. 6a and Fig. 6b). Once the hatch is closed on the receiving chamber the pressure is released so that the bell can be used again while the first divers continue their decompression in greater comfort. The refinements of the second bell, compared with the first, other than the tremendous value of the possibility of transfer of the divers under pressure from sea to shipboard, are communications, closed circuit television monitoring, and gas supplies carried in cylinders round the upper part so that during very deep dives the submersible chamber becomes a base for operating swimmers without too many lines and hoses in the water and yet the surface controllers are kept fully informed about the safety of the men. As well as operational advantages, the transfer system allows rapid medical assistance in case of injury to the diver during the decompression.

c) Breathing Equipment

In the sea, 42 dives were carried out using entirely self-contained equipment; 664 dives were done using standard equipment (Fig. 7). This is the familiar idea of a diver who has a surface supply
(Fig. 7). This is the familiar idea of a diver who has a surface supply
to a helmet and corselet attached to a rubberized twill suit and the buoyancy is counteracted by heavy boots and chest and back weights (naturally the process of entering or leaving the water with 160 lbs. of equipment is energetic). A transistorised communication system was used and the wire was included in a braided rope which acted as lifeline. Enough air was provided to ventilate the helmet to prevent carbon dioxide accumulation and it was supplied at a slightly higher pressure than that to which the diver was exposed; the diver regulated his buoyancy to just negative by controlling the escape of gas by the valve in his helmet. The self-contained equipment used was similar to the standard gear except that the gas supply was contained in four cylinders on the diver's back and breathing was carried out in a closed circuit system - this equipment did not come into general use.

The remaining sea dives - all deep dives, 206 in number - were carried out by men, dressed in rubber suits entered through the neck and intended to keep the swimmers dry and with fins on their feet, and commonly described as frogmen. They were not entirely self-contained as the breathing equipment consisted of an open circuit system where gas from the surface - or from the cylinders of the submersible chamber - was supplied by airpipe to a reducing system and demand and exhaust valve on the diver's back and then by breathing tubes to and from a mouthpiece set in a wide vision mask (Fig. 8). The main supply was so arranged that an emergency supply of gas carried in two small cylinders on the diver's back would automatically come into use if the main pressure dropped. This "get-you-home" supply is the modern counterpart of the volume of gas available in the helmet and upper part of the suit of the standard diver and lasts just long enough for the diver to reach his base without delay.

The Base

Every dive is controlled from a base where all administrative details can be dealt with. H.M.S. Vernon, a training establishment carried out this function for the divers while they were carrying out the initial compression chamber dives. The Admiralty Experimental Diving Unit (A.E.D.U.) situated within the boundaries of H.M.S. Vernon, is a small unit of engineers, divers and draughtsmen responsible for devising and developing diving equipment. It is a mixed civil and uniform establishment of the Royal Naval Scientific Service. Both have their own compression chamber facilities and both have their own medical organisation. A.E.D.U. sponsored the trials on the air dives, combined dives, and surface decompression dives and the Unit medical officer had the major responsibility in seeing the work through.

H.M.S. Dolphin is also a training establishment but only for submarine crews. As part of the training, submarine escape is carried on in a special department which has a full time staff including a doctor, who has some advisors to call on if required. The advisors are doctors who have had experience in this field and are available either at A.E.D.U. or the R.N. Physiological Laboratory (R.N.P.L.). Compression chamber facilities are available at the training tank.

R.N.P.L. is a research establishment of the Royal Naval Scientific Service and is staffed by scientists and technicians of the civil side of the Admiralty, with the assistance of two Medical Officers from the uniformed side. Much of the work concerns basic research into diving and animal work is an important part of this. Co-operation between R.N.P.L. and A.E.D.U. is important and one of the doctors is appointed to both units. Thus the deep diving programme came from discussions with both units, animal work by R.N.P.L. with the scientists having the major role. Then A.E.D.U. arranged for enough divers from H.M.S. Vernon to travel daily to R.N.P.L. (geographically quite close) and carry out dives agreed between scientists, doctors, and divers of the two units in the most convenient compression chambers (sometimes the scientists travelled to H.M.S. Vernon). The teamwork was such that R.N.P.L. staff would operate the compression chambers, under the care of qualified naval diving officer, from A.E.D.U. with the medical officer examining, advising, assessing and if need be instructing on treatment measures from his dual post. The next stage was to plan the sea trip where the A.E.D.U. took the major responsibility to carry out the dives required by R.N.P.L., the doctor continuing his role.

This type of shore base organisation led to considerable flexibility in arrangements in that roles were fairly closely defined but allowed considerable co-operation between the research side, the user side, and those who were responsible for the victims if all did not go well. Thus some of the trials were more in the nature of experiments carried out for Scientific Officers of R.N.P.L. (37. 39. 80. 81. 127) while others were really evaluations of routines devised on their information by Naval Officers of A.E.D.U. and Medical Officers of both units (34. 36. 38. 101. 102. 107. 117).

The sea dives were all carried out from H.M.S. Reclaim which had been completed as a deep diving training and research ship but during the period covered in this work she was given an alternative role as a support ship (Fig. 9 and 10). Originally she carried a team of 2 Diving Officers and 12 diving ratings and 1 diving Medical Officer with adequate storage, working and maintenance space. Latterly the needs of her other role had reduced the storage and maintenance space and her team was reduced to 1 Diving Officer and 6 diving ratings and her Medical Officer was less familiar with diving problems. This deprevation meant that for the diving trials her team had to be augmented by up to 2 Diving Officers, 1 diving Medical Officer, 8 experienced divers and 2 engineers to cope with problems of gas mixing and supply and equipment generally. However the ship was still able to find the appropriate water conditions for trials whether in West Scotland sea lochs or Canary Island harbours, Norwegian fjords or Iberian bays.

CHAPTER VI

IMPORTANT FACTORS

Many factors are relevant to the problem of decompression sickness in divers and in view of the obscurity of such aspects as mechanism and pathology, doubtless there are many still unappreciated. The pressures to which the diver is exposed and the duration of exposure are closely linked and fundamental aspects. In this chapter some material points are discussed in more detail.

Pressure Control

Pressure in a compression chamber is relatively easy to measure, the main problem being the desirable accuracy. Simple Budenberg gauges with dial display are common but exact accuracy on such a gauge is only possible at a particular point although the error at either end of the scale can be reduced by various means. These gauges need to be regularly calibrated by hydraulic dead load testers. All the sea dives and the majority of chamber dives were carried out using this type of gauge. Latterly a range of Bristol recording gauges were used on the main chamber and by selecting the appropriate instrument, very great accuracy in chamber diving was achieved (Fig. 2). In sea dives the gauges measure the pressure in the air-pipe carrying the gas supply to the diver or submersible chamber and this pressure must be the same as that of the depth of water at the diver's chest in standard gear if he is breathing comfortably or at the water level when the submersible chamber is used. In standard dives this value was further cross checked by the use of a measured lead-line, by echo-sounder, by the measured marks on the diver's life-line, or by the reading of the gauge on a weighted open ended air pipe when gas escaped at depth. Such readings as were taken had to agree within 5 feet for satisfactory control but the master reading was the one on the gas supply to the diver. The depth of the submersible chamber was more difficult to assess at the start of a dive as great volumes of gas, delivered at high pressures through a small pipe, were required to keep the water level down and the total reservoir pressure was needed to enable the diver to control this level. When the chamber reached the pre-determined depth the main supply line was shut, the diver's control valve inside the chamber was opened wide, and the residual pressure on the line gave the depth of the chamber in feet of water. This figure was the internal pressure of the chamber so if the bottom hatch was shut, it did not necessarily record the actual depth of water. This method was of little value where it was desired to take a diver to a specific depth rather than to discover what depth he had reached. For the former purpose the only satisfactory means was to measure directly and mark appropriately the special non-spin, non-stretch hoisting wire of the chamber and to repeat this at weekly intervals when errors of up to 2 feet in 500 feet might be found. The depth of the chamber could be cross-checked by echo-sounder and by recording the required number (previously counted) of revolutions of the winch drums.

Time Control

All dives were recorded to the nearest half-minute using various types of wrist-watches and clocks. In long dives discrepancies arose and in ship or establishment the most consistent bulkhead clock was found and was used as the standard but checks were kept by stop watches or by the individual recorder's wrist watch. Diving practice has been - and is - to use intervals of 5 minutes or multiples of 5 minutes for the duration of dives and the duration of decompression stops; this custom cannot be continued where changes of pressure or depth occupy an appreciable time. Thus in the air dives the compression or descent of the diver at 100 feet per minute was included as part of his stay at maximum pressure as such a period could not exceed two minutes; his ascent to his first stop, at 60 feet per minute was included in the time spent at that stop which was adjusted to take this period into account; the time of ascent between stops - normally a distance of 10 feet at a similar speed - was included in the time of the shallower stop. In deep diving the increase in pressure had to take longer as the same compression and descent rate was maintained and the time was then considered separately from the duration of the time at maximum pressure or bottom time; the ascents were also considered as separate activities and after the initial rate of 50 feet per minute to the first few stops, the ascent was controlled to take a full or a half-minute between stops. It was fairly rapidly found that 5 minute intervals were not helpful in experimental deep diving and the duration of bottom time and each decompression stop time was given in single minute values. Whatever the routine, it was strongly emphasized that the rate of change of pressure in compression chambers or of descent and ascent in sea dives, should be as smooth as possible; in fact accuracy of timing was, within limits, less important than regularity of rate. Smooth accurate movement was easier in a chamber than in sea dives; chamber compression could slow up towards depth if the cylinder supply pressure was low and the diameter of the piping system was inadequate, to pass the volumes required to raise the pressure inside the chamber.

In effect, the probable operational routines had a slight safety margin when considering the descent time as time spent at full pressure and a greater margin when rounding the ascent and stop duration to the next 5 minute interval; while calculations had to be made, in the experimental procedures, for the uptake and release of gas during the time the diver was undergoing pressure changes.

Depth Keeping

In the sea dives an important matter was the ability of the diver to maintain his depth. In tidal waters, especially in long dives, his actual depth could change with the state of the tide. Whatever the waters, his ability to maintain his depth during decompression could be affected by the strength of a current or by the rise and fall of swell. This latter factor could be exaggerated by the movement of the ship caused by weather conditions and result not only in a wide range of movement by the diver but also in a snatching type of motion. This effect, most noticeable during the shallower decompression stops, could be avoided by the use of submersible chambers.

The decision on what constituted marginal weather conditions first in respect of the diver and second for the use of submersible chambers - with the problems of control during transfer from sea to ship board - was difficult and always liable to appear wrong by sudden changes in the weather.

Sea Temperature

A factor of note though of debatable importance was that of sea temperature. There is little argument on the preferable comfort of a short dive in the warm waters of a Canary Islands spring to that of a long dive in the cold waters of a Hebridean winter. The morale amongst the surface attendants tended to vary directly with the temperature and inversely with the precipitation. The Standard Diver could dress with many layers of clothes - long cotton and heavy wool underwear, flannel body belt, long stockings and woollen cap and even electrically heated combinations on occasion. Such clothing left only his hands exposed to the environmental temperature and to some extent gloves could ease this problem. An important item in very long dives was a man sized napkin to absorb urine if micturition became necessary. On the other hand the swimmer could not wear so many undersuits because either he could not then don his neck entry rubber suit or he would become so buoyant he would require unacceptable amounts of lead to counteract this. His normal underwear would consist of a combination suit of cotton and a similar thin suit of wool over a pair of bathing trunks or underpants. It was essential that he exercise during his stay in the water to keep warm and the potential ill-effects of such activity during decompression were avoided by the use of the transfer under pressure facility. A few divers used "wet suits" - these are suits made of foamed synthetic rubber open at ankles, wrists and neck which permit a static thin film of water between suit and the bare skin of the diver and which rapidly reaches body temperature. However the construction of the material is such that at depth the foam flattens and the diver might as well wear a suit of tissue paper. All in all, the divers kept reasonably warm so that no conclusion could be drawn on the effect of sea temperature on decompression sickness, although there was no doubt about the more pleasant diving conditions such as increased visibility in warmer waters.

General Health

Finally the general health of the divers was important. While they were all generally fit men, episodes of illness did occur, sometimes of infectious origin. As post-dive complaints were the main sources of information in assessing the dive, it followed that divers were expected and asked to declare any signs and symptoms present before a dive. These were not always reported and men dived with boils of the perineum; they dived when they were suffering from hangovers, from muscle stiffness after gardening; and one man dived in standard equipment while wearing his corset during a mild exacerbation of symptoms of a slipped disc.

(The corset was spotted while the diver was undressing in an obscure corner after his dive). At least two such men developed decompression sickness but the true incidence could not be assessed as undoubtedly all the cases were not discovered. A frequent condition in British divers is a sub-acute rhinitis and it soon became apparent that men were diving without ill-effect who had nasal mucosal swelling and whose tympanic membranes could not be seen to move during a Valsalva manoeuvre. Eventually it was found that those divers who complained of a fullness of the head or heaviness of the face or inability to clear their ears were those who should not dive and, notwithstanding the clinical findings, the remainder usually succeeded in carrying out their dive. It was also noticed that men who used considerable effort during a Valsalva manoeuvre or who repeated the manoeuvre often - a common fault in the relatively inexperienced men - reached a point where the manoeuvre became ineffective and the dive had to be abandoned. This presumably was a tissue reaction to unaccustomed violent movement as instruction and practice rapidly produced a situation where the minimal rise in pressure obtained by closing off the mouth with the tongue and barely occluding the nostrils was adequate. [No case occurred of tinnitus and deafness in these trials but it has occurred in divers who have to use a little more force than usual to clear their ears because of mild congestion; this injury is more common at shallow depths but it emphasizes that divers must be able to equalize their middle ears normally before diving].

CHAPTER VII

TRIALS OF STANDARD AIR TABLES

Background

In point of time, these trials (107) followed the assessment of the two air diving routines discussed later but as the pattern is basic to all trials for diving experimental work, this account is placed first. New diving decompression schedules were introduced into Royal Naval service in 1958 in the form of two tables (35. 132). Table I was the routine working table designed to give a total decompression time of about 35 minutes or less for a dive and any depth-time combination that required a longer decompression was described in Table II. This timing was chosen as it seemed a reasonable period during which a man would stay fairly inactive in the cold seas round Britain. The latter table was provided in case the limits of Table I were exceeded for accidental reasons or deliberately for operational reasons of such importance that a risk of decompression sickness was acceptable. Table I had been fully tested and experience confirmed the opinion in the report that it offered a reasonable economy in decompression time with a negligible risk of bends(35). Table II was not tested as it was an emergency table but the new theories had after calculation resulted in schedules which were in general longer than those in the table it was replacing and hence it was presumably as safe. However the proposed routines (36) of surface decompression and combined dives involved an increased use of Table II and the results described later cast doubts on the merits of this table and thus on the assumptions on which the table had been based. The first step was to test the calculated table uncomplicated by the proposed routines and the second step would depend entirely on the results of this approach.

Basic Decompression Theories

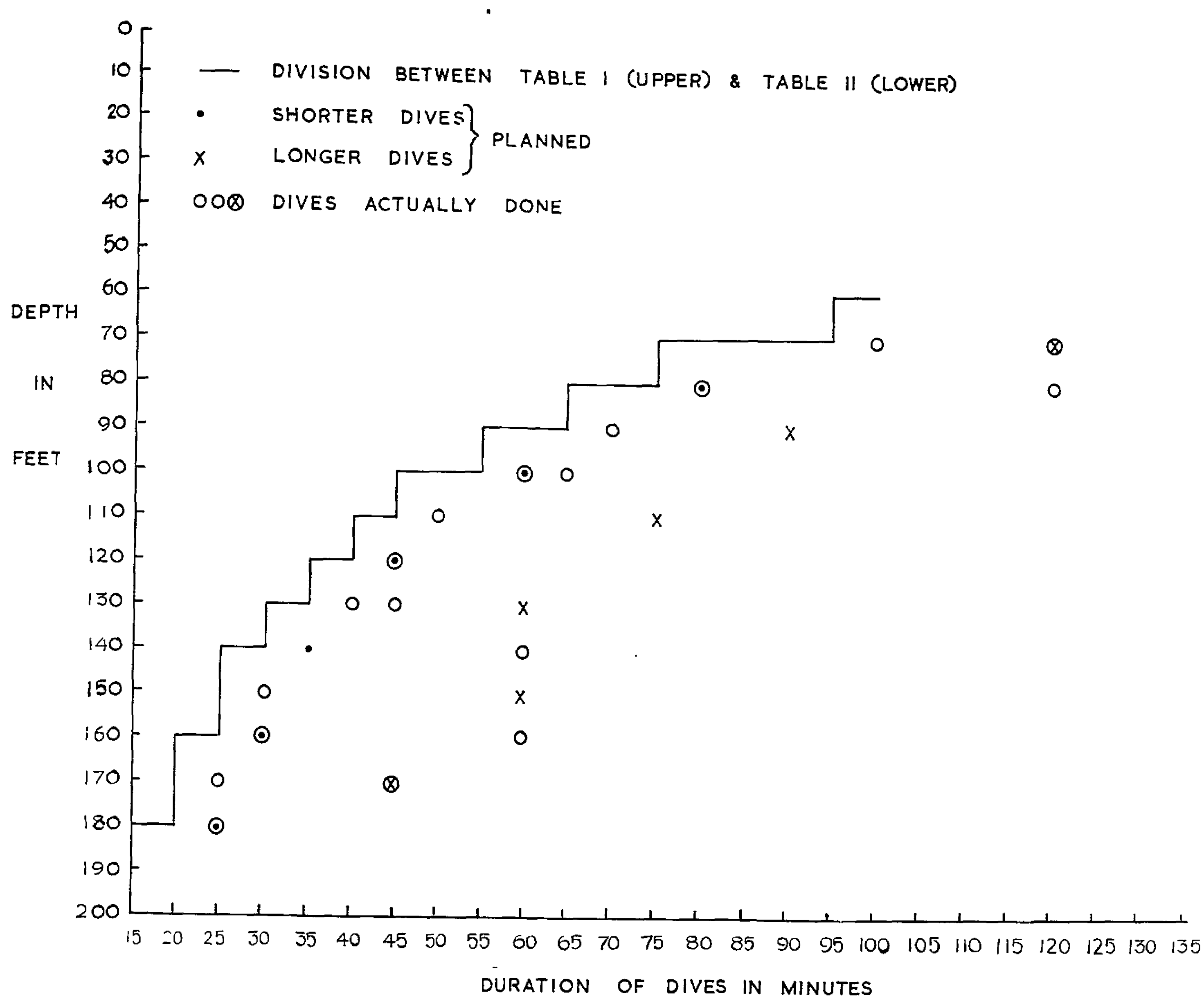
Due to world-wide dissatisfaction with diving tables which were felt to be too safe in some parts and too dangerous in others, other countries had also been revising their routines and the United States Navy issued their latest tables (145) as work was about to start on testing the British tables. The Royal Naval tables had been devised on a concept of a single homogeneous tissue which absorbed gas in an exponential manner on exposure to pressure and on subsequent exposure to a reduced pressure the release of gas followed a reflection of the curve so that the amount of gas in solution varied with the absolute pressure and the square root of the time; when this amount expressed in term of total absorbed gas in feet of sea water exceeded a value of 30 feet above ambient pressure, then the ascent of the diver was controlled to maintain this excess pressure at or below this value so that he could ascend to a shallower depth or surface without the risk of decompression sickness. The U.S.N. tables were a sophisticated development of the Haldanian concept that the absolute gas tension in a tissue at pressure could be halved safely; the sophistication lay in the use of several hypothetical tissues of different half-times to saturation each with its own ratio for reduction of pressure based not on the 2:1 air ratio of Haldane but on a nitrogen content ratio which also varied for each tissue with different ambient absolute pressures.

Selection of Tables

It seemed that it would serve a useful comparative purpose to adapt the U.S.N. tables to R.N. diving techniques and to carry out the trials with the same men at the same time with both tables. The modification entailed the conversion of dive and decompression stop durations to 5 minute groups and inclusion in the stops of the time taken for the ascent. The R.N. tables were forwarded on a pocket card version (13.116) but the compiler did not inform those carrying out the trials that, in anticipation, he had already modified the tables arbitrarily and it was much later before a cross-check of the tables was made and the card version abandoned. Accordingly the adapted United States Navy tables were dived initially at the same time as the Card version and latterly concurrently with the published Royal Naval tables. For convenience the several versions of the tables as finally used will be referred to as the American (A), Card (C), and British (B) tables respectively.

Trial Orders Requirements

The trial orders called for 10 dives to be done on selected schedules on each diving table. The depths of the dives selected were at each 10 foot interval from 70 feet to 180 feet. The durations of the dives alternated with successive depth intervals from the minimum time on Table II at a given depth with a duration 20 - 30 minutes longer at



GRAPH VII·1

PLOT OF DIVES PLANNED AND CARRIED OUT

the next greater depth (See Graph VII.1). Later the longer dives were abandoned and the shorter duration introduced for the majority of the intervals. Each selected schedule had to be dived in a compression chamber before being dived in the open water but this later proved to be of doubtful value in anticipating risks and was suspended.

Period of Trial

Over the period of five years that this work was carried on intermittently, various changes in technique and interpretation took place so that a careful review of the reports had to be made to decide which dives were within normal operating limits and which had gross deviations. Most of these errors usually arose from the training received by diving personnel to use the next deepest or the next longer schedule whenever a dive nears the limit for depth or duration. For assessment, the trial dives were required to be as near these limits as possible. However the dives excluded from comparison were of value in demonstrating the incidence of cases of decompression sickness when the routines are abused and what variations there were both between men and in the same man from time to time.

The Divers

Altogether 96 men took part in the trials but the diving team rarely exceeded 15 in number at any one time. Seven men carried out 20 or more dives each; twenty-six men carried out 10 to 19 dives each; twenty-one men 5 to 9 dives each; twenty-seven men 2 to 4 dives each; and twelve men carried out one dive each mainly for experience in the techniques involved. Apart from the basic diving qualifications and the fitness resulting from being a member of an armed Service, there was no obvious common factor of experience or build. No detailed clinical examination records were made in keeping with the deliberate policy of the minimum departure from normal working routines. No selection was made for any man to dive on a particular table so that it was hoped there would be a random selection of divers on the schedules under test at any one time depending on the composition of the diving team at that time.

Twenty-three men dived only on the British tables with no major incidents and eight men had equally uneventful dives only on the American tables. Eighteen men dived on both British and American tables and 12 major cases of decompression sickness occurred in 8 men. Twelve men dived only on the Card tables and 6 men had 7 major attacks between them. Further sub-division into the effect of chamber and sea environment on the separate schedules is unprofitable because of the small numbers involved. Table VII. 1 shows the combination of diving tables dived by the numbers of men involved and the distribution of major cases of decompression sickness.

Tables used	A only	B only	C only	A & B	A & C	B & C	A & B & C
Number of men diving	8	23	12	18	24	1	7
Number of major cases	0	0	7	12	6	1	4
Number of men affected in major cases	0	0	6	8	5	1	4
Number of dives	12	54	64	165	256	5	98

Table VII. 1

Distribution of Decompression Tables and Divers

A = American tables   B = British tables   C = Card tables

The Dives

Altogether 764 dives were carried out but 89 (12%) had such departures from the desired routine that they were excluded and 19 dives which used the correct schedule but in which decompression was carried out in the submersible chamber were considered separately. In the remaining 656 dives there were 30 major cases of decompression sickness and 112 less severe cases an incidence of 4.6% major and 17.1% minor cases.

Twenty-one schedules were tested by dives but 4 had a total of only 6 dives between them; one other schedule was dived 10 times on only one set of tables; the remaining sixteen schedules were dived on at least two tables - some in fact were dived on two tables in the chamber and three tables in the sea.

Environment		Dry			Wet		
Tables		A	B	C	A	B	C
Schedules							
Feet	Minutes						
70	100	-	-	10	-	-	-
70	120	-	-	-	9	10	-
80	80	-	-	10	10	13	-
80	120	-	-	-	10	10	-
90	70	16	-	12	9	14	-
100	60	16	-	25	10	11	10
100	65	-	-	-	-	-	-
110	50	15	-	10	9	9	12
120	45	11	-	14	14	10	9
120	75	13	-	13	10	11	-
130	40	-	-	10	9	10	8
130	45	-	-	-	1	-	7
140	60	12	-	10	9	10	-
140	75	-	2	-	-	-	-
150	30	10	-	12	10	10	10
150	60	-	-	-	10	10	-
160	30	-	-	-	10	10	-
160	60	7	-	8	10	10	-
170	25	-	-	-	-	1	-
170	45	-	-	8	10	10	-
180	25	12	-	10	10	10	11
Total		112	2	152	160	169	61

Table VII. 2

Dives Carried out in an Acceptable Manner

a) Chamber Dives

Only 2 dives out of 266 acceptable chamber dives were carried out on the British tables, the remainder being dived on the American and Card tables. From Table VII. 3 it might seem that if there was an attack of decompression sickness on the Card tables it tended to be more serious than an attack after a dive on the American version. 5 of the major cases on the Card tables occurred after 2 group dives of 4 men each on one particular depth-time combination, so that the overall differences may be due more to the chance of selection of men than to differences in the safety of the decompression routine.

Dives		Minor Cases		Major Cases	
Table Used	Number	Number	%	Number	%
A	112	31	27.7	3	2.7
B	2	1	(50)	1	(50)
C	152	20	13.2	8	5.3
Total	266	52		12	

Table VII. 3

Decompression Sickness in Chamber Dives

b) Sea Dives

390 acceptable sea dives were carried out on the three tables under trial and are tabulated in Table VII. 4. It would appear that the relative severities of the American and Card tables are reversed when compared with the chamber dives. Again there was one particular schedule

that upset the record - this time on the American schedules when the weather deteriorated rapidly during the dive - the only occasion this happened - and all 4 men in the sea suffered major attacks. If this point is taken into account there is apparently little difference between the British and American tables when the dives are carried out in a similar manner.

Dives		Minor Cases		Major Cases	
Table Used	Number	Number	%	Number	%
A	160	25	15.6	10	6.3
B	169	23	13.6	7	4.1
C	61	12	19.7	1	1.6
Total	390	60		18	

Table VII. 4

Decompression Sickness in Sea Dives

c) Excluded Dives

If the decompression schedule used was not the correct one for the depth-time combination, whether the dive resulted in a form of decompression sickness or not, it could not be used as a test of adequacy of the schedule or used in comparison with other routines. Such dives were still of value in suggesting where extra safety already existed or was needed; in showing by the variability of response in the men how reliable this method of assessment might be; and in providing evidence on the value of the routine therapeutic measures. (Table VII. 5).

(i) Wrong schedule used: excess decompression

In 30 dives the decompression was prolonged for periods varying from 5 to 40 minutes from that intended. A major incident occurred in one dive that had 15 minutes extra decompression and 4 minor incidents occurred once each after 5 minutes; 5 minutes; 15 minutes; and 40 minutes extra. In detail, 15 dives were decompressed on the schedule for a dive 10 feet deeper than that actually carried out (2 minor cases); 11 dives on the schedules for a dive 5 minutes longer than the one performed (1 major and 2 minor cases); and 4 dives on a schedule both 10 feet deeper and 5 minutes longer than that needed for the actual dives (no cases).

(ii) Wrong technique used: excess decompression

In addition 36 dives (including 5 dives using the submersible decompression chamber) had extra decompression added to the schedules through a misunderstanding. Previous tables specified a time for ascent to the first stop from the maximum depth and then a period at that stop. This meant that divers paid too much attention to the overall time and not enough to the manner of the ascent - [R.N. divers carry out their own ascents under signal control from the surface instead of being hoisted on a stage as happens elsewhere.] It is strongly suspected that dives with irregular ascents alternating fast and slow periods are more productive of cases of decompression sickness. In this work, trial orders included instructions to ascend at a steady rate, 60 feet per minute being the target rate and the divers were not to leave the first stop till a specified period after leaving the bottom had elapsed. The trial tables thus had the time for ascent included in the time of the first stop. Initially this was not appreciated by older divers and the whole of the combined period was spent at the first stop. It has always been thought that the depth and duration of this stop was more critical than the other stops and hence the extra periods which varied from 1 to 3 minutes disaqualified the schedule for comparative analysis and assessment. One major and seven minor cases occurred in this group.

(iii) Miscellaneous: excess decompression

12 other dives - with one minor incident in the group - were excluded for various errors which also increased the total decompression time. These slips included errors in arithmetic by the recorders; accidents involving delay in the diver changing his depth on time, such as getting the lines fouled round the guide ropes; and taking too long to leave the water.

(iv) Insufficient decompression

11 dives altogether were discounted because of inadequate decompression. The commonest fault (8 dives) was the use of a schedule for a shallower dive than the one done so that the reduction in time varied from 15 to 30 minutes - 7 major cases of decompression sickness resulted. One dive had 15 minutes less decompression as a schedule for a dive of shorter duration than the one intended was used without ill-effect on the diver. The remaining two dives, also without ill-effects

on the divers, had 5 minutes deducted because of arithmetical error, the slip being made at the shallowest stop.

(v) Submersible decompression chamber dives

In 19 dives the decompression schedules used were the ones intended, 10 on the British table and 9 on the American table. However to avoid prolonged stops in cold water the submersible decompression chamber was used in such a way that the diver could climb into it at his first stop. The greater comfort was desirable but the exercise involved in climbing into the chamber during decompression and removing parts of the equipment was potentially a cause of increased incidence of decompression sickness. The results when compared with the same dives carried out in the sea without the use of the submersible chamber were thought to show an increase in "bends". The use of the chamber was discontinued and the dives were not included in the final analysis. (All these dives were carried out at the same depth for the same time interval).

Types of Faults			Minor Cases	Major Cases
Class	Comment	Number	Number	Number
Extra Decompression	Actual dive shallower	15	2	0
	Actual dive shorter	11	2	1
	Actual dive Shorter and shallower	4	0	0
	Ascent added	31	7	0
	Miscellaneous	12	2	0
	Sub-total	73	13	1
Insufficient Decompression	Actual dive deeper	8	0	7
	Actual dive longer	1	0	0
	Stop out	2	0	0
	Sub-total	11	0	7
Submersible Chamber used	Planned	19	4	1
	Ascent added	5	0	1
Total		108	17	10

Table VII. 5

Summary of Dives Excluded from Analysis

Effect of Duration and Environment of the Dive

When considering the project initially, it was thought that if the tendency of the decompression was to be inadequate, the longer the duration of a dive the more the deficiences would become apparent. It was also commonly accepted that a sea dive would disclose deficiences in a schedule not necessarily apparent after a chamber dive. It was decided that a chamber dive should be done first because a case of decompression sickness arising during decompression could be looked after better if the dive took place in the means of treatment, and because too great an incidence of cases would indicate that that schedule should not be used in the sea.

Table VII. 6 compares the relative durations of dives on each table, Table VII. 7 the environment of the dives on the tables and Table VII. 8 the effect of duration and environment of the dives.

Dives			Minor Cases		Major Cases	
Relative Duration	Table	Number	Number	%	Number	%
Short	A	172	31	18.0	5	2.9
	B	98	8	8.2	1	1.0
	C	174	22	12.6	2	1.1
	Total	444	61	13.8	8	1.8
Long	A	100	25	25.0	8	8.0
	B	73	16	21.9	7	9.6
	C	39	10	25.6	7	17.9
	Total	212	51	24.1	22	10.4

Table VII. 6

Duration of Dives and Tables

Note: "Short" and "Long" : See Graph VII. 1

Dives			Minor Cases		Major Cases	
Environment	Table	Number	Number	%	Number	%
Dry	A	112	31	27.7	3	2.7
	B	2	1	(50)	1	(50)
	C	152	20	13.1	8	5.3
	Total	266	52	19.5	12	4.5
Wet	A	160	25	15.6	10	6.3
	B	169	23	13.6	7	4.1
	C	61	12	19.7	1	1.6
	Total	390	60	15.4	18	4.6

Table VII. 7

Environment of Dives and Tables

Note: "Dry" - dive in a compression chamber

"Wet" - dive in the sea

Dives			Minor Cases		Major Cases	
Environment	Relative Duration	Number	Number	%	Number	%
Dry	Short	193	24	12.4	3	1.5
	Long	73	28	38.4	9	12.3
Wet	Short	251	37	14.7	5	2.0
	Long	139	23	16.5	13	9.4

Table VII. 8

Environment and Duration of Dives

It will be seen that dives of short duration were less likely to lead to cases of decompression sickness than longer dives and that this tendency persisted whether the dives were done in the sea or in a compression chamber. It was remarkable in view of the widely held opinion that sea dives were always more dangerous than chamber dives that the results were comparable. The figures for each set of tables show diametrically opposite tendencies between the American tables - risk increasing - and the Card tables - risk decreasing. As the American tables generally had shorter decompression times than the British tables which were in turn shorter than the Card tables for the same dives, one gains an impression that for short dives, the longer the decompression the safer the dive. It is difficult to explain at present the reasons for the apparent increase in risk in longer dives as all decompressions become longer.

<u>The Tables</u>

There are two points of comparison for any given depth and duration of dive as far as decompression tables are concerned. These are the total decompression time and the distribution of the stops, - in particular the depth of the first stop. Both these points are shown in Table VII. 9.

Dive		Decompression Tables					
		Total Time (min.)			Depth First Stop (ft.)		
Depth feet	Duration min.	A	B	C	A	B	C
80	80	36	41	51	20	30	30
90	70	41	46	56	20	30	30
100	60	41	46	51	20	30	30
110	50	36	41	46	20	30	30
120	45	46	41	46	20	30	30
130	40	41	41	46	20	30	30
150	30	36	41	46	20	30	40
160	30	41	46	-	30	40	-
180	25	41	46	51	30	40	40
130	45	56	-	61	20	-	40
70	120	56	56	-	20	30	-
80	120	76	86	-	20	40	-
120	75	101	111	116	30	50	50
140	60	101	111	126	30	50	50
150	60	116	131	-	40	50	-
160	60	136	146	156	40	60	60
170	45	101	106	121	40	50	60

Table VII. 9

Comparison of Total Decompression Times and Depth of the First Stop for the Dives Done on the Various Tables

a) Total decompression time

As is always the case in diving trials, there is no consistent difference. In the shorter dives carried out, the total decompression times of the American tables were the same in 1 schedule, 5 minutes shorter in 7 schedules, and 5 minutes longer in 1 schedule than those in the British tables for the same dives; those in the Card tables were 5 minutes longer in 6, and 10 minutes longer in 2 schedules than those in the British tables, and 15 minutes longer in 2, 10 minutes longer in 4, 5 minutes longer in 2 and of the same duration in 1 schedule when compared with the American tables. In the longer dives the American total decompression times were the same as those in the British table once, 5 minutes shorter once, 10 minutes shorter 4 times and 15 minutes shorter once; the Card tables were only dived on 4 schedules for long dives and these were longer than those in the British tables by 5 minutes once, 10 minutes once and 15 minutes twice and longer than those in the American tables 15 minutes once, 20 minutes twice and 25 minutes once.

b) Depth of first stop

The first stop is considered to be especially important as this marks the maximum difference for elimination of absorbed gas between dissolved tension and alveolar pressures i.e. the extraction gradient. In this respect the American tables have a first stop 10 feet shallower than the British tables in the 9 shorter dives done on both tables and 10 feet shallower in 3 schedules and 20 feet shallower in 4 schedules for the longer dives. The Card tables have the same depth of first stop in 7 schedules and 10 feet deeper in one compared with the short British tables and 10 feet deeper in 7 and 20 feet deeper in two schedules compared with the short American tables. In the longer dives the Gard tables have the same depth at first stop in 3 and start 10 feet deeper than the British in one schedule and are 20 feet deeper than the American tables in all four schedules. The importance of the depth of the first stop is thus less critical than previously assumed when the difference is only a few feet between possible choices.

The Cases of Decompression Sickness

One would expect that the more often a man dived on an experimental table the more likely he was to suffer an attack of decompression sickness in some form and probably both minor and major in severity. This expectation is based on the chance that he will dive sooner or later on an inadequate schedule. This is borne out by the details in Table VII. 10.

Group	Number of Divers	Number of Dives	Number of Minor Cases	Number of Major Cases
No trouble	33	137	-	-
Minor trouble only	34	312	75	-
Major trouble only	13	87	-	14
Minor and Major trouble	16	228	54	26
Total	96	764	129	40

Table VII. 10

Divers Grouped According to Attacks of Decompression Sickness

The surprising groups are those who dived fairly frequently but suffered only one form, either minor or major. Concealed in the data are the records of individuals who were exceptional in their performance. For example 3 men carried out 52 dives between them without any incidents and 6 men who carried out 103 dives between them, had an average of 4 minor incidents per man. A simple analysis of the four groups is given in Table VII. 11. Study of the men in these groups did not show any obvious difference in experience, age or body build, nor was there any difference in the particular diving trip and season. Some of the more notable records in each group are given in Table VII. 12.

Group	Detail	Range	Average	Median
No trouble	Dives	1 - 23	4.1	3
Minor trouble only	Dives	1 - 22	9.2	8
	Cases	1 - 7	2.2	2
Major trouble only	Dives	1 - 14	6.7	9
	Cases	1 - 2	1.1	1
Minor and Major trouble	Dives	1 - 33	14.3	11.5
	Minor Cases	1 - 8	3.4	3
	Major Cases	1 - 4	1.6	1.5

Table VII. 11

Some Details of Groups of Divers

Diver	Minor Attacks	Major Attacks	Number of Dives	% Incidence of trouble
DA	-	-	23	-
KB	-	-	13	-
RB	-	-	16	-
DT	7	-	21	33
EA	2	-	4	50
EM	2	-	4	50
RO	2	-	4	50
TH	4	-	22	18
BG	-	2	5	40
BN	3	1	7	57
CA	3	2	12	42
GR	4	1	10	50
HA	3	2	5	100
HO	8	2	13	77
KA	3	4	22	33
MS	2	2	7	57
NB	8	2	33	30
SO	2	1	26	12
WS	5	1	24	25

Table VII. 12

Some Notable Records

Symptoms and Signs in Minor and Major Cases

(i) Pain

The commonest symptom was pain which varied in severity from such as to cause extreme restlessness to a persistent ache which could lead to "syncopal attacks" and, in the mildest cases to an ache which was a vague discomfort constantly obtruding on the attention and difficult to locate accurately. In diving jargon these were differentiated as "pain", "ache" and "niggle" respectively. Very rarely could the location be given by pointing with one finger; more often the whole hand was placed over the area involved. The pain often radiated proximally or distally or in both directions. This symptom was recorded after 102 dives and in over 30 of these dives the pain was in more than one site.

Eight dives resulted in the men having miscellaneous types of pain such as generalised aches, headaches, colicky abdominal pain and aching in jaws. The only type that would seem to have an obvious explanation are the abdominal cases in that gastric and intestinal distension from air swallowed while under pressure is well known but pain arising from other abdominal sites had to be excluded.

The joint and its surrounding area most frequently involved in this trial was the right shoulder which was specifically mentioned on 23 occasions and included in "both shoulders" on 4 more. By contrast the left shoulder was only specified on 9 occasions. The shoulder girdle and various parts of the upper limbs were reported as the site of pain on 78 occasions. The pelvic girdle and lower limbs were recorded as the sites of pain on 31 occasions (left knee 9 times, right knee 7 times, both knees once). The predominance of the upper limbs in this trial is probably due to the need to exercise the arms to maintain position at a stop during decompression; to change depth with stops; and to operate the control valve high on the right side of the helmet. Often the man preferred to wait to see the progress of his pain before reporting and with experienced men, it was a useful guide to ask them if they wished to be recompressed. A great many cases responded to local heat and rest. Analgesics were rarely given lest masking of developing severity of pain occurred.

(ii) Itch and rash

Itching was noted after 68 dives and its distribution varied from head, face, and neck; limbs; to torso but never on hands or feet even in chamber dives. The true incidence was difficult to assess in that if a diver was asked if he had an itch, he developed one. Some men stated that they always itched after a dive but as it was never troublesome they did not worry about it and rarely reported it. No diver was ever seen to have excoriations of his skin due to scratching and in any case a hot shower or bath cleared the symptom from all cases. Little importance was attached to this symptom as experience was compatible with some reported laboratory investigations (129).

Rash was reported after 19 dives. Typically it was irregular blotchy with no raised edges and varied in colour from dusky blue to bright red even in a single patch and described as mottling or marbling (Fig. 11). The lesions were confined to the shoulders and trunk and were normally noticed during the undressing of the diver or in his customary post-dive shower or bath when his skin usually returned to normal. If the diver delayed his ablutions, the blotchy lesions could persist for some hours. Recompression cleared the discolourations.

No particular significance is attached to itching or to rashes when no other symptoms were present but they were considered, when volunteered or observed amongst the other factors in assessing the adequacy of the decompression schedule. Many men are not apparently affected and therefore such ailments could be skin signs of decompression sickness. The effect of local heat suggests that both itches and rashes might be due to bubbles present in the tissues of the skin. This is not necessarily a guide to the degree of tissue saturation elsewhere in the body as these cases usually arise where the divers clothing permits adequate air space round his body with the possible effects of percutaneous diffusion of gas adding to the local tissue saturation levels.

(iii) Central Nervous System

Thirteen times a diver became pale, light-headed, and looked about to faint. The whole picture suggested shock but the pulse was usually about normal in rate for the individual and of adequate volume on palpation. This picture was sometimes complicated by low chest pain, nausea and vomiting, dizziness and exhaustion. Rapid recompression was the treatment of choice and was rapidly effective.

Disturbed sensations also occurred; misty vision of the left eye once; diminished sensation of a thigh, or of a hand, or of a forearm, after other dives; paraesthesia in the distribution of an ulnar nerve twice; and weakness of a limb three times. Four times there was a sensation of stiffness, once in the neck and three times in the right knee, without associated pain, swelling or limitation of movement.

(iv) Oedema

The most baffling sign was the painless, non-pitting, oedema which occurred in 4 men, once in the right ankle, once in the left forearm, once over the dorsum of the right hand, and twice in the same man on the face where it started symmetrically over the malar areas. /Figure 12 illustrates the facial lesions/ The fluid gradually dispersed, being aided by gravity especially noticeable in the facial cases.

Notes on major cases of Decompression Sickness

After each case a note is made on whether the case was treated according to the instructions recommended in the R.N. Diving Manual (Appendix II); if not it is noted whether the therapy was longer or shorter than the recommended procedure.

a) Chamber dives

Diver PT reported half-an-hour after surfacing from a dive to 150 feet for 30 minutes on the Card table. He had fairly severe aches in his right arm and right hip which cleared at 22 feet on recompression.

He surfaced after treatment on Therapeutic Table I with no ill effect. (Recommended)

Diver KA reported two and a half hours after surfacing from a dive to 140 feet for 75 minutes on the British table. His main complaint was mild pain in his left knee of doubtful causation so he was treated by a hot bath which relieved the pain but a sensation of weakness slowly developed. The pain recurred and one hour after reporting, he was recompressed. His symptoms cleared at 120 feet. Therapy on Table II was completed successfully. (Recommended)

Diver MS reported four and a half hours after surfacing from a dive to 120 feet for 75 minutes on the Card table. An ache in his right knee was relieved at 55 feet. He was successfully treated on Therapeutic Table I. (Recommended)

Diver HS reported three hours after surfacing from a dive to 120 feet for 75 minutes on the Card table. An ache in his back was relieved at 22 feet. There was no recurrence after treatment on Therapeutic Table I. (Recommended)

Diver FP and Diver MS reported on surfacing from a dive to 160 feet for 60 minutes, on the Card table. Diver FP had pain in both forearms and upper arms while Diver MS had pain in his left knee. Both men were recompressed and they were relieved by 105 feet. Therapeutic decompression Table II was used. (Recommended). Diver HU carried out the dive with these two men but he did not report till the next day with general aches and a headache. He was recompressed and all his symptoms cleared at 55 feet. In view of the delay and site of symptoms, it was decided to use Therapeutic Table II. (Longer). He surfaced feeling well and there was no recurrence of symptoms. [If the headache had been considered to be due to central nervous system injury, then Table III should have been used and his treatment was shorter than recommended]

Diver SL and Diver SC carried out a dive to 160 feet for 60 minutes on the Card table. Diver SL reported a severe pain in his right shoulder on surfacing and he was immediately recompressed, relief being obtained at 45 feet. Therapeutic Table I decompression was carried out uneventfully. (Recommended). Diver SC did not report till the following day when he complained of persistent mild aches in both knees which were not entirely relieved in spite of therapy on Table III. (Longer)

Diver NE reported with severe pain in his right shoulder after a dive to 150 feet for 30 minutes on the American tables. He was recompressed and after his symptoms were relieved at 49 feet, he was decompressed on Therapeutic Table I.(Recommended)

Diver WS carried out a dive to 100 feet for 60 minutes on the American tables one afternoon. Next day, he reported with severe pain in an ankle and he was recompressed. The pain cleared at 44 feet and treatment was then carried out on Therapeutic Table I. (Recommended)

Diver BN carried out a dive to 140 feet for 60 minutes on the American tables and reported with pain in his right shoulder and arm. He was treated by recompression but the remaining details have been lost. (Assumed recommended as he himself was the doctor in attendance)

b) <u>Sea dives</u>

<u>Diver HO</u> reported severe pain in his right shoulder on surfacing after a dive to 130 feet for 40 minutes on the Card table. He was recompressed and, after he had obtained relief at 42 feet, Therapeutic decompression Table I was used. (Recommended). Shortly after surfacing, for the second time, a residual bruised sensation in his shoulder became more painful. He was again treated by recompression and decompression was carried out from 41 feet, the depth of relief, on Therapeutic Table IV. (Recommended for a recurrence)

<u>Diver HO</u> reported on another occasion with an ache in his right shoulder after a dive to 120 feet for 45 minutes on the American tables. On recompression his symptoms were relieved at 49 feet; he was treated with Therapeutic Table I. (Recommended)

<u>Diver MO</u> developed an ache in his right shoulder after a dive to 120 feet for 45 minutes, on the American tables. His symptoms cleared at 60 feet on recompression. Treatment started on Therapeutic Table I (Recommended) but after surfacing, his symptoms recurred. He was again compressed and this time his symptoms were relieved at 40 feet from where he was decompressed on Therapeutic Table IV. (Recommended for a recurrence)

<u>Diver GR</u> carried out a dive to 150 feet for 30 minutes on the American tables, using the submersible decompression chamber in the latter part of the ascent. 3 hours after surfacing, he reported complaining of severe pain in his right upper arm and forearm. He was

recompressed, his symptoms being completely relieved by the time the pressure was raised to 64 feet. Treatment on Therapeutic Table I was successful. (Recommended)

Diver MM also carried out a dive to 150 feet for 30 minutes using the submersible decompression chamber but on the British tables. During the ascent he developed a pain in his right shoulder which eased and then increased in severity on arrival at the surface. He was recompressed and his symptoms cleared by the time he reached 66 feet. Therapeutic Table I was used successfully. (Recommended)

Diver FR reported 20 minutes after reaching surface from a dive to 140 feet for 60 minutes on the British tables. His main complaint was itching of both forearms with other troubles in the form of a mild ache in his right elbow and a faint mottled rash over his forearms. After a hot bath, the itch and the rash disappeared and the elbow ache was improved. However 5 hours after surfacing, the ache radiated into the upper arm and he developed someweakness of his grip. He was recompressed, his symptoms being relieved at 100 feet, and Therapeutic Table II was used. (Recommended unless weakness not secondary to pain, in which case routine shorter than recommended)

Diver ST dived to 90 feet for 70 minutes on the British tables. Soon after surfacing he reported with a pain in his left shoulder which after a hot shower, radiated up the left side of his neck. On recompression the pain became more severe and was eased a little by tablets of aspirin. During the decompression, at the 120 feet stop, the pain disappeared and decompression on Therapeutic Table II was completed. (Recommended)

Diver KA carried out a dive to 80 feet for 80 minutes on the British tables. After surfacing, he had some itching of his arms and back and 5 hours later he reported with some pain in his left knee and misty vision in his left eye. He was kept under observation for another two hours when although his vision was back to normal, his knee pain was unchanged; he was then recompressed. His symptoms cleared by 66 feet so Therapeutic Table I was used. (Shorter. His visual signs, although clearing quickly, indicated his central nervous system had been affected). 2 hours after surfacing from this compression, his symptom of pain recurred so he was again compressed. His symptoms cleared at 65 feet and Therapeutic Table III was used for the subsequent treatment. (Shorter than recommended for a recurrence)

Diver WB developed pain in his right shoulder about 2 hours after surfacing from a dive to 120 feet for 75 minutes on the British tables. On examination there was some minimal loss of power of his right hand which was unaltered after a hot bath. Half-an-hour later there was a definite weakness in flexion of the right elbow, so he was recompressed. As all signs and symptoms had cleared by 66 feet, he was treated on Therapeutic Table I. (Shorter)

Diver PO dived to 120 feet for 75 minutes on the British tables. He reported 2 hours after reaching surface with pain in his left shoulder and upper arm. He looked unwell and he had weakness of his left arm and hand. On recompression, he made a complete recovery at

25 feet and he was treated effectively on Therapeutic Table I. (Shorter)

Diver WL complained of pain in his left shoulder after reaching surface from a dive to 80 feet for 80 minutes on the American tables. The pain radiated in a mild stabbing fashion to his left wrist and into his neck. The whole incident was not severe in character and was improved by local heat and codein compound tablets. However there was no further improvement in the next few hours so he was recompressed. Initially the pain was aggravated and he developed weakness of his left hand but he became symptom free at 100 feet. He was treated on Therapeutic Table II and surfaced with a very mild residual bruised sensation which wore off steadily. (Shorter)

Diver AS reported about one hour after surfacing from a dive to 120 feet for 75 minutes on the American tables with general malaise which became more severe over the next hour during which he also developed aching in all his limbs. He was recompressed with complete relief of his complaints at 22 feet. After surfacing from decompression on Therapeutic Table I, he had a slight residual ache in his left knee which gradually cleared. (Shorter)

Diver KA dived to 120 feet for 75 minutes on the American tables. One and a half hours after surfacing he reported with pain in his left knee, temporarily relieved by a hot bath and aspirin tablets. He was compressed with relief of his symptoms at 100 feet. He was treated on Therapeutic Table II (Recommended) but on reaching surface his symptoms recurred. He was again compressed; his symptoms were not fully cleared till 165 feet was reached and he was then decompressed on Therapeutic Table III successfully. (Shorter than recommended for a recurrence)

<u>Diver CR</u> dived on the same day as the two preceeding cases to 120 feet for 75 minutes but he was decompressed on the British tables. He reported with mild aches in his left elbow and both legs after surfacing but he preferred to carry out some social duties than be treated. 4 hours later he felt very unwell and complained of severe pain in both hips, across his abdomen and in both legs. He was pale and cold with a pulse rate of 64 per minute and he suddenly fainted while being taken to the compression chamber. He regained consciousness at 20 feet on compression and there was only a slight residual ache in his left elbow at 165 feet. However on beginning decompression he developed a slight ache in his right shoulder which persisted unchanged during the decompression on Therapeutic Table III and gradually cleared at the surface. (Shorter)

<u>Diver BG</u> dived to 140 feet for 60 minutes on the British tables. He felt generally unwell on surfacing and he reported 1½ hours later when he was seen to be unsteady in his gait, pale and cold, with symmetrical malar swelling and general weakness. He complained of a pain in the front of his chest, his pulse was 80 per minute and his blood pressure 95/65 mm.Hg. A short period of recumbency did not lead to improvement but on recompression his condition improved steadily and he had recovered - except for the facial swelling - within 10 minutes at 165 feet. After surfacing from a decompression on Therapeutic Table III

he felt tired and bruised. (Recommended). The facial swelling decreased over the next two days; his gait was stiff legged for about a day.

Diver KA dived to 150 feet for 60 minutes on the American tables. 1 hour after surfacing he reported with aching in his calves and his left knee, slight pain in his chest and general malaise. He was kept under observation and in another hour as his general condition had deteriorated he was recompressed with relief of his signs and symptoms at 130 feet. Decompression on Therapeutic Table III was successful. (Recommended)

Diver BG surfaced from a dive to 160 feet for 60 minutes on the British tables apparently well but 2 hours later he complained of general malaise, abdominal pain, cold and sweating, and feeling faint. In spite of lying flat, his condition was unchanged so he was recompressed and steadily he improved till after 15 minutes at 165 feet he was completely recovered. He was decompressed on Therapeutic Table III uneventfully. (Recommended)

Diver DM dived to 160 feet for 60 minutes on the British tables. Soon after surfacing he reported an ache in his left shoulder which gradually worsened. Aspirin tablets and local heat had no effect. He gradually developed loss of power of his left arm and hand due to pain and he was recompressed. His troubles cleared at 61 feet and Therapeutic Table I recompression was carried out successfully. (Shorter)

Diver MU, Diver CR, Diver HA and Diver MI all dived one afternoon to 170 feet for 45 minutes on the American tables. The weather suddenly deteriorated, while the men were at various stages of their decompression routines. It was decided that the men would complete the dives in the sea instead of surface decompressing but in the final stages they had great difficulty in maintaining their depth on the stops because of the disturbance of the water. Diver CR started his symptoms with itching and a mild ache in his left upper arm at his 20 feet stop and which were not too severe on reaching surface. His condition deteriorated very slowly and 2 hours later, he was recompressed with relief of his symptoms at less than 60 feet. Diver HA had only mild niggles at his 20 feet stop but they became aches after surfacing and 3/4 of an hour later he was recompressed with relief at less than 60 feet. Diver MU developed pain in his right knee at the 20 feet stop which was severe on reaching surface so he was recompressed with relief of his symptoms at less than 60 feet. These three men were compressed simultaneously in one chamber and were all satisfactorily decompressed on Therapeutic Table I. (Recommended for all three). Diver MI was the last to reach surface (within 5 minutes of Diver MU) and as he reported well except for exhaustion, the therapeutic routine started without him. Shortly afterwards he developed a severe ache in his upper arms and suddenly fainted. He was immediately recompressed in a second chamber and completely recovered by 60 feet and decompression started on Therapeutic Table I. (Shorter). He developed nausea and he had an attack of vomiting during the decompression; on surfacing he had a mild pain in his right knee and a bilateral facial swelling of non-pitting oedema over the malar areas. As sleep was impossible because of restlessness due to the irritating ache, he was again compressed with marked improvement in his comfort. Therapeutic decompression Table III was used (Shorter) but he still had a marked residual bruised feeling in his knee and the facial swelling which had gravitated to the areas over the jaws. Over the next two days the bruised sensation cleared and the swelling dispersed over his neck. [This case was complicated as it transpired during therapy that he had concealed a "hangover" and a very late night in the hope that by his turn to dive in the late afternoon, he would have recovered.]

Diver HA and Diver DE dived on the same day to 160 feet for 60 minutes on the American tables. At the 10 foot stop Diver HA developed an ache over his right elbow which became more severe at the surface although he did not report for 1½ hours. He was obviously in pain, and there was general swelling of the dorsum of his Right hand with patches of paraesthesia of his fingers. He was recompressed with relief of all his troubles, except the swelling, by 30 feet. Diver DE also was relieved at 30 feet of his symptoms which had been aches in his Right shoulder and Right elbow on surfacing slowly becoming more severe till there was limitation of power of all muscle groups at the shoulder and distally. Therapeutic decompression on Table I was used uneventfully. (Shorter for Diver HA. Shorter for Diver DE if weakness was not secondary to pain)

Diver DA, Diver MJ, Diver KI and Diver MD dived on the same day in a flat calm sea using the British tables, to a depth of 130 feet for 40 minutes. Diver DA reported 2½ hours after reaching surface that he felt faint and giddy; that niggles in his right shoulder on surfacing had gradually been developing into severe aches; and he was found to have paraesthesia of the ulnar distribution of his left hand. He was recompressed with relief of his symptoms at 165 feet and Therapeutic decompression Table II started. (Shorter). At 10 feet he had a mild recurrence of his symptoms and on reaching surface, he developed pain in his left shoulders, left hip and left thigh so he was again compressed. His symptoms cleared at 25 feet and decompression was carried out from there on Therapeutic Table IV. (Recommended). Diver MJ reported 1 hour after his dive and at the same time as Diver DA, but his complaint was headache and mild aches in his right shoulder unrelieved by a hot bath. He was compressed with his colleague and he also did not get relief till 165 feet. Therapeutic decompression Table II was the one used, (Recommended) and he reached surface without complaint; on arrival he reported continuing malaise and pain in his left shoulder so he also was recompressed, again with relief at 165 feet. Decompression on Therapeutic Table III was used (Shorter) but 4 hours after surfacing he again had symptoms and recompression was again required - this time therapy was on Therapeutic Table IV. (Recommended). Diver KI reported 40 minutes after reaching surface that he had discovered a general mottled body rash while he was having a hot bath for some aches in his left upper arm and across his back. As he reported while the other cases were being considered, he was recompressed with them and his symptoms cleared quickly. After the completion of the decompression on Therapeutic Table II (Longer) he had a residual bruised sensation which cleared gradually over 24 hours without further therapy. Diver RD reached surface after the initial therapy of his three colleagues had started and, after a meal and shower, he had a nap from which just more than 2 hours after surfacing, he wakened to find he had difficulty in standing, and in moving his limbs because of severe pain. He was recompressed and all his symptoms cleared at 40 feet. He was decompressed on Therapeutic Table I with no ill-effects remaining. (Shorter)

Therapeutic Regimes

169 cases of decompression sickness occurred but only 38 were recompressed. It is difficult to say whether this proportion is small or large but under the conditions of close observation in such work it is probable that some cases that were treated by local heat and rest might, elsewhere, have been recompressed. Part of the reason for not recompressing marginal cases immediately was the desire to build up mutual confidence so that men would report or admit their symptoms however trivial as soon as possible. It is obvious from the case histories that the time to reporting did decrease as they are arranged in chronological order (except for the last 3 chamber cases which occurred after the first few sea cases). Residual symptoms were not

always entered in the records as a sensation of stiffness and bruising was accepted as a common temporary terminal phase of treatment in confined conditions.

On the whole, the therapeutic tables in the R.N. Diving Manual (132) were used as recommended; this particularly applied to cases of uncomplicated pain, especially those where examination disclosed no abnormality and the diagnosis was perforce made on the history alone. Sometimes when the pain was accompanied by a history of long delay in reporting, or when effects such as limitations of movement or syncope were thought to be secondary to pain, the basic tables for pain were still used. Other cases which had neurological signs and symptoms should always have been treated on the longer routines recommended. The longest routine was also the one supposed to be used for recurrences arising during a therapeutic decompression with the decompression re-starting from the depth of relief.

16 cases were not treated as recommended, 3 of these using a longer routine. 6 of them were treated on a shorter routine with acceptable results. In the tenth case, his pain changed to "weakness" during decompression which cleared before maximum pressure was used and he was treated as if he had pain only but there was a residual bruised sensation on surfacing. The eleventh case had had malaise with his pain but he was treated on a pain routine which left him with a residual mild ache. The last five cases recurred; two after following the recommended tables and three after following shorter therapeutic routines.

The first pair were treated the second time on a shorter table than the one recommended; the second group were also recompressed with the diver having the recommended routine responding as well as one of his colleagues and a little better than the third in his group both of whom had a shorter therapy. Of the 22 cases treated as instructed, 2 men had a recurrence of signs or symptoms which resulted in further recompression once each along recommended lines.

The deterioration in the symptoms of two men during compression is of interest. The correct action was clear in the one whose symptoms cleared while the compression continued but the explanation for the man who suddenly improved during the course of subsequent decompression was not clear. While the relief of the patient is often so dramatic that one can find a precise effective pressure, it is perturbing that sometimes after a further increase in pressure, often considerable, the patient may report further symptoms. The other point that raises questions about the assumptions on which the therapeutic tables are based was the appearance of pain during or after the use of the tables longer than those intended for pain cases on two out of three occasions. An explanation of these unexpected events might lie along the following lines. Dramatic relief of signs and symptoms occurs where the size of the traumatic bubble is rapidly reduced. If the reduced bubble does not redissolve but persists, then, if in an intravascular site, it could be driven further into a sensitive area. If it persists, whether intravascular or extravascular in site, then reactive oedema might occur with impairment of gas exchange so that the bubble does not dissolve but may even grow, both by bubble physics laws and by any subsequent decompression. On this explanation, signs and symptoms should then be treated as evidence of a bubble and the nature - whether pain or collapse or some other - is of interest only as site. A loose analogy is the fracture of a bone which is treated primarily by the basic principle of immobilisation and secondary by fixation, traction, or splinting. A separation of decompression sickness cases into "pain cases" and "others" suggests that symptom is more important than site whereas the injury has to be established and then appropriate treatment given. While generally cases with a particular symptom might be treated in a similar manner, it does not follow that the injury is similar in size, site, or reaction. There is no clear evidence as to whether such bubbles are intravascular (8) or extravascular (65) although animal work and post-mortems have suggested extravascular sites, clinical progress of a case as often is indicative of intravascular. The impression is gained that once bubbles are presumed to appear then all theoretical curves of gas elimination are at best very poor approximations. Under these circumstances, the administration of pure oxygen was not really indicated and any beneficial effects were probably countered by the discomfort of the equipment for its administration available during this trial.

Comment

These results show the crudity of this approach to the evaluation of decompression tables and the futility of theories and experiments designed to add a minute here and to subtract a minute there when planning new tables. It seems that the larger increments added operationally by using the decompression schedule for a deeper and/or a longer dive, than the one actually dived, may reduce but not abolish the risk of decompression sickness. A radical view might be that the assumptions on gas elimination by maximum extraction gradients are wrong; that all tables have the first stop too shallow; and that there is a possibility of giving too short a decompression time at deeper stops and too long at shallower depths. An alternative view is that the lesion of decompression sickness, the hypothetical bubble, may arise - or indeed always arises - during the initial decompression and thereafter any distribution of decompression time is almost immaterial; signs and symptoms would then appear in a proportion of cases varying with the actual site of the lesion, the size and numbers of such bubbles, and the susceptibility of the individual on that day.

There was little to choose between the American and British tables on such crude testing and no real assessment of the theories behind each table could be made. It was found that environment did not have much effect, provided the depth could be accurately controlled. It appeared that increasing the total decompression time did not always lead to an increase in safety suggesting that there is an optimum time - perhaps for the individual rather than the dive. No explanation was obvious for different susceptibilities to decompression sickness among the divers. The treatment routines had some surprising immediate failures in view of the apparent specific corrective procedure applied to a traumatic physical agent. Certain departures from recommended routines demonstrate an approach which might be of value in modifying initial therapy.

CHAPTER VIII

MULTIPLE DIVES

Problem

All methods of calculating decompression schedules assume that the diver will reach atmospheric pressure with excess gas dissolved in his tissues which will, however, cause him no harm. While he remains at atmospheric pressure, he will gradually come into equilibrium with his environment. If he dives before he has eliminated all the excess gas previously absorbed, he will start taking up gas on top of a higher tissue level than if he had started at equilibrium. Diving tables are devised primarily for the diver in equilibrium and they may entail too great a risk of decompression sickness for routine application to the man carrying out more than one dive in reasonable succession. Some formula is required before the tables can be applied to the dive to discover the decompression needed. Various mathematical manipulations are available to find a solution. The principle is similar in all, that is to attempt to convert into a measure of time the excess gas remaining in the diver's tissues at the start of a subsequent dive. This time may be considered either as duration to be added to the time on the bottom of the subsequent dive or as decompression time to be added to the total decompression time of such a dive. This increment is added as appropriate to the duration or decompression of the current dive and the actual decompression schedule to be used is found in the tables. In effect an equivalent fictional dive is obtained and combined with the actual dive to produce a schedule that will permit the diver to surface with an acceptable level of tissue gas saturation. In these trials the extra time was added to the initial total decompression time and the distribution of stops found by looking in the tables for the dive at the same depth with the same or next greatest total decompression time as the combined figure. (102)

Notes on Technique

The diving method was routine as far as depth assessment and the actual performance of each dive was concerned; standard helmet-diving practice as previously described was the method used. It was intended to carry out 10 pairs of dives in each series so that a dive would be followed after a specific interval at atmospheric pressure by a repetition of his first dive by each man. In practice because of tides, a dive was paired with another depth and time combination which was considered to be equivalent in gas uptake and elimination. The "double dive" plan was prepared with different surface intervals as well as several groups of paired dives and the envisaged programme was rather daunting in the total number of immersions anticipated. To make the maximum use of time and personnel a complicated time table was evolved which, in any one day, mixed different combinations of dives with different surface intervals and which, it was hoped would even out the effect of variables such as weather and individual responses. The dives carried out before the programme was abandoned are summarized in Table VIII. 1.

Diver	Chronological Order of Dive	First Dive			Surface Interval Min.	Second Dive				Notes with time to reporting bend
		Depth Ft.	Duration Min.	Total Decompression Time Min.		Depth Ft.	Duration Min.	Decompression Time in Mins.		
								Calculated	Actual	
NE MI	1 2	160	20	25	65	180	20	65	85	
CO DO	3 6	180	20	30	65	180	20	65	85	DO Bend 14 hours
SL	4	190	20	35	70	180	20	65	85	
HU	5	180	20	30	125	180	20	55	65	HU Bend 2 hours
SM FR PE NE	7 8 9 10	140	25	20	70 70 115 65	140	25	55	65	SM Bend 11 hours PE Bend 2 hours
PE SL MI SC MA FR	11 12 14 16 17 18	140	15	10	125	140	15	20	30	
KE SM NE JE	13 15 19 20	140	15	10	65	140	15	25	30	

Table VIII. 1

Record of Dives

Results

It will be seen from Table VIII. 1 that 7 men dived on only one combination each and that 6 men did the remaining 13 pairs of dives. What is not apparent is, that, as a result of a misunderstanding, only dives 5, 13, 15, 19 and 20 were carried out correctly. When the tables were consulted using the calculated total decompression time, if there was a schedule with the same figure then that schedule gave the distribution of the stops. If there was no such schedule then the next longer schedule was taken. The latter procedure was done correctly for the five dives mentioned - but the next schedule was also erroneously used for the remaining dives. In spite of this mistake which one would expect would have decreased the risk of decompression sickness, all 4 cases which needed recompression developed in this group of divers. Some minor cases also occurred but, due to inexperience, any complaints such as rash or itch were regarded as trivial and no record was made. It will also be noticed that the cases occurred after dives which themselves were routine but where the decompression schedule for the second dive was to be found in Table II in the 1958 edition (132) - or below the limiting line in the 1964 edition of the Royal Navy Manual (133). Unusual points are the very long period to reporting signs and symptoms in the case of two of the divers as experimental work often leads to complaints within minutes of reaching surface; and the fact that the extra 45 minutes on the surface interval for Diver PE did not put him less at risk than his colleagues FR and ME, or even better off than Diver SM.

Case Notes Diver MU

This man was very stout being a heavy beer drinker but he could carry out a tolerance (chair-step) test within the 45 seconds allowed for recovery, and his very active organising job with no apparent difficulty. Two hours after reaching the surface, he developed nausea and abdominal pain of a collicky nature but examination was negative. Many possible diagnoses were considered but recompression had to be the first treatment and all his symptoms cleared at 60 feet. It was decided to decompress him on Therapeutic Table I (Shorter). Four hours after he had completed this therapy apparently successfully, his symptoms recurred, again with negative findings on examination. Again on recompression, his symptoms cleared at about 60 feet but this time he was decompressed on Therapeutic Table III (Shorter than recommended for a recurrence). 3 hours later, he again reported feeling sick but it was decided that further recompression would be of little avail as he was thought to be suffering mainly from exhaustion. He was put to bed but 2 hours later still he complained of pain in both knees and it was decided to recompress him for the third time. As soon as he was on his feet he felt better and after 12 minutes walking up and down, his only complaint was extreme exhaustion. He returned to his bed and after an extremely sound night's sleep, he had fully recovered in the morning. It is relevant that he had been instructed to reduce weight the previous week - which he had decided to do with his own diet of cabbage, rum and beer and had lost

8 lbs. It is a matter for discussion whether he ever had decompression sickness but he had to be treated as if he had the injury. It is also debatable whether the first table should have been Table III and the recurrence should have been treated on Table IV from 60 feet. He had had a recurring bend in his right shoulder 3 months before.

Diver DO

This young man was lean and athletic and carried out his dive satisfactorily, reaching surface at 1700. Next morning he reported that on waking, he had no power in his right hand and fingers and examination confirmed that only very weak movements of the hand were present. Although his lesion was neurological, when power returned completely at 60 feet on recompression, it was decided to decompress on Therapeutic Table I (Shorter); this regime was successful. He had had a bend in his right wrist and forearm 4 months before.

Diver SM

A man in his middle twenties, he was very stocky and heavy. About 11 hours after surfacing he complained of pain in both his knees but no abnormality was found on examination. His symptoms were relieved on recompression at 60 feet; he was brought back to atmospheric pressure on Therapeutic Table II (Recommended). (Subsequently, in other work, he developed similar knee bends but never in a shorter period than 8 hours after his dive).

Diver PE

This young man was lean in build. Two hours after reaching the surface, he developed pain in his left shoulder, with no abnormal findings on examination. His symptoms cleared at 25 feet on recompression and the use of Therapeutic Table I (Recommended) was successful. He had not had decompression sickness before.

Therapeutic Routine

The initial high incidence of cases of decompression sickness badly affected morale, and it was obvious that no matter how successful the subsequent diving might be, either the basic tables had to be changed or a new routine devised. Other points to be noticed were that two of the cases were not treated according to instructions, one completely successfully and one with recurring trouble; that the case of Diver HU had to be recompressed whatever the possible diagnosis as decompression sickness was more likely than e.g. gastric distension or appendicitis; the great variability in response between men which makes assessment difficult; and the possibility of excessive decompression causing trouble rather than preventing it. This trial was carried out at a time when the divers, instead of receiving a daily retaining fee irrespective of work, were receiving a monetary award based on a rate per minute; this rate varied with the maximum depth of dive and also applied during the recompression treatment for that dive; the attendants received a proportion of the total sum awarded to the diver. This encouraged the development of symptoms without signs and only close knowledge and observation enabled the distinction to be made between a genuine and a "financial" bend. In this particular trial, there were no such problems; the four cases were genuine and none of the others had any symptoms which might have been misdiagnosed.

Comments

The decompression theory may possibly be inadequate and when manipulated for this routine of repetitive diving the risk of decompression sickness is too high. The Therapeutic Tables may be used deliberately as four separate routines, each one being used as appropriate irrespective of differentiation by signs and symptoms.

CHAPTER IX

SURFACE DECOMPRESSION DIVES

Problem

Sometimes weather conditions are such that a diver cannot carry out his decompression in the water because strong currents or heavy seas prevent reasonable depth keeping on decompression stops by excessive movement - which may in turn lead to sea sickness. His ship might even have to run for shelter. On other occasions, in self-contained equipment, it may be that the task is of such a nature that it is preferable for the diver to use all his limited gas supply in performing his task rather than be forced to abandon it unfinished. In such cases the advantages resulting from the ability to bring the diver directly to the surface safely and then to recompress him in a chamber are obvious. Such advantages include operations in worse weather, greater comfort for the diver, more efficient use of limited gas supplies, a continuous effort on the task, direct observation of the diver, direct reporting of his findings, and less problem in keeping depth during decompression stops. This type of routine had been available with previous tables for emergency use, especially in the case of the helmeted diver who became over-inflated and "blew-up" to the surface. It was necessary to check that the new tables could also be used for such a manoeuvre and some changes in the drill were made in keeping with the principles of calculation of the tables (36).

Notes on Technique

Whereas the divers described earlier were decompressed to atmospheric pressure so that the excess gas saturation did not lead to obvious bubble formation, in surface decompression the diver returned to the surface without stopping and was thus in a potentially dangerous situation. Previous routines had forbidden direct surface decompression if the depth of the diver was greater than 200 feet unless one or two stops were made in the water. The drill that was to be superseded was that the diver ascended as quickly as possible without losing control and, at the surface, attendants divested him of his surface lines, weights and helmet before pushing him into a compression chamber where he was recompressed to his original depth. This whole manoeuvre had to be completed in 5 minutes or less. The decompression schedule used to bring him back to atmospheric pressure was that for a dive of his actual depth and of a duration which was a total of actual dive time plus time of drill plus 5 minutes that he spent at depth in the chamber. If the dive was near permissible limits of duration, this addition of 10 minutes could mean that a dive on Diving Table I was decompressed on a Diving Table II schedule (or on a dive below the limiting line - see Table II. 1). The new drill aimed at providing less stimulus to bubble formation by insisting on a steady rate of ascent of 60 feet per minute; and at reducing the amount of excess gas absorbed in the final compression, by returning the diver for a period of 5 minutes, to a pressure only one atmosphere greater than the depth his first stop would have been if he had been carrying out his decompression in the water. The unknown factor was the presence of decompression bubbles developing during the initial ascent, would the subsequent compression be adequate to return them to solution and only then could one assess how effective was the subsequent decompression. The general timing remained the same except that the actual time of drill was treated as a constant of 5 minutes so that the schedule found in the tables would always be the one for a dive 10 minutes longer than for the dive actually done.

Results

210 acceptable dives were carried out by 39 individuals over the period September 1957 to March 1958. 12 men carried out one trial dive each while of 18 men who did 5 dives or more each, the maximum number by 1 man was 15. The vast majority of dives were carried out by men dressed in standard diving equipment but 42 dives were done by men wearing the cumbersome self-contained Mine Recovery Outfit which eventually did not reach operational service.

26 cases of decompression sickness that responded to local therapy and/or time were noted. It was felt that some divers considered the minor symptoms as unavoidable complications of any dive and that they did not report them unless they became troublesome - an impression perhaps borne out by the fact that 21 of the reported cases occurred in 7 men. 1 of these minor cases was unusual and it is described in more detail in the notes on Diver MA.

9 cases of decompression sickness requiring treatment by recompression occurred in the dives properly carried out. A 10th case - again in Diver MA - developed in one of two dives which were grossly under decompressed, when by error the recorder omitted to add the 10 minute increment when looking up the correct schedule in the manual. This meant that the divers were surface decompressed for the dive actually done. These two dives are excluded from the analysis.

<u>The Dives</u>

It had been intended that dives would be carried out in paired depths e.g. 120 and 130 feet and that they would be of such durations that one of the pair would be well short of the limit in Table I and the other would be on the border-line between Table I and Table II with 10 dives at each of the chosen points. (Well above the limiting line and on the limiting line in the latest R.N. Diving Manual (133)). On studying the records, the dives were found to be widely scattered over the depth range (from 60 feet to 180 feet) and in duration (from very short to over the limit). The dives were thus better classified according to whether the final decompression schedule remained on Diving Table I or whether it was to be found on Diving Table II (132). The results are given in Table IX. 1.

Decompression Table Used	Number of Dives	Cases of Decompression Sickness			
		Minor		Major	
		No.	%	No.	%
Table I	105	9	8.6	2	1.9
Table II	105	17	16.2	7	6.7
Total	210	26	12.4	9	4.3

Table IX. 1

Results arranged by Decompression Table used

Concealed in the table lie minor departures from the instructions to the attendants conducting the dives. On six occasions between 7 and 9 minutes were added to the actual time of dive, when finding the correct decompression schedule as had been customary on the previous routine, so that the divers underwent a shorter decompression than was intended. On 19 occasions there was no dive schedule for a dive exactly 10 minutes longer than the dive actually done; a schedule for a dive 15 minutes longer was used and the divers underwent a longer decompression than was intended - and one man had to be recompressed for an attack of decompression sickness. On 9 occasions, the recorders used the schedules for the next deeper interval i.e. 10 feet deeper again leading to extra decompression. Adjusting the figures by excluding these dives led to an overall incidence of major cases of 4.5% and the difference between the incidence of minor and major cases on Diving Table I and Diving Table II remained similar.

Case Notes

Diver MA had two serious episodes in his 4 dives on this trial. On the first occasion he was decompressed for the dive he actually did instead of for a dive 10 minutes longer. This meant that he had 30 minutes less decompression time and his first stop was 10 feet shallower than it should have been. Because the error lay in the schedule, the maximum pressure of recompression in the chamber was also 10 feet shallower than it should have been. He reported while he was on his 10 foot stop but his symptoms in fact had appeared at his 20 foot stop. He reported nausea and further questioning disclosed paraesthesia of limbs and forehead, low backache, and dyspnoea; on attempting to stand his legs gave way. Examination disclosed some loss of power of his left leg; tendon and plantar reflexes were present, equal, and normal; and he had full voluntary movement. He was recompressed and all signs and symptoms cleared by 50 feet. He was decompressed successfully on Therapeutic Table I (Shorter). In view of his history in other diving work with other medical advisers, he was considered unfit to dive in experimental work for 3 months. Shortly after he resumed, he carried out another surface decompression trial dive. This time there were no errors in the drill and he reported he was fit after it. He was due to dive again the next day but just before his dive he stated that the previous day, about 1/2 an hour after his dive, he had developed extreme weakness of his body from the waist down which had cleared over a period of 1½ hours with the aid of a hot bath and he had not informed and person. Examination at the time of his reporting disclosed no abnormality but he was forthwith removed from all diving in the Royal Navy. (Note: 3 years later in another part of the world he persuaded the local naval diving team to let him accompany them on a routine practice dive in a compression chamber with a well tried schedule and a similar lower limb paralysis developed, treated successfully by therapeutic recompression).

Diver PI carried out 3 dives at widely spaced intervals and needed recompression after 2 of them. On the first occasion he developed an ache in his left upper arm between 10 and 15 minutes after surfacing. A therapeutic test of a hot bath was tried; his symptoms increased in severity and spread to his right arm and involving both elbows and both shoulders. He also developed an aching sensation in both thighs, the anterior abdominal wall, and scalp. He was recompressed 50 minutes after surfacing and all his symptoms cleared at 35 feet. He was treated on Therapeutic decompression Table I (Recommended) returning to atmospheric pressure at 2211. At 0315 he reported again, in obvious pain which he stated was sited in his upper left leg and which had wakened him 2½ hours earlier when it was a mild pain in his left knee and left hip. He was again recompressed but this time his symptoms did not clear till the pressure reached 155 feet. He surfaced after a therapeutic decompression on the Table III routine (Shorter than recommended for a recurrence), with stiffness and some residual bruised sensation in the left thigh which eased with exercise.

4 months later, without a dive in the intervening period, he again developed trouble after a trials dive. His ascent had been very irregular in rate. On leaving the compression chamber, he complained of a sensation of lumps in his scalp, loss of appetite, stiffness and pain in the right side of his chest causing difficulty in breathing, and disturbed sensation of his right leg from buttock to toes. Examination could not confirm any of his complaints but he was recompressed and reported all symptoms relieved at 35 feet. In spite of the neurological complaints, he was treated on Therapeutic Table I (Shorter). When he left the 10 foot stop he developed a slight nagging pain in his left shoulder. Regrettably his personality had raised strong suspicions that he was - and had been - malingering to earn the fee paid per minute under pressure to divers in those days. He was put to bed with placebos initially but much later it was obvious that his case had genuinely recurred and he was then treated with strong analgesics and sedatives. These were used as it was considered that in the natural course of the injury, recompression therapy would not be so effective after the delay before reconsideration and that the duration of recompression therapy would probably be longer than effective bed treatment. Eventually 48 hours after he had last reached surface he had recovered although for a short time he was conscious of a sharp pain in his left shoulder tip on coughing. (Eventually for executive reasons he was considered generally unsuitable for diving and he was relieved of his diving qualifications.)

Diver ME features in these accounts, mainly because of the amount of trouble he developed in each trial. He dived very often - in this surface decompression trial his 15 dives were 3 more than any other diver and he had two episodes treated by recompression. For his first incident 3 hours after surfacing, he complained of an ache in his right shoulder more severe than a dull ache in his right elbow; he had had a dulled feeling immediately after the dive in the same areas. No abnormality was found on examination. He volunteered the information that one week before he had had a pain in his right shoulder after he had acted as attendant to Diver SM (q.v.) during a therapeutic recompression but which he had not hitherto reported. (Since then he had dived every day without trouble). He was recompressed and his symptoms cleared when a depth of 150 feet was reached. The use of Therapeutic Table II was completely successful (Recommended).

His other main episode occurred about 3 weeks later when he reported on reaching surface that he had pain in his left shoulder and upper arm which had been felt for a short time on arrival at 20 feet, and again at 10 feet, and yet again at the surface. Examination revealed tenderness over the shoulder with slight limitation of movements and it transpired that he had had a knock to his shoulder the previous day. The clinical picture was akin to decompression sickness so he was recompressed with relief at 78 feet and he responded to the use of Therapeutic Table II (Recommended). Bruise discoloration appeared on the medial aspect of his left upper arm below the axilla during the therapy, but bubbles may have formed in the damaged tissue so they had to be treated whatever the final diagnosis.

Diver LE carried out a routine dive using the self-contained equipment. He reached surface and complained of abdominal distension and numbness of his right leg. He rapidly deteriorated with numbness developing in his left leg and lack of co-ordination apparent in both legs. The abdominal pain was severe. He was rapidly recompressed without an examination and his condition observed from outside the chamber as the medical officer was temporarily unfit to be compressed. His pain cleared at 10 feet and his neurological signs and symptoms disappeared at 50 feet. He was treated on Therapeutic Table I with complete success (Shorter).

Diver WH also used the self-contained equipment but his initial ascent was fast and uneven - in fact he was told three times to slow down and steady up. He appeared to be well till 2 hours after the end of his dive when he developed - but did not immediately report - a throb under both knee caps which became more a sensation of warmth. Examined 3 hours later there was no abnormality and a hot bath was prescribed. 5 hours later still a sharp pain developed in the right knee and a dull ache in the left knee. He was recompressed with relief at 55 feet and a routine Therapeutic Table I decompression was uneventful (Recommended).

Diver SM finished his dive at 1018 with no ill-effects. It was his first dive after an episode of decompression sickness 8 days earlier during multiple dive trials (q.v.). About 2145 as he had some discomfort in both his knees, he had a hot shower whereupon his sensation changed to dull ache and stiffness. Although physical examination was negative he was recompressed and all his symptoms cleared by 73 feet. Routine therapeutic decompression using Table II from 165 feet was successful (Recommended).

<u>Diver FR</u> was an experienced diver who developed signs of peptic ulceration during these trials. He was allowed to continue diving and carried out 12 dives in this trial. On one dive he developed a nagging pain in his left upper arm while at the 10 foot stop which persisted on reaching surface; in view of its reported mildness and in the absence of physical findings it was decided to await further developments. These occurred about 1½ hours later when the pain increased and he lost fine sensation of the fingers of his left hand. After relief of signs and symptoms at 65 feet on recompression, he was decompressed on Therapeutic Table I with no further trouble (Recommended if neurological signs secondary to pain). (He was referred for routine annual chest X-ray on return to port two months later when a shadow of early adult tuberculosis was seen on the X-ray plate).

<u>Diver DR</u> surfaced from a routine dive at 1030 and, shortly afterwards he noticed some discomfort in his left fore-arm which he reported at 1230 - more to obey instructions than for any other reason. He refused any treatment at that time. During the afternoon the pain spread to involve his whole arm and "was becoming a nuisance". A hot bath produced some waxing and waning in his symptoms and when he was

seen again at 1630 loss of grip of his left hand was found. He was recompressed with restoration of power at 140 feet and he was decompressed on Therapeutic Table II (Recommended if weakness secondary to pain). His ache was eased but didnot clear during treatment and it lasted with some stiffness in the arm for about three days after his therapy.

Comments

The most noticeable point is the frequent lack of physical findings in many cases which must be due to decompression sickness as evidenced by the response to recompression. The spread to involve nerves, presumably by local oedema in some cases is an indication of delay which leads to greater pressures being required for improvement and consequently longer periods spent in the recompression chambers. Frequently this results in a prolonged post-therapy sensation of bruising. In spite of a financial benefit to patient, and attendants under conditions then prevailing, the shorter treatments used on two occasions without ill-effects - and without the problems of personality clashes - were popular.

It was felt that the manipulations of the theories had led to a satisfactory routine which was adopted later as a routine technique. There was grave doubt about the adequacy of the decompression for longer dives. This led to the extension of the investigation into the basic tables described in Chapter VI. When the cases were properly assessed, the depth of relief of the signs and symptoms was thought to be a better guide to the subsequent therapeutic decompression than to use their actual nature as an aid in selecting the routine to be used.

CHAPTER X

SUBMARINE ESCAPE TRAINING

Background

This training is not experimental in nature but it does involve a risk of injury due to the rapid changes of pressure undergone by the trainee. The signs and symptoms often resemble serious cases of diver's decompression sickness. The patients are treated in a similar manner by recompression. The training is carried out in a warm well-lit cylindrical tank of 20 feet diameter and 100 feet depth (Fig. 13). Access locks are situated at 30 feet, 60 feet and the bottom. In addition there is a diving bell that can travel the depth of the tower.

Routine

The trainee usually wore light goggles, swimming trunks and an inflatable lifejacket, with a relief valve, to provide buoyancy; or else he dressed in the Submarine Escape Immersion Suit (Fig. 14). Each class of 9 men and an instructor was compressed in the appropriate lock by flooding up with water and when the pressure equalised, the communicating door into the tank opened. In turn, each trainee took a breath from the appropriate air supply and was pulled backwards through the door by two instructors who held him until a senior instructor was satisfied that he was exhaling steadily. The trainee was then released; his natural buoyancy plus the buoyancy of the lifejacket took him rapidly to the surface under constant surveillance by instructors stationed in the water and at the surface. On arrival at the surface he left the water unassisted and he was kept standing near by under observation for a short period. Any abnormality of behaviour, or physical condition could be immediately noticed. Unless there was an immediate alternative explanation, the trainee was assumed to be suffering from some form of pulmonary barotrauma and he was recompressed rapidly - 30 seconds from suspicion of injury to start of compression being considered slow. While there have been no fatalities in training in the Royal Navy, they have occurred in other circumstances (98) and then most commonly in less than 5 minutes from reaching surface. Each trainee, after a practice dive to 100 feet in a compression chamber, carried out two ascents from 30 feet, one from 60 feet and one from the bottom of the tank in the course of 2 days.

The incidence of cases that needed recompression, including those in which an alternative explanation was later found, was between 1 in 8,000 and 1 in 10,000, ascents by trainees (the ascents by instructors were done without lifejackets and there were only 2 incidents in 8 years). The signs and symptoms depended on the site reached by the bubbles of air which enter the tissues from the alveoli. [Complete responsibility for treatment was limited to a few cases ab initio but the remainder of the cases described became my responsibility when I was called in as adviser on the subsequent decompression].

<u>Therapeutic Approach</u>

The therapy used was recompression on the assumption that the gas pockets or bubbles must be reduced in volume before ischaemic or pressure damage became irreversible. Such treatment should lead firstly to the bubbles in the circulation passing on to be filtered out in a relatively harmless area or in the lungs or to reduce the area of effective damage; or to gas in the pockets or bubbles going into solution in the tissues; or finally, in certain circumstances, to allowing time for other therapeutic measures to be taken. It was noteworthy how frequently the presumed initial breach of tissue continuity in the lung appeared to be immediately sealed as evidenced by the disappearance and failure to recur of signs and symptoms. The patient had then to be returned to atmospheric pressure and it was customary - but not invariable - to use the therapeutic tables that were used by divers for decompression sickness. In the light of experience in divers, it was felt that the situation of the escape training casualty was different. In decompression sickness the hypothesis was that bubbles tended to form de novo in tissues supersaturated with gas. In pulmonary barotrauma, especially the air embolism forms, the bubbles were thought to be introduced into tissues where the atmospheric gases in solution were still essentially at normal atmospheric tension as there had been insufficient time at high pressures to alter the levels to any great degree. This led to the attitude that the therapeutic recompression of a submarine training accident could be regarded as a double chamber dive carried out by the patient at rest. A routine was evolved on these lines for cases which had apparently responded completely to the initial compression. It became apparent that if the bubble had not completely redissolved or been filtered out so that signs and/or symptoms persisted then a prolonged stay under pressure was required till the effects of the bubble disappeared as pressure could not be further increased, because of equipment limitations. The suggested decompression routine (Appendix 3) was based on standard air Diving Table II (132) and this sometimes caused confusion with Therapeutic Table II (132) (new editions of the Diving Manual (133) now refer to these tables as Table I below the limiting line and Table VB respectively). Important subsidiary factors in investigating the value of a shorter routine were an ambient temperature of 90°F, high humidity, and close confinement in the small compression chamber.

Case Notes

Trainee CX carried out an ascent from 100 feet while on re-qualifying course. About 30 feet he thought he was running out of air because of tightness in his chest as if it was about to burst. While climbing out of the tank he appeared to have some difficulty and then his legs gave way. He was immediately rushed to the chamber (about 15 feet away) and though his arms seemed to become flaccid, he did not appear worried and his speech was clear and rational. He was compressed to 100 feet but as he was not completely recovered, pressurisation continued till he reached 165 feet. Physical examination at that depth disclosed no abnormality. He had remained conscious with unimpaired speech, sight and hearing and he had deliberately not tried to move till he was asked to do so during the compression. Decompressed on standard air diving tables as if he had dived to 165 feet for 35 minutes i.e. maximum depth for total time from initial pressure exposure that day and he regained the surface 2 hours from the start of treatment. Frequent examinations during this period were negative and subsequent chest X-rays were normal. The clinical picture was that of cerebro-spinal air embolism but in the absence of positive findings the site and diagnosis are not confirmed (Shorter).

Trainee CS carried out a 30 feet ascent on this his third routine course (second requalifying course). After climbing out of the water, an instructor questioned him because of suspicion that he was puffing and blowing excessively and that he was not moving very easily. The patient denied any difficulties; on questioning a little later he admitted feeling giddy; a check on his vision by asking him to follow the examiner's fingers was normal but an attempt to make him walk disclosed an inco-ordinated spastic gait. As he was being lifted to the chamber, he developed a flexor spasm first in his right arm and then in his left arm which caused some difficulty in passing him through the chamber hatch. He was compressed to 165 feet and examination was negative; except for amnesia from the time of request to follow the finger - that is he did not remember seeing the finger or responding till the chamber had nearly reached maximum pressure. He was decompressed on Therapeutic Table III (Recommended). While at the 50 feet stage, he complained of retrosternal discomfort, suspected to be due to mediastinal emphysema;

it was decided to continue the decompression and at the 40 feet stage, surgical emphysema was detected in the right supraclavicular triangle. A careful watch was kept on the patient's condition as decompression continued but as his discomfort was unaltered and the only positive finding was a slight increase in the emphysema in the neck, no other action was needed. On examination after transfer to hospital 4 hours after reaching surface, E.E.G. showed no focal disturbance but chest X-ray confirmed the mediastinal emphysema. On repeat X-ray one week later no abnormality was seen. The diagnosis was pulmonary barotrauma presenting as cerebral air embolism and complicated by interstitial emphysema.

Trainee GM This man on his first course, appeared to be apprehensive as shown by excessive frequency in carrying out the Valsalva manoeuvre during his practice chamber dive. He carried out his water drill satisfactorily. On climbing out of the tank after his 60 feet ascent, he seemed to waver and to have difficulty in finding the rung of the ladder. When he did not reply when he was asked if he was alright, he was rushed to the chamber and he reached 112 feet within 90 seconds of reaching surface. This unusual depth was not deliberately selected but happened to be the level where the attending doctor stopped compression having decided that the incident was not due to barotrauma but possibly due to hysteria and abdominal distension as a result of excessive air swallowing during ear clearing. The patient reported that he had had a sudden pain in his epigastrium on the ladder and that he had not lost consciousness but the attendant reported that he had to assist the patient to clear his ears during the therapeutic compression by closing the patient's nostrils. Decompression on standard air tables for a dive to 120 feet for 40 minutes was carried out (Shorter). He was examined on surfacing, by the author, who could find no abnormality and who recommended observation for 4 hours in the training tank building (standard practice in case of recurrence). Half-an-hour later he was seen by the original medical officer because of developing restlessness and lack of co-operation. Physical examination was negative and again a presumptive diagnosis of hysteria was made. 1 hour later still he was seen by a third medical officer who diagnosed acute confusional state, and after recalling the author who confirmed the disturbed mental state; the patient was recompressed to 165 feet. As a result of the long period to the start of adequate therapy there was no dramatic improvement but experience had shown that Therapeutic Table III usually resulted in recovery in this type of case so it was used instead of the longer Therapeutic Table IV. At 50 feet his conversation became rational and when he was re-examined at 10 feet by the author, the only abnormality found was some interstitial emphysema in the right anterior triangle of the neck. Chest X-ray in hospital showed this emphysema but no mediastinal gas shadow was detected and the E.E.G. was a normal record. This man suffered from pulmonary barotrauma presenting as cerebral air embolism and later interstitial emphysema but an error in diagnosis by an inexperienced doctor led to difficulties in subsequent therapy. When seen after the first compression, there did not appear to be any indications for recompression; presumably this was in the latent period of a partially treated lesion before reactions such as local oedema develop; the wisdom of a period of close observation is apparent.

Instructor HG This man, surfaced from a 100 foot unassisted ascent after the last man of his class. He complained after about 10 minutes of pain in his left shoulder radiating to his elbow and wrist and which then developed into paralysis of his left arm and forearm with paraesthesia of the two lateral fingers of his left hand. He was recompressed and his signs and symptoms cleared at 110 feet. As examination showed no abnormality he was then further compressed to 165 feet before decompression on standard air tables for a dive to that depth for 50 minutes (Shorter). Progress was uneventful. It later transpired that this man had been treated while on leave one month before for bronchitis (with a rumour of pneumonia). Full plate X-ray, taken with knowledge of his task but ignorance of his illness 5 days before this incident, was reported normal. Hospital investigations including chest X-rays and E.E.G. disclosed no abnormality. The most probable diagnosis was cerebral air embolism; decompression sickness could not be excluded, as it has been known to occur exceptionally after a dive to 100 feet for 10 minutes as this man had done. (Diving tables give a minimum duration of 20 minutes at 100 feet before decompression is required).

Trainee MM This man surfaced from 60 feet during his initial training and lay on the surface of the water with his eyes closed. While his dead weight was being pushed into the chamber, he began to protest but he was compressed to 165 feet. General examination showed no abnormality and he seemed fully aware of his surroundings and events. He was decompressed on standard air diving tables for a dive to 165 feet for 35 minutes with no apparent ill-effects (Shorter). Re-examination disclosed a small posterior traumatic perforation of the left ear drum. No chest X-ray was done in hospital; his E.E.G. was normal. The diagnosis is obscure, but observers were convinced he was unconscious and hence cerebral air embolism was a possibility and treatment had to be given.

Trainee FD left the water after his first ascent from 30 feet apparently well but within a minute complained of dizziness and inability to use his right hand. (Later it transpired that he also noticed numbness round his mouth, numbness on the medial aspect of his right elbow, and in the approximate distribution of the ulnar nerve in the right hand). He was immediately recompressed to 165 feet. As on arrival at this pressure some numbness was present round his mouth and over the medial three fingers of his right hand and there was inequality of lower limb reflexes with right brisker than left, he was decompressed on Therapeutic Table III (Recommended). During this period full sensation returned and his reflexes became equal. Chest X-rays and E.E.G. on admission to hospital disclosed no abnormalities but the clinical picture was air embolism.

Trainee MM This man had attended the course twice before. On the first occasion he had carried out the full course but shortly after surfacing from 100 feet, he had been found apparently unaware of his surroundings; he had not been recompressed and observation in hospital had not disclosed any abnormality after he had quickly regained his sense of his surrounding. On the second occasion, he did not carry out his 100 foot ascent because he developed a cough on the morning of the second day. On this third course he surfaced from 60 feet and complained of a twitching in his hamstrings on climbing out of the tank although his walking seemed normal. While he was being examined he developed paraesthesia of his knees and then loss of active movement of his knees and recompression was started. These complaints steadily improved during compression but he then found difficulty in raising his arm to clear his ears. By the time 165 feet was reached, all signs and symptoms had disappeared. He was kept there for 11 minutes and decompressed on standard air diving tables for 1 hour at that depth - i.e. a total decompression time of 2½ hours - and no signs or symptoms recurred over 24 hours observation (Shorter). This man showed neurological abnormalities possibly due to air embolism.

Trainee NN was carrying out his second escape course. On the first occasion, he had developed numbness of his 4th and 5th fingers left hand and he had been treated by recompression; initially it seems his decompression had lasted 1 hour (no details of depth known) but when he had then developed weakness in his legs. Therapeutic Table III had been used. This time, again after his 100 foot run, he developed numbness in his right little finger and he was compressed till this cleared. This depth was 120 feet where he was kept for 11 minutes and then decompression was carried out over 2 hours (Shorter). While this man's complaints were minimal on both occasions, the initial failure of a very short routine on the first occasion and the success of a slightly longer procedure (but still shorter than the routine therapeutic tables) on the second are of interest though the diagnosis of air embolism is only presumed.

Trainee LW was on his fifth escape course and had just completed the last ascent from 100 feet, when he began to feel unwell as he climbed out of the tank. He then fell to the floor, overcome by weakness and dizziness but he later maintained he did not lose consciousness. He was immediately recompressed with such marked improvement to his general condition that numbness and weakness of his right arm became noticeable. At 165 feet, the reflexes of his right arm were increased and there was loss of fine finger movement so a therapeutic table was indicated and Table II was the one selected (Shorter). During the 10 hours decompression, the signs improved although on reaching surface the right biceps reflex was still brisker than the left. Observation in hospital showed continued progress in a patient who had fairly classical clinical cerebral air embolism.

Trainee MB carried out a most unsatisfactory ascent from 60 feet with no apparent exhalation for the first 25 feet from release. (He had exhaled satisfactory before he was released so his chest was not fully expanded at the start of this period). 2 minutes after surfacing he complained of heaviness in his right arm and he suddenly lost consciousness as he was entering the compression chamber. During recompression, he started to recover, initially being confused and disorientated but within one minute at 165 feet he became rational and co-operative. No abnormality was found on examination and he complained only of very transient pins and needles over his left antecubital fossa in addition to a headache over the vertex (where it was thought his head had hit the chamber wall during entry). He was decompressed on standard air diving tables, the whole procedure taking 3 hours (Shorter). Observation and investigations in hospital disclosed no abnormality. This case clinically resembled those with cerebral air embolism and responded to a short routine, in spite of the persistence of some signs on arrival at maximum pressure, usually considered an indication for one of the standard therapeutic decompression routines.

Trainee LM on his first course seemed to be unable to leave the water after his 100 foot ascent. He was promptly transferred to the compression chamber and compressed to 165 feet where he was found to be dazed and frightened. He had some bleeding from his nose but was otherwise well. He was then rapidly decompressed to 100 feet and examined again. Standard air decompression was then started but at 50 feet, he complained of right inframammary pain so pressure was increased to 60 feet and in a few minutes the first signs of a right pneumothorax were found. Pressure was maintained and interstitial emphysema tracked behind the right clavicle after about 20 minutes. The patient was extremely anxious and complained of difficulty in vision and inability to breathe; the former appeared to be due to a wandering scotoma and the latter was not confirmed by examination. After various pressure fluctuations, he was given chlorpromazine and his visual defect, tubular in character by this stage, gradually cleared. The decompression thereafter was a modified Therapeutic Table I (Shorter). Observation and investigations in hospital confirmed the pneumothorax and he was found to have an unusual E.E.G. depression reaction to chlorpromazine. The initial rapid visit to 165 feet and back to 100 feet was unusual and in the author's view led to subsequent complications in the treatment of undoubted pulmonary barotrauma presenting as cerebral air embolism, pneumothorax, and interstitial emphysema.

Trainee FB completed his second course but 6 minutes after his final ascent - from 100 feet - he was seen to be clumsy and inefficient with his suit fastenings and as his replies to questions were confused he was recompressed to 100 feet before any medical officer saw him. As he was normal, the medical officer considered that there was no evidence for the need for a therapy and the patient was decompressed, the whole cycle taking 25 minutes. Over the next two hours he had slight dizziness and headache for which he obtained some aspirin before leaving the establishment with a friend. On a ferry he had an epileptiform attack and his friend persuaded the crew to take the patient back and 20 minutes after boarding the ferry FB was back in a compression chamber on his way to 165 feet. He was seen by a second medical officer who found him drowsy and complaining of a frontal headache but co-operative. No other abnormal signs were found. After 5 minutes, decompression to 100 feet was carried out and a more intensive interrogation disclosed amnesia from the time of his fit till he was in the chamber. Therapeutic Table II was started from this depth but when 60 feet was reached 50 minutes after the entry into the chamber, FB had another major epileptiform convulsion in which he bit his tongue slightly but during which he remained continent. Pressure was immediately increased to 165 feet but for half-an-hour the patient's personality was inaccessible; he was restless, with all his limbs flaccid, his reflexes exaggerated, and his toes upgoing. He then responded to questions and Therapeutic Table III decompression was commenced (Shorter). Re-examination at 120 feet showed recovery of all abnormal signs except that he had a further amnesic period for the second fit and about half-an-hour afterwards. Intramuscular paraldehyde was used to sedate the patient and Table III was modified for the final 3 stops which took 3 hours, 5 hours and 8 hours successfully instead of the schedules 12 hours, 2 hours and 2 hours. In hospital, clinical examination and chest X-ray showed no abnormal signs but the E.E.G. was grossly abnormal especially in the posterior right hemisphere. Follow up E.E.G. one month later showed no abnormalities.

This case undoubtedly had cerebral air embolism and demonstrated how inadequate initial care complicated the subsequent therapy.

Trainee AA had not carried out an entirely successful ascent from 100 feet, on this his first course, when his red face and very firm grip on the ladder led to his being immediately recompressed to 165 feet. On examination there he appeared fit and well so decompression commenced on a standard air diving table. At 100 feet interstitial emphysema was found behind the right clavicle and signs of a right pneumothorax noted. Using his condition as a guide, decompression continued, taking 1½ hours (Shorter). On reaching surface, the superficial emphysema was present over both sides of the face and neck, the right shoulder, and the right pectoral area. X-rays disclosed a right pneumothorax confined to the base by adhesions, and added retroperitoneal emphysema to the known area involved. However 14 days convalescence led to the disappearance of all abnormal signs and symptoms. This case of pulmonary barotrauma, as shown by interstitial emphysema and pneumothorax (and perhaps air embolism if his initial grip was spastic in nature) demonstrated that a short routine could be used provided mediastinal emphysema and pneumothorax were either confined strictly or else released to areas so that no cardiac or respiratory embarrassment occurred.

Trainee HD had completed the course successfully once before. On this occasion he had a mild tracheitis which he did not report and which was not detected on examination. He carried on the course successfully and had left the tank top area to get dressed after his 100 foot ascent when he noticed increasing numbness and lack of control initially over his legs and then his arms. He felt confused and dizzy and appeared disorientated although he responded to questions and was co-operative. He was recompressed to 165 feet 17 minutes after leaving the water and examination at pressure disclosed no abnormality; he was decompressed to 100 feet and re-examined and bilateral aural barotrauma was found. Questioning revealed partial amnesia for the short interval between the development of dizziness and recompression. Decompression was then carried out on standard air diving tables for a dive to 165 feet of 27 minutes (Shorter). Further investigations were negative throughout but the initial picture was that of cerebral air embolism.

Trainee MF apparently surfaced feeling well after the 100 foot ascent on his second course. He did not report for several minutes but he had noticed numbness, loss of control, and weakness in his right thigh just after he climbed out of the water. These symptoms radiated down the leg and up into the trunk and he reported when he needed help to stand up. While he was being helped to the compression chamber, the numbness spread to his right shoulder and arm. Seven minutes after leaving the water he was compressed to 165 feet and other than aural barotrauma bilaterally, no abnormality was found on examination. Decompression was commenced on standard air diving tables but on reaching 70 feet, the symptoms recurred now involving the right side of the face as well. The patient was recompressed to 165 feet with relief of his signs and symptoms. Therapeutic Table III decompression was started and completed successfully (Recommended). Further investigations were negative. Clinically this was a case of cerebral air embolism.

Trainee WD felt a little confused on reaching the surface after a 100 foot ascent on his first course. He started to climb out, looking normal, but he suddenly crumpled to the floor whereupon he was immediately put in the compression chamber and within two minutes of surfacing, he had reached the equivalent of 165 feet. At this depth the patient remained quiet and seemed asleep but no efforts were successful in rousing him for about 10 minutes when he suddenly recovered. There was bilateral otitic barotrauma and a left epistaxis but otherwise examination revealed no abnormality. Decompression on Therapeutic Table III was started (Recommended). On reaching 100 feet, after 8 minutes, the patient complained of difficulty in vision and bilateral central scotomata were found. He was recompressed to 165 feet where the visual defect decreased and there was found pupil inequality, with the left larger than the right; light and accommodation convergence reflexes were sluggish; and there was transient nystagmus to right and left. In addition he had developed frontal headache with nausea and vomiting of altered blood. Decompression on Therapeutic Table IV (Recommended) was commenced and there was steady improvement with time as judged by the print he was able to read with each eye centrally. Some slight pupil inequality persisted in hospital and a very transient nystagmus could be elicited, but other examinations and investigations disclosed no abnormality. This case was clinically one of cerebral air embolism. Perhaps an initial higher pressure would have been beneficial but the chamber was not designed for such pressures.

Trainee PP carried out his first escape satisfactorily until the 60 foot ascent when he made a groaning expiration on arrival at the surface. He started to climb out but collapsed back into the water apparently unconscious. Even on compression to 165 feet, he remained unconscious and showed laboured respiration with mild cyanosis of his face and neck. Over 10 minutes, the patient passed through a restless condition to one of co-operation and rationality in which he complained of retrosternal pain. Examination disclosed signs of weakness in his left arm, poor co-ordination of all his limbs and possible diminution of the area of cardiac dullness as well as bilateral otitic barotrauma and mild epistaxis common in rapid therapeutic compressions. Decompression on Therapeutic Table III was started after his chest pain had almost cleared over a period of half-an-hour (Shorter). At 80 feet over a period of 12 minutes the patient rapidly and progressively became disorientated and unco-operative and developed jargon aphasia and mis-understanding of simple commands. Recompression to 165 feet led to very slight improvement in his response to forceful commands but his moods rapidly alternated between a childish euphoria and aggressive restless-ness. (He was a big athletic individual) His tendon reflexes became very brisk. After 2 hours, decompression on Therapeutic Table IV was started and intramuscular paraldehyde was used to control the restlessness. 12 hours later, at 40 feet, he began to respond more to simple commands and questions and to appreciate his surroundings and at 20 feet his mild euphoria and final traces of aphasia disappeared. His brisk reflexes were the only abnormalities on clinical examination before transfer to hospital; E.E.G. showed an abnormal record with slow theta and delta activity in the right hemisphere; chest X-ray disclosed a small left apical pneumothorax, a localised air cyst at the left base, and a well marked pneumo-pericardium. 3 days later, a chest X-ray showed decreased pneumothorax and pneumopericardium only and in another 3 days, these findings had gone. A repeat of the E.E.G. after an interval of 1 week showed a normal record. This patient had pulmonary barotrauma, as shown by the triad of pneumothorax, pneumopericardium and cerebral air embolism, which was too serious to consider the use of a short therapy.

Trainee MJ was on his first escape course and his first ascent from 30 feet was satisfactory after considerable initial difficulty in exhaling to the satisfaction of the instructor (he re-entered the air lock three times before he was released and each time he was keen to try again). His second ascent, also from 30 feet started well but his exhalation became intermittant in the shallower depths. On climbing out of the tank he collapsed with loss of consciousness which did not apparently respond during compression till he reached 165 feet. Examination disclosed no abnormalities so decompression on standard air diving tables started (Shorter). This had to be halted at 56 feet because of a complaint of inability to see. He was immediately recompressed to 165 feet where he also mentioned the new developments of retrosternal pain and ache in his neck. On examination, there was no evidence of meningism and all movements of his neck were full and painless. No abnormality was found on examination of his chest or fundi. There was no response to light of his dilated pupils and he had a blink reflex but blindness seemed to be complete. His co-operation decreased as he became drowsy and eventually his respirations became stertorous and rapid and he seemed to be in coma. Trial decompression to 100 feet was carried out and his coma was replaced by semi-conscious activity which was violent if he was disturbed. An attempt to recompress him again to give him a prolonged pressure exposure failed because of obvious pain in his facial sinuses, at a depth of 122 feet. Therapeutic decompression on Table IV was started with intramuscular paraldehyde as a sedative, which however was not completely effective till 16 fl.oz. of urine were drained from his bladder by catheter. He slept for 7 hours and examination of him then showed lack of awareness of his surroundings and total lack of response. Physical examination was negative but he became restless until he was incontinent of urine and faeces whereupon he settled back to sleep. For the next 30 hours, physical examination showed no change and he had alternating short outbursts of violence and long periods of sleep. At 10 feet some subcutaneous emphysema was detected in the right side of his neck. The picture of cerebral irritation and interstitial emphysema was confirmed in hospital where X-rays disclosed pneumopericardium and air tracking into the upper mediastium and the neck and E.E.G. showed a generally disorganised record with excess slow activity in the left hemisphere. He made slow steady progress and physical and mental recovery on clinical examination was complete in three weeks though another three weeks was needed for the E.E.G. record to become normal. This case of cerebral air embolism and mediastinal emphysema failed to respond to a short therapy and was not entirely successfully treated by a very long routine; this poor response might have been due to inadequate initial treatment allowing reactionary damage to occur.

Trainee ID had reached the 100 feet ascent stage of his first escape course. His own story was one of hitting his head as he left the lock - not confirmed by the two attendant instructors - and that his next memory is reaching the surface, vague recollection of people talking to him, and then clearing his ears during compression to 165 feet. The attendants reported poor exhalation during the ascent and failure to respond to instructions on arrival at the surface so he was compressed. His attendant during the compression reported that he seemed fully orientated and rational. Physical examination was negative, even to signs of head injury, and after 30 minutes at maximum depth the patient was decompressed on standard air diving tables uneventfully (Shorter). In hospital, E.E.G. examination showed episodic theta activity in all areas and a slow clearing delta response produced by overbreathing. A repeat examination in 4 days showed diminution of these findings and three weeks later the E.E.G. trace was within normal limits. Under the circumstances, it is wiser to regard this case as one of cerebral air embolism which responded to a short routine.

Discussion

Many of these nineteen cases showed signs and symptoms suggestive of neurological damage. In view of the short period of time possibly available before death, the patients were recompressed as soon as possible after suspicion had been raised, without waiting for the medical officer to make a diagnosis. Over the years the medical officer in the building changed. While the medical officer for the first few of these cases was called in to advise in the remainder, each new doctor would exercise his perogative to treat his patient initially to the best of his belief pending arrival of assistance, sometimes the case was not seen by a more experienced doctor till the routine was well underway. This led to errors of diagnosis e.g. trainee FB or errors of assessment e.g. trainee MJ.

It is possible that only 8 of these men suffered from pulmonary barotrauma; none of the other men had abnormal findings on X-rays or electroencephalographic examination but with the proceeding activity and similar clinical picture, it was the most probable diagnosis. When no physical signs were present the diagnosis could only be made on the history. The case of trainee FB and to some extent that of trainee GM show that any alternative diagnosis may lead to considerable complications. During the 5 year period covered by these cases, only two other cases were compressed; one was decompressed on the standard air diving table with a diagnosis of disorientation under water and the other complained of pain in his foot - on being further questioned at 165 feet he added that he had accidentally kicked the tank wall wile climbing out after his ascent. While there may be doubts about the diagnosis, any benefit must be given to the patient and inconvenience and discomfort to the staff are not important.

13 cases were considered suitable for trial decompression on a short routine taking a few hours. Of these 4 eventually had to be further treated, two by routines taking 20 hours, a third by a routine taking 40 hours, and the fourth by a modification of a 6 hour routine. 4 men were treated from the beginning by Therapeutic Table III and of these, 2 had to have further treatment by Therapeutic Table IV. One man was treated on Therapeutic Table II which should not normally have been considered for this but it was effective. The remaining case sprang from an error in diagnosis and had a complicated compression history.

From this it can be seen that the routine treatment of neurological cases by a long therapeutic decompression is not always the best treatment. If proper selection of cases is made then a trial at a short routine may be justified provided the physician is prepared to return to higher pressures and a much longer routine when the condition of the patient warrants it. Only those cases whose signs and symptoms have completely cleared by the time maximum pressure is reached should be considered for a short therapy. Experience suggests that cases which still show some troubles, for however short a period, on the conclusion of compression will later require to be treated with further compression or transferred to a long routine. In addition, there is evidence here for always using pressures of 6 atmospheres absolute right at the beginning and which should be maintained for some time, probably 30 minutes, before decompression commences. The possible use of higher pressures may be considered, if equipment limitations are overcome.

The discovery of pneumothorax or interstitial emphysema does not necessarily lead to further compression as the former can be treated by orthodox means if needed - and has been on one occasion in the past - and the latter usually tracks into the soft tissues of the neck so releasing the tension and the dangers of both are avoided. The dangers of pneumopericardium may not be avoided so easily and in such a situation the compression and decompression would have to be controlled by the degree of cardiac embarrassment produced, with a very slow release of pressure over days being theoretically one solution. These conditions are basically mechanical in their action in producing signs and symptoms. Air embolism has however the secondary effect of producing local hypoxia and the later appearance of signs and symptoms may be due either to the recrudescence of the embolus or to cellular hypoxic effects or to reaction by the tissues to the traumatic insult. In all cases, an increase in pressure should lead to improvement by reducing the size of embolus or increasing the amount of oxygen dissolved in the tissues. The risk of the effects of hypoxia are less if adequate pressure is applied rapidly enough.

Any therapy for pulmonary barotrauma should involve immediate recompression to high pressures. The chambers were designed for an absolute working limit of 7 ats. abs. as Duffner and his colleagues (51) had shown that 6 ats.abs. was quite adequate and that a further relative slight increase in pressure was not worthwhile (although later work here shows that in fact 8 or 9 ats.abs. may be valuable). Thus 165 feet as quickly as possible without too much regard for the tympanic membranes and sinuses of the patient is indicated. This pressure is 2 atmospheres more than the maximum to which the trainee is usually exposed on his course. To encourage gas in any bubbles or pockets to go into solution, not only is a pressure gradient between bubble and tissue gas tensions required but also a certain time element and this period has been fixed arbitrarily at 30 minutes. The diffusion of gas in and out of the body tissues has varied with the pressure exposures of the individual during the proceeding training and account has to be taken of this in devising suitable decompression tables to avoid the production of decompression sickness. To make a dogmatic instruction, it has been accepted that the sum of time spent under pressure that day, the time from the last ascent to compression, and the period spent at 165 feet - usually 30 minutes - will be regarded as the total time spent at that depth and hence the appropriate diving table can be found and used with some confidence in the right cases.

Examination of nineteen cases of pulmonary barotrauma lends support to the treatment of cases whose signs and symptoms clear during compression to 6 ats.abs. by the use of a standard diving table for an artificial aggregate time. Other cases should be treated by the standard therapeutic tables strictly applied. Under both circumstances a few cases will not respond completely and subsequent therapy has to be directed on an ad hoc basis by experienced doctors.

CHAPTER XI

DEEP DIVING EXPERIMENTS

Background

Deep diving is regarded in the Navy as diving to depths in excess of 200 feet. This figure is chosen because it is a convenient whole number near the depth beyond which only very experienced individuals can dive efficiently using air as their breathing medium, although dives to 400 feet or so, using air, have been recorded. The main reason is the loss of efficiency and manual dexterity due to depression of the higher intellectual centres that occurs with nitrogen either by direct action or indirectly as a result of carbon dioxide retention as discussed earlier. These problems can be avoided by using helium to provide the bulk of the respirable gas as theoretically, similar effects should not be expected till depths of the order of 1,000 feet or more are attained. Air at 300 feet or 10 atmospheres absolute, contains toxic quantities of oxygen as well as nitrogen. One solution is the provision of an artificial atmosphere where the proportion of oxygen is reduced the diluent being helium.

Notes on Techniques

a) Chamber dives

In chamber experiments, the subjects were usually compressed in pairs and they either donned the breathing equipment - usually a mouthpiece mounted demand valve - supplied from various banks of artificial atmospheres stored outside the chamber; or they continued to breathe the chamber atmosphere which was supplied directly from the banks (Fig.4). Once compression was completed the divers exercised alternately, on a rowing machine or other device, till just before the end of the dive when they dressed in warm clothing (Fig. 15). Decompression commenced and the breathing mixture was changed to avoid severe hypoxia on reaching surface. Varying mixtures of oxygen and helium were used so that the proportion of helium was kept as low as possible consistent with safety in respect of the oxygen content; this was done to keep the pressure gradient as steep as possible between the tension of helium in the tissues and the partial pressure of helium in the respired gas to encourage elimination of the gas and hence reduce the risk of decompression sickness. During the decompression the men relaxed as much as possible to avoid stimuli to bubble formation.

b) Sea dives

In sea dives, the men used the submersible decompression chamber (S.D.C.) as a lift and donned their breathing equipment at 100 feet during the descent; if the water level in the chamber was being kept down by supplying the correct oxy-helium mixture for the dive they continued to breathe the chamber atmosphere (this supply was intended originally in case of equipment failure, but was later done for comfort and economy). After a spell of swimming or working (Fig. 16) the divers were recalled into the chamber and the ascent commenced. The selection of the various breathing mixtures in the course of a sea dive was sometimes affected by the ease of using different mixtures for the diving set supplied from the cylinders mounted on the S.D.C.; the submersible chamber atmosphere supplied from storage cylinders in the ship; and the transfer chamber supplied from other storage banks on board the ship. The decompression continued in a similar manner to that described for chamber dives once the divers had transferred satisfactorily.

Approach to the Trials

General principles, were that the number of dives to be done on each safe schedule was to be 10 and that minor cases of decompression sickness would signify caution but a major case would normally entail change either in total decompression time, oxygen percentage in the mixture, reduction in dive time, or complete recalculation depending on the course of action previously agreed. As the trials progressed they became more experimental in nature then potential operational routines. This resulted in changes in such respects as numbers of dives; number of men to do them; and in the action to be taken if serious cases developed. Such changes can best be followed by describing them in the various stages as they occurred.

THE DIVES

a) First Period (103)

(i) Preparation

In this initial phase of optimism it was anticipated that the team would be diving within 2 months to 1,000 feet with shorter decompression times than ever previously envisaged. Several chamber dives on the new concepts were carried out on air to 300 feet to test both schedules and rates of ascent. This decision arose from theoretical and practical work abroad which suggested that oxygen and helium mixtures were safer than oxygen and nitrogen. Similar calculations were used to produce a schedule for a dive to 250 feet on air in the sea which would serve as a final work-up dive as well as acquainting the divers with the effects of narcosis in case air had to be breathed in an emergency during deeper dives.

(ii) Results

Stage	Dive			Schedule Number	Number of		Decompression Sickness	
	Depth Ft.	Environment	Gas		Dives	Divers	Minor	Major
First Reclaim	300	Chamber	Air	1	10	10	7	1
				2	19	18	-	-
	300	Chamber	O_2/He	3	2	2	-	-
	400	Chamber	O_2/He	4	4	4	-	2
	250	Sea	Air	5	12	12	1	-
	300	Sea	O_2/He	3	6	6	-	3
Vernon	300	Chamber	O_2/He	6	10	10	2	2
Second Reclaim	250	Sea	Air	5	26	14	7	2
	300	Chamber	O_2/He	7	9	9	1	3
		Chamber		8	13	13	1	1
		Sea		8	14	10	4	5
		Chamber		9	14	8	1	1
First Period Total					139	27	24	20

Table XI. 1

Record of Dives. First Experimental Period

The main burden of diving fell on 12 men who carried out 110 dives and who suffered 21 minor and 12 major cases between them. Of this group 3 men had one major attack each but no minor attacks while another 3 men had no major attacks but 8 minor incidents between them. Of the support group of 15 men 11 were not permanent members of the experimental team or the ship's team and were available only for a very limited period; 3 who were permanent members had had a serious attack of decompression sickness early in the trial and had not recovered fitness to dive before diving stopped in this period; and the last individual was not a fully trained diver and, as he had other responsibilities in the organisation, he was not permitted to dive often. One man who had the major attack on the first air chamber dive, (his first trials dive) in the first Reclaim stage, had another attack on his first dive in the second stage, also on air but this time in the sea. The other diver who had a major attack after an air dive in this second stage was also carrying out his very first dive of the trials. The cause of these attacks was debatable but the schedules involved an unusually fast rate of ascent to the first stop which was slowed in subsequent periods. Table XI. 1 shows the serious effects of these dives. In the later dives of the series 100% oxygen was used instead of air during the shallower stages of decompression.

b) <u>Second Period</u> (79. 104)

(i) Preparation

It can be seen that the first experimental period resulted in a lack of success as far as the ability to provide safe diving tables for 300 feet, much less 1,000 feet, was concerned. Much information was obtained and further work was started to prepare schedules for a second period of chamber and sea dives. It was intended that all dives would finish with a spell of oxygen decompression and that no breathing mixture containing nitrogen would be used after the start of oxy-helium breathing till the diver reached surface again. The intention was to carry out dives at increasing depths to 450 feet of 10 and 20 minutes duration at each selected depth, using 10% oxygen and 90% helium as the main dive gas.

(ii) Progress

Stage	Dive: Depth Ft.	Dive: Duration Mins.	Dive: Environ-nment	Dive: Main Gas	Schedule Number	Number of: Dives	Number of: Divers	Decompression Sickness: Minor	Decompression Sickness: Major
Vernon	300	10	Chamber	He	10	4	4	1	1
					11	6	6	3	-
					12	30	7	1	-
		20			13	10	6	2	-
					14	10	5	1	-
Reclaim	400	10	Chamber	He	15	10	10	-	-
	300	10		Air	16	5	5	-	-
	400	20		He	17	6	6	5	-
	450	10			18	6	6	3	-
	300	10			12	6	6	-	-
	250	10	Sea	Air	19	14	14	-	2
	300	10		He	12	30	14	6	2
	450	10	Chamber	He	20	10	10	1	-
	400	20			21	6	6	1	3
	400	10	Sea	He	22	2	2	1	1
	400	6			22	2	2	-	-
	400	10			23	10	6	2	-
	450	10			24	6	6	-	2
	300	10			25	4	4	-	-
	300	7			25	2	2	-	-
Second Period Total						179	21	27	12

Table XI. 2

Record of Dives: Second Experimental Period

The results recorded in Table XI. 2 show why efforts were eventually concentrated on the dives of shorter duration. None of the schedules had been used previously in the experimental work but schedule 16 which was based on published tables (132) and which was well established in the past, was used in this period to introduce 5 men to depths greater than they were accustomed to visit. It can be seen that eventually a schedule was produced for 300 feet for 10 minutes at the maximum depth which could be considered satisfactory in its chamber stages but in the sea it was not quite so satisfactory. The timing of schedule 12 was retained but the oxygen content was raised from 10% to 13% and the few dives carried out on the schedule renumbered as schedule 25 seemed at worst to be no more dangerous. A similar pattern of successful chamber dives more risky when tried in the sea and then becoming safer when the oxygen content was adjusted, can be seen in the dives to 400 feet for 10 minutes. No satisfactory explanation could be found for the more serious outcome of schedule 21 which was supposed to be adjusted to be less risky than schedule 17. The most probable explanation lay in a misunderstanding of the rate of gas absorption during longer dives but as time was short it was decided to concentrate on the shorter dives to show that the technique was possible and that the risk in diving to 400 feet was acceptable if a real necessity to dive to such depth arose. However even adjusting the breathing mixture before the first sea dives did not ensure complete success on the dives to 450 feet for 10 minutes.

(iii) Results

9 experienced men carried out the 60 dives in the Vernon stage. It was felt that the problems had been nearly mastered when only 1 major case and 8 minor ones occurred. The chamber dives in the Reclaim stage were not so satisfactory. 16 men carried out 49 chamber dives for 10 minor and 4 major cases between them. (No cases occurred in the 6 dives carried out by 3 men who were much less experienced than the others). 19 men took part in the 70 sea dives with 9 minor and 7 major cases between them. One very experienced man had a major incident on his only sea dive and he remained unfit to take further part underwater; 6 men with relatively little experience did 9 dives between them with only 1 minor case occurring in this novice group; and 3 of the experienced men did 35 dives with 4 minor and 7 major attacks between them but 2 of them withdrew from the team during this stage of the trials.

c) Third Period (80. 105)

(A) Laboratory Stage

(i) Preparations

The third experimental period started with an attempt to check or establish certain basic points first on the assumed curves of gas elimination of dives which did not require decompression; second on the pressure drop for safe decompression by ascent to the first and subsequent stages; and third on the duration of these intermediate stages. The approach was based on the experiences in the previous periods, and on animal experiments. The use of 10% oxygen/90% helium for the dive and 100% oxygen for the shallow stages of decompression was augmented by the use of various oxygen and helium mixtures richer in oxygen such as 20/80 and 40/60. All dives were intended to be 16 minutes duration from leaving surface to leaving maximum pressure, with the descent at a rate of 100 feet per minute; this time was selected as giving a 10 minute working interval at 600 feet. Finally if a schedule was considered unacceptably risky, minor changes only were to be made to define the area of risk if possible.

(ii) Progress and Results

The progress and results are shown in Table XI. 3 which covers the laboratory stage only. After the initial work-up dives on air, various points on the assumed depth-time curve for helium absorption by the body were tested initially with minimum decompression time (i.e. time for ascent only) to atmospheric pressure and then with a decompression stop at 10 feet. 125 feet was considered to be about 20 feet shallower than the risky depth as indicated in work elsewhere (50) and this depth was selected as the first one to be tried. The schedules were numbered in order of first use and the effect of cases of decompression sickness can be noted. After the depth of the no-stop dives was reduced to 90 feet progress was more orderly. One dive to 235 feet had to be shortened because of illness of a diver at depth. The dives at 340 feet were unexpectedly risky initially and 2 pairs diving to that depth also had their dives curtailed for unexplained illness of one man in each pair while at this depth. Subsequent progress was more hazardous but new

Dive			Schedule Number	Number of		Decompression Sickness	
Depth Ft.	Duration Mins.	Gas		Dives	Divers	Minor	Major
250	16	Air	26	4	4	-	-
300	16	Air	16	9	6	2	2
125	16	He	27	11	5	1	-
165	16	He	28	4	4	-	-
210	16	He	29	3	3	3	-
160	16	He	30	4	4	-	2
160	16	He	31	5	3	-	1
185	16	He	32	4	4	-	1
100	16	He	33	9	7	1	1
160	16	He	34	12	5	-	-
220	16	He	35	10	4	1	-
90	16	He	36	17	11	-	-
135	16	He	37	12	5	2	-
280	16	He	38	8	4	1	-
235	16	He	39	20	10	1	-
235	14	He	39	2	2	-	-
340	16	He	40	3	3	-	1
340	16	He	41	2	2	-	1
340	16	He	42	12	6	2	-
340	5	He	42	2	2	-	-
340	16	Air	43	2	2	-	-
400	16	He	44	10	6	1	-
400	16	He	45	10	8	3	-
300	16	He	46	14	10	-	1
500	16	He	47	4	4	1	2
500	16	He	48	4	4	1	1
500	16	He	49	10	7	4	-
400	16	He	50	6	6	-	1
All chamber dive (Main diving team)				213 (186)	25 (12)	24 (22)	17 (10)

Table XI. 3

Result of Dives: Laboratory Stage, Third Experimental Period schedules were calculated and it seemed reasonable to proceed to the sea stages. The main burden of the diving was carried out by 12 men. Among the 13 men who carried out a small number of dives were 8 men who had two acquaintance helium dives each in the chamber before going on the sea trip.

(B) Sea Stage

(i) Preparation

To make maximum use of the time available to the ship for this sea period, it was not intended to recalculate the schedules in case of unacceptable incidence of decompression sickness but to reduce the durations of the stay at maximum depth progressively by 1 minute intervals while retaining the same decompression routine. Handling difficulties meant that the first modifications had in fact to be made to the decompression routines as the rates of ascent to the first stop demanded in the schedule could not be met by the winches. The times in the tables used in the laboratory were delayed by a half-minute from arrival at the first stop upwards, to meet the problem.

(ii) Results

The operating team aboard H.M.S. Reclaim included 6 men in the ships' diving team; 8 men from the experimental diving team; and 4 diving officers. In addition 3 men were released, from their particular responsibilities, to experience the actual routine, and, together with 1 of the ship's divers and 1 diving officer carried out 8 dives between them, the bulk of the work being done by the remaining 16 men. The results are shown in Table XI. 4. (Note: 1 pair were deprived of their oxy-helium gas supply while at 300 feet and carried out the decompression on emergency air tables).

Dive				Schedule Number	Number of		Decompression Sickness	
Depth Ft.	Duration Mins.	Gas	Environment		Dives	Divers	Minor	Major
250	16	Air	Sea	26	18	17	-	-
300	16	He	Sea	46	16	16	2	-
300	12	He/Air	Sea	43	2	2	-	-
300	16	He	Chamber	46	2	2	-	-
400	16	He	Sea	50	2	2	1	-
400	16	He	Sea	51	4	4	1	2
400	15	He	Sea	51	6	6	1	1
300	16	He	Sea	52	4	4	1	-
400	14	He	Sea	51	2	2	2	-
300	16	He	Chamber	52	2	2	-	-
400	14	He	Sea	53	8	8	1	-
300	10	He	Sea	52	2	2	-	-
500	16	He	Sea	54	2	2	-	1
500	15	He	Sea	54	12	10	3	-
Third period: Total, Ship					82	21	12	4

Table XI. 4

Result of Dives: "Reclaim" Stage, Third Experimental Period

d) <u>Fourth Period</u> (81)

This period is incomplete in this work as only dives supervised till the demission of office by the writer are considered. It is relevant to this project as the cases of decompression sickness that developed could not be treated by previously published therapeutic tables because of the depth of occurrence of signs and symptoms, and the complications of the use of high partial pressures of dry oxygen. In essence, the experience gained as described in previous sections on air diving and submarine escape together with the experience gained in the earlier deep diving periods was invaluable in the minute by minute changing circumstances of the cases that are now reported.

(i) Preparation

From animal work that had been continued in parallel by others at the laboratory it became apparent that earlier theories of helium absorption and elimination were unreliable. In particular it appeared that the body became saturated with helium more quickly with the result that the short duration dives that had been attempted had been on the steepest part of the exponential curves for gas uptake and hence there were too many variables to afford a reasonable prospect of finding a reliable decompression routine. The whole plan of attack was changed and it was decided to expose divers first for a series of two hours and then for a series of four hour no-(decompression)-stop dives which with the established 90 feet for 16 minute no-stop dive would show the probable shape of the curve. As usual all dives would be exercise dives, on a rowing machine. A carbon-dioxide absorption system was to be used which needed a foot-operated bellows for circulation of gas, as all the dives would be done breathing various chamber atmosphere mixtures of oxygen in helium (100% oxygen was provided by the usual demand valve to prevent hypoxia on initial compression as well as during certain parts of the decompression).

(ii) Progress

The animal experiments had suggested that 45 feet would be the danger depth for men on 2 hour exposures but Table XI. 5 shows that 70 feet was accomplished reasonably easily by the small diving team. As a consequence of this experience it was decided to start the 4 hour dives at 55 feet - i.e. 10 feet deeper than the depth previously thought the limit for 2 hour dives; the table shows the results, the effect of leave, and of lack of practice.

As a result a curve was found and considered established. It was decided to carry out a further series of dives aimed more to check theoretical points than to produce a practicable schedule for sea dives. Hence the requirement to carry out a fixed number of dives was changed to a requirement to dive each of the individuals in the small team once on each schedule. In addition it was not so important to consider the total decompression time as it was better to remain at various decompression stops for a time long enough for any signs and symptoms of decompression sickness to appear; this pause would then point to the safety of the preceeding part of the schedule. The dives selected were 300 feet for

Dive			Number of		Decompression Sickness		Notes
Depth Ft.	Duration Mins.	Schedule No.	Dives	Divers	Minor Cases	Major Cases	
90	16	36	12	12	-	1	Case: Diver PK.
35	120	55	6	6	-	-	-
40	120	56	6	6	-	-	-
45	120	57	6	6	1	-	Case: Diver FE.
48	120	58	6	6	-	-	-
51	120	59	12	7	1	-	Case: Diver PT Post-leave Diver LB locum for Diver BF.
54	120	60	6	6	-	-	Diver CR locum for Diver PT.
57	120	61	6	6	2	-	Cases: Diver BF,HI. Diver BF first dive on return.
60	120	62	6	6	1	-	Case: Diver CR.
63	120	63	6	6	-	-	-
66	120	64	6	6	3	-	Cases: Divers FE, LS, BF.
69	120	65	6	6	2	-	Cases: Divers HI, BF.
72	120	66	6	6	2	1	Cases: Minor - Divers BF, WF. Major: Diver PT, first dive on return to team.
75	120	67	4	4	-	-	Case: Diver BF.
55	240	68	6	6	-	-	Diver CR locum for Diver BF.
60	240	69	4	4	-	2	Cases: Divers PT, HI.
300	240	70	2	2	-	2	Divers BF, WF. Both Chesty.
		71	2	2	2	-	Divers CR, HI.(CR Chesty).
500	120	72	2	2	2	-	Divers LS, FE.
		73	2	2	-	-	Divers CR, HI.(CR Chesty).
		74	2	2	1	-	Diver WF. (Diver FE well).
300	240	75	2	2	-	1	Diver BF. (Diver LB well).
800	120	76	2	2	-	2	Divers FE, LS.
700	120	77	2	2	-	2	Divers CR, HI. Both Chesty.
700	120	78	2	2	-	2	Divers WF, LB.
55	120	79	4	4	2	1	Diver PK, major. Divers LC, MM, minor. (Diver CW well).
45	240	80	2	2	-	-	-
300	240	81	2	2	-	1	Diver LC. (Diver CW well).
Total			130	12	19	15	

Table XI. 5

Result of Dives: Initial Part of Fourth Experimental Period

(All carried out in compression chambers at Royal Naval Physiological Laboratory using several mixtures of oxygen and helium as well as 100% oxygen. Programme continued under other Medical Officers).

4 hours, 500 feet for 2 hours, and because it was the maximum depth of the facilities, 800 feet for 2 hours. Various alterations to the tables were made as the programme advanced, mainly to the oxygen content of the breathing mixtures at the various stops but after the failure of the 800 feet schedule, the same schedule was also used for the next 700 feet dive.

(iii) Comment

As well as showing that a man like diver FM could vary by as much as 20 feet between dives of similar duration that produced transitory symptoms of decompression sickness, Table XI. 5 shows the effect of a lay off in a man like diver FT. This lay off effect is difficult to assess later because each dive then took so long that any man had up to 14 days between his dives - the last 8 dives in the table were spread over 2 months - and there was much more trouble then. In these last dives, the men surfaced on occasion complaining that their chests felt tight and raw retrosternally on inspiration and clinically the best diagnosis appeared to be "pneumonitis" because of the slight changes in vocal resonance and occasional coarse rales. One man had radiographic changes described as "pneumonitis". Three episodes occurred in the heaviest smoker in the group.

Decompression Sickness

It was not possible to compare the records of individual divers to find the differences between men who only had major attacks and men who only had minor attacks as the decompression routine would be altered after such episodes and thus the men would not carry out similar dives. Even the various periods cannot be reliably contrasted with each other because of modifications made in the basic assumptions and differing degrees of overlap of membership of the experimental team from one period to the next. 66 divers carried out 734 dives which were distributed over 81 different decompression schedules. 170 cases of decompression sickness occurred of which 62 were treated by some recompression routine. 1 man was left with a permanent disability and one other had a very slight residual impairment to his hearing which he did not notice. A factor that may have masked other cases was the occasional recompression of men in a pair of divers if one developed signs and symptoms which indicated a need for such treatment. This masking may have occurred in those few cases where there were no facilities to separate the men and the need for recompression arose during the decompression before arrival at atmospheric pressure. Several times however the second diver also developed less severe symptoms which might have responded to less intensive therapy than that needed by his partner but it was accepted that he would be over-treated and he would act as attendant to his less fortunate colleague.

3 men dived on over 50 occasions each, with 19, 12, and 5 incidents in decreasing order of attacks but recompression was required on 5, 1, and 3 occasions respectively. The range of frequency of dives was from 1 to 58 depending on whether the individual was a regular member of the team or a visitor - for example 2 men of the ship's diving team during

the sea stages later joined the experimental team for subsequent laboratory and sea stages. 19 men dived and did not have any attacks - but none of these dived more than 4 times each. 10 men had 13 attacks of decompression sickness between them, none treated by recompression while 12 men with 16 attacks were always treated by recompression and had no other attacks. The remaining 25 men had 141 attacks of decompression sickness of which 46 required recompression. The only deduction to be made was that the oftener a man dived, the more likely he was to dive on a schedule which had inadequate decompression.

It is worth recalling that the difference between minor and major cases depended on the treatment given and in turn this depended on the assessment by the same doctor of the victim's reactions in the light of experience and of the severity and nature of the symptoms. No man who wished to be recompressed was ever denied such treatment - several men had to be bullied into going into the compression chamber. The reporting of minor complaints by the man or the inquisition for them by the doctor was always a vexed point and depended to a great extent on the doctor - patient relationship. This naturally fluctuated with daily close contact but on the whole an atmosphere of trust was engendered. This meant that the diver could report any sign or symptom with the expectation that the doctor would make the treatment suitable while considering his patient as well as the injury. Inevitably in such a situation some cases arose which in retrospect might have been more effectively treated in some other way.

There was the customary variety of signs and symptoms in keeping with the hypothetical variety of sites of bubble formation. Signs could occasionally be found either as direct consequence of the specific trauma or as result of reaction such as local tissue oedema. Assessment was often complicated by the multiplicity of sites involved concurrently - for instance pain occurring in the right elbow and left knee - or consecutively as in pain occurring first in the right shoulder then clearing, then developing in the right hallux then clearing then settling in the right knee for a more prolonged spell. The difficulties were compounded when therapeutic recompression was carried out for a particular symptom or sign but in the later stages some new symptoms or sign would appear to pose the question of recurrence or new attack.

The type of onset of symptoms and signs may be dramatically sudden or insidious to such an extent that only later is it possible to say when unease marked the start of the incident. Such a slow onset may be aggravated by wishful thinking on the part of the victim. As the dives were experimental in nature, the onset of decompression sickness could occur at any pressure. 58 of the cases first developed some indication of future troubles while still under pressures which varied from the equivalent of 490 feet to 10 feet. In many of those occurring at shallower depths no report was made till arrival at atmospheric pressure. Of these cases, 28 did not require recompression, 13 were started on therapeutic recompression before reaching atmospheric pressure, and 17 were recompressed later. It was important to the divers to reach atmospheric pressure as this would permit transfer to more comfortable facilities as well as providing a "smoking-break".

The time of onset - and of reporting varied considerably. It was thought that most urgent cases of collapse would occur within 10 minutes of the reduction of pressure and most other cases within 4 hours. This approach was a guide on how near to recompression facilities the divers should remain after they had reached surface and they had no complaints. The type of onset made timing difficult but cases with neurological damage could usually be assessed more accurately. The longest period between reaching surface and the onset of the first symptoms was $8\frac{1}{2}$ hours, and 5 had intervals longer than 3 hours. Some cases had early troubles which cleared and later developed a constant symptom not necessarily in the same site. The time of onset during decompression is vital as it indicates the stage where the routine has been inadequate - a point exemplified by the case that occurred after 1 hour at the first stop after leaving maximum pressure. First stops previously had always been short, sometimes as short as 2 minutes and may well have been inadequate in the past to show where the defect in the decompression schedule was to be found. It will be seen that there was no difference in its character whether helium or nitrogen was the inert gas used.

Pain in some form was the commonest complaint. The "niggle" was a consciousness of pain which was more of nuisance value than causing disability or discomfort; it was usually transient rather than persistent. It could develop however to "ache" which was more constant and distressing being described as dull, deep seated, throbbing, drawing, or nagging; there was more persistence with this symptom and the severity varied from responding to time and mild analgesics to a syncopal attack. "Pain" was more intense, more localised, and sharper than an ache and usually indicated that recompression would be needed. 109 of the 170 cases had pain in some form varying in severity and in site (Table XI. 6).

Site	No. of Cases
Upper limbs and Shoulder girdle	61
Lower limbs and Hindquarters	86
Trunk (excluding chest)	8
Generalised headache	2
Pain in chest	5

Table XI. 6

Sites of Pain

When exercise was weight-pulling upper limb sites were more frequent than later on when a rowing machine was used. Pain in the chest was a problem as it was usually associated with marked difficulties in respiration. It was always treated by recompression. Among the divers it seemed to be the worse degree of "tightness of the chest" rather than the muscular and skeletal pains of the rest of the body. No assessment was possible on whether the sensation had a cardiac, respiratory, or parietal origin.

An unusual blotchy reddish-purple rash was reported on 13 occasions.

The rash did not have a raised edge and was more suggestive of vascular stasis in the skin vessels with cyanosis. It did not cause any inconvenience and it was usually noticed on changing clothes or while having a shower. The distribution tended to be confined to the upper trunk and arms. It did not indicate severity of the condition as rarely was it found in cases needing further treatment. As it responded to a hot shower or simple passage of time, no particular importance was attached to the appearance of this lesion.

Itching, mainly of a prickly nature, was reported on 22 occasions. This symptom was most common in the beard area, the forearms and the trunk. It also occurred on the thighs. At no time did it lead to such scratching as to cause abrasions and the duration was short, being often cut even shorter by a hot shower. It appeared to be associated with chamber dives where the body was more exposed to large volumes of air and the large temperature changes than when the diver was in his form-fitting suit in the sea.

The respiratory system was apparently involved in 23 cases. 17 of them being recorded as simple "tightness of the chest". The significance could not be assessed because of individual variations. For example, one diver had this symptom recorded on 4 occasions but he claimed that he had some degree of difficulty of expiration after more than 40 of his 50 dives. In none of the cases did the symptom persist more than a few minutes and it cleared without treatment. The possibility remained that the sensation was really an indication of the extra effort required of the respiratory muscles in the ventilatory dynamics under pressure. The remaining 6 cases had a retrosternal sensation of fullness associated with a short dry ticklish cough and basal râles; one man had X-ray changes suggestive of a patch of pneumonitis but the X-ray films of the others were reported as normal. These cases all occurred in men carrying out long deep dives who developed decompression sickness during the decompression necessitating therapeutic recompression without a surface interval. The duration of exposure to pressure varied from 22 to 52 hours when the partial pressures of oxygen were 1 atmosphere or greater. It is a debateable point whether the signs and symptoms were decompression sickness or not; and if not, whether they were due to oxygen or dry gas. The signs and symptoms lasted 3 days to 6 weeks. It should be borne in mind that after an exposure which could lead to decompression sickness, most cases of tightness in the chest and a slight cough either clear quickly or rapidly lead to a deterioration in the patient's condition with the consequent urgent need for recompression.

18 cases complained of some disorder of power which was sometimes associated with pain as in cases of paralysis and anaesthesia with a band of pain immediately proximal to the level of anaesthesia. On other occasions weakness seemed to follow pain and it was then found as a reluctance to move a joint rather than intrinsic loss of power. On four occasions, there was general weakness associated with exhaustion of the individual. One man had a paraplegia about the level of the eleventh

thoracic segment with anaesthesia of the same distribution which left him a permanent cripple in spite of recompression therapy. Both lower limbs were found to be weak on eight other occasions, while in a further three cases the right lower limb only was involved twice and the left once. The left upper limb was involved in the remaining two cases, once in the whole limb and once confined to the forearm. In only one case, involving the lower limbs, were there any tendon reflexes changes and then the knee and ankle reflexes were more brisk and bilaterally equal, after the dive than before.

Sensations were disturbed in 14 cases. 2 of these cases were associated with paralysis - one the paraplegic mentioned above and the other when the paralysis involved the left upper limb from the shoulder distally. In this latter case the disturbance took the form of complete loss of light touch, pressure and pinpricks; proprioception was also disturbed. 4 cases had localised areas of diminished response to light touch and pinpricks on the anterior aspects of both thighs (once), the dorsal aspect of the right foot (once), the anterior aspect of the right thigh (once) and the left thigh (once). A seventh case had loss of discrimination of the terminal pads of all the digits of each hand - he also had possible oxygen damage to his lungs (similar sensory loss in association with oxygen convulsions has been described (15)). 3 cases complained of paraesthesia, one in the right shoulder and two as a generalised phenomenon. 3 cases complained of vertigo, it being confirmed later in one case who was considered to have transient vestibular oedema and audiogram changes suggestive of a small cochlear haemorrhage; all three had unilateral impaired audiograms which cleared rapidly in two.

10 men had "syncopal" attacks. By this is meant a rapid onset of weakness, pallor, cold sweat, nausea (with vomiting on three occasions) and transient loss of consciousness (twice) very suggestive of syncope except that the radial pulse was steady, rather slower than expected, and of good volume. Immediate recompression restored the normal physical state dramatically and on 6 occasions no other signs or symptoms appeared. The remaining four cases had either complained of some limb pain shortly before the attack or on recovery and were treated accordingly. All were considered to be cases of decompression sickness.

Personality was effected on 4 occasions, twice as an extreme degree of apprehension which developed during the stay at maximum pressure and persisted throughout the decompression and for some time thereafter; no adequate explanation is avilable for this clinical picture. The remaining 2 cases were classical cases of depression arising during the decompression and who returned to their normal state of lively, alert interest during recompression as if they were statues being unveiled.

In retrospect 6 of the men involved should have been recompressed as the quickest and most comfortable treatment. None of them appeared to have any permanent damage but the duration of symptoms was much longer than a therapeutic recompression might have been. Several of the milder cases of aches and pains and some of the cases of general apprehension were almost certainly not due to inadequate decompression but they had to be considered as such as the worst possibility.

Notes on Major Cases: First Period

Diver DA had dived in a compression chamber to 300 feet for 10 minutes using air before; on this occasion a shorter decompression routine was used which involved an ascent rate of 120 feet per minute to the first decompression stop. On reaching 40 feet, he first felt slight difficulty on inspiration and this increased at the surface where he also developed aches in his chest. He had used "controlled deep breathing" during the ascent on his own initiative. He went about his duties for 20 minutes before he developed, first difficulty in controlling and then loss of power in his legs. He was recompressed without further examination and he had made apparently, a complete recovery by the time the pressure had reached 100 feet. He was further compressed to 165 feet and a therapeutic decompression routine was started on Therapeutic Table III but as physical examination was still negative and his condition was so good, it was decided to reduce the time at 30 feet to 2 hours thus converting the therapeutic routine to Therapeutic Table II (Shorter). No complaints were made and examination was still negative. Several days later he mentioned a slight woolly sensation in his right foot which had persisted since the therapy and which he had concealed. No further treatment was thought worthwhile and gradually the symptoms cleared. His attack was thought to be due to pulmonary barotrauma due to his controlled respiration, aggravated by considerable exercise immediately after surfacing.

Divers UL and AN together carried out a chamber dive to 400 feet for 10 minutes using 5% oxygen in 95% helium. Both men had been trained to equalise the pressure in their Eustachian tubes by swallowing and neither man had previously dived deeper than 300 feet or used a helium mixture. The dive proceeded according to plan with the mixture being breathing from 100 feet on compression to 140 feet on decompression, otherwise the chamber atmosphere of air was breathed. On reaching 20 feet, Diver UL complained of abdominal discomfort, backache radiating round the abdomen, and he looked distressed; Diver AN complained of a mild ache over the left shoulder area. Examination suggested that gastric distension was the main trouble in each man but in any case recompression was required. In both men symptoms were relieved - and in Diver UL retching followed by vomiting, probably helped as much as the pressure increase - and Therapeutic Table II was used with apparent complete success (Recommended). It was considered at the time that lack of familiarity with depth and gas as well as apprehension and their earclearing technique had led to excessive gas swallowing rather than that inadequate decompression was the fault. That explanation was too facile in retrospect and it is now considered that they were genuine cases of decompression sickness.

Divers CK and MR had the honour of carrying out the first sea helium dive under the new experimental programme after a work-up to ensure that the drill was correct. Both men breathed the 5% oxygen/

95% helium mixture from 100 feet on the descent to 300 feet for the period of 10 minutes at that depth and then to 90 feet on ascent and thereafter they breathed air. The submersible chamber was being transferred on to the receiving chamber at 20 feet - the deepest stop of duration long enough to permit the manoeuvre - when the divers requested recompression. The transfer was completed first and it was then seen that diver MR was writhing on the chamber floor and that he had great difficulty in breathing. Recompression to 100 feet was immediately carried out. Examination of both men at this depth was negative and they each complained of a very slight general sensation of stiffness. It now became known that a serious mistake in depth keeping had occurred and that the men had been 14 feet shallower at each of the designed 40 feet and 20 feet stops; and that both men had developed slight difficulty in breathing during the ascent between these stops which had become more marked on arrival at the shallower depth. In Diver MR this dyspnoea had been accompanied by a tightness in the chest which developed into a severe pain which radiated generally while in Diver CK a similar start was followed by radiation to the left shoulder and to the occiput. As soon as pressure began to be increased, the symptoms had ameliorated. In view of the speed with which pressure was increased; the rapid response to recompression; and the negative examination at 100 feet, it was decided to depart from standard practice and to try using Therapeutic Table I (Shorter) under constant observation instead of the recommended Table III. If any signs or symptoms recurred then the alternative of Table IV would be immediately used. On reaching the surface, the only complaint was that the sensation of stiffness had persisted unchanged. These two cases were undoubtedly the type of decompression sickness referred to as "chokes" and assumed to be due to multiple pulmonary artery gas emboli initiated by the gross error in decompression.

Diver WN and his partner later carried out the same dive planned for Divers GK and MR after another pair who had uneventfully carried out the same dive. As soon as Diver WN transferred to the T.U.P. chamber, he was seen to be distressed. Pressure was immediately increased from 20 to 60 feet where he seemed to have recovered. Examination was negative; the history was similar to Diver MR. He and his partner were further compressed to 100 feet and it was decided to use Therapeutic Table I again. However after 25 minutes at this depth and 5 minutes before decompression was due to commence, Diver WN complained of coldness of his feet and numbness of the front of his thighs; he was immediately further compressed to 165 feet with complete relief of his coldness and a decrease in the area of numbness. The intended therapy now was to consist of a 2 hour exposure at this depth and then decompression on Therapeutic Table IV. His condition gradually deteriorated at this depth and he developed a paraplegia with paralysis and anaesthesia to the nipple area with a constricting band of pain and a narrow band of paraesthesia cranially to this level. Decompression was eventually commenced with no further deterioration. General nursing procedures were used along with antibiotics and sedatives. Attempts to use closed circuit oxygen breathing equipment to increase the oxygen content of the patient's inspired gas caused severe distress and laboured respiration and were abandoned. It was felt that the pause in recompression at 60 feet to allow examination was the main fault as some of the pulmonary arterial emboli of "chokes" were presumed to have been compressed enough to pass through the pulmonary shunts thus reaching the central nervous system where growth of the bubbles restarted and each further increase in pressure only temporarily alleviated the condition. If the pressure had been increased initially to 165 feet or subsequently to 250 feet then the bubbles might have been compressed below the critical size for re-dissolving. In addition, the use of a less dense 20% oxygen/80% helium as a breathing medium during the therapeutic decompression might have been more tolerable for the patient as well as playing some part in encouraging any nitrogen which had diffused into the original helium bubbles to diffuse out thus making a less persistent traumatic agent. (2 years later, WN, still a paraplegic, has some movement in one leg; he has managed to remain standing without support for a short period; and to walk about 30 feet unsupported but then loses his balance because of clonic spasms. His progress is continuous but very slow - in keeping with observation by foreign colleagues with experience of similar diving cases).

Diver EU carried out a chamber dive to 300 feet for 10 minutes using 5% oxygen in 95% helium on a decompression routine which had a slower ascent rate than before and in which the transfer under pressure was simulated during an 8 minute stop at 100 feet. He surfaced with a stiff right arm which rapidly became very painful. Regrettably personality problems overshadowed the case and he was not recompressed. Strictly, this incident does not satisfy the criteria for classification as a major case but in every other respect of onset and severity it was a serious incident and it would be grossly misleading to omit it. His symptoms slowly waned over 3 days.

Diver AD also carried out this same chamber dive some days after Diver FU. He had slight sensation of stiffness of both his shoulders which steadily developed as an aching pain worse on the right and he was recompressed when he reported 2½ hours after reaching surface. His symptoms were relieved at 120 feet and decompression on Therapeutic Table II was carried out (Recommended). Shortly after surfacing, he had a very mild ache in his right knee and examination disclosed a small quantity of fluid in the knee-joint; conservative treatment was prescribed. (24 hours later, a diving officer seeing Diver AD limping, and on his own initiative, recompressed him again to 165 feet with no relief and used Therapeutic Table II to return to the surface - and then Diver AD informed the diving officer that he thought there had been some relief to his mild ache). These incidents showed that the cases were now not so dramatic. The latter case showed that long delayed recompression for minor symptoms is not necessarily the most effective treatment.

Divers DA and RB both carried out the work-up sea dives on air to 250 feet for 10 minutes on the bottom. Neither men had carried out this dive on the previous trip, Diver DA because he was unfit to dive following a case of decompression sickness (q.v.) and Diver RB because of rib injuries. [The work-up decompression schedules involved a fast rate of ascent but as 12 individuals had used them without incident on the previous trip they were retained for the work-up on this occasion. On this trip 14 men used them but only 7 uneventfully and 5 others with minor complaints.] On surfacing Diver DA had a sharp pain in his chest, mild dyspnoea, generalised paraesthesia and a marbling skin rash of his trunk. Examination suggested a local area of hyperresonance in his left chest posteriorly compared with the right but no other abnormalities. As his condition was improving, rest and observation were ordered. He had made a complete recovery in 1½ hours. Diver RB started with an ache in his left shoulder which clearedcompletely within 10 minutes of surfacing and he complained of a patch of diminished sensation over the right forefoot. Examination disclosed a transient hyper-resonance similar to that in Diver DA and no other abnormality and as symptoms cleared rapidly no further treatment was used. No radiographic facilities were available for either case. As it seemed that both men had some pulmonary abnormality which might be causing pulmonary barotrauma, it was decided that they should be considered serious cases who might well have required recompression - at any rate it was decided that the risks were too great for them to continue experimental work and they were given other duties.

Diver FE was also a man who was not recompressed although his incident in retrospect after a chamber dive to 300 feet for 10 minutes on 5% oxygen in 95% helium should have been considered "major". At the 20 foot stop, Diver FE developed an ache in the low lumbar area, which waxed over 3 minutes and then waned to disappear over the next 15 minutes. Examination disclosed no abnormality. 5 minutes after reaching surface, his symptoms returned in a milder form and examination showed that there was loss of power of both legs on resisted extension. As his general condition was good, and more severe symptoms earlier had cleared, it was decided to wait and watch his progress. After 2 hours, no weakness could be detected but he still felt slightly weak and this condition persisted for 24 hours. During this time he remained in a comfortable bed instead of an uncomfortable recompression chamber where the return of power would probably have been quicker but the therapy would have taken as long. On reconsideration this case was considered as a major one as recompression was the correct therapy and there was no certainty of recovery without it indeed the delay could easily have resulted in permanent neurological damage.

Diver WT and Diver BO carried out the same dive in the chamber as Diver FE later the same day. 5 other men had also previously carried out this dive, one of whom had had very mild niggles in his shoulders. At 20 feet Diver BO developed a dull ache in his coccygeal area with slight diminution of sensation in his right foot. After clearing while still at that depth, his symptoms recurred with increased severity on reaching surface; he also developed a typical trunk rash. His pain worsened and spread to the perineum and he developed a pain in his left shoulder. Recompression was advised and while he was being taken into the chamber he developed extreme weakness of his legs. Meanwhile Diver WT developed severe pain in his left calf and upper left thigh about 10 minutes after reaching atmospheric pressure. 18 minutes after reaching the surface, recompression of both men started. Diver BO's signs and symptoms, although apparently more serious, cleared at 100 feet while Diver WT did not respond till shortly before reaching 165 feet. Therapeutic Table II was used with complete recovery in the case of Diver BO (Shorter) and a stiff sensation in the legs of Diver WT (Recommended). (Divers WT and BO had canoed for over 2 hours the previous evening and it is tempting to ascribe the unusual sites of their pains to this).

Diver WT carried out another chamber dive to 300 feet for 10 minutes using the same gas as before. This dive followed another dive, which had resulted in therapeutic recompression, after an interval of two clear days. 12 other men carried out uneventfully this particular routine. Diver WT complained while at the 20 foot stop of pain in his chest and numbness and stiffness of his hands, wrists, buttocks, thighs, and feet. His condition rapidly deteriorated and numbness spread to the lumbar area. He was recompressed to 165 feet where examination showed that the patient was very depressed, and, had some scattered rhonchi. Decompression was started on Therapeutic Table III (Recommended) but his condition at 100 feet suddenly caused anxiety so he was again recompressed to 165 feet. Re-examination showed that the patient's morale was better and that he had had a syncopal attack apparently vaso-vagal in origin. After 2 hours, decompression on Therapeutic Table IV was started (Recommended) and, although he had some generalised aches at 50 feet which responded to tablets of codein compound, he eventually reached atmospheric pressure well but extremely fatigued. It was considered that Diver WT had not really been fit enough to dive. The case showed the routine of changing from one therapeutic table to another. The cause of the depression was debateable as long afterwards it was disclosed that he had been up till 3 a.m. drinking beer the night before - a fact deliberately concealed from the doctor who examined him as he knew he would not be allowed to take any further part if detected, in the trials.

Diver DR dived to 300 feet for 10 minutes and the dive went according to plan. 20 minutes after surfacing, he had mild pains in his shoulders, a marked body rash and he felt faint. On examination he was pale and had a cold sweat but his pulse was good; his rash was the typical marbling kind. It was decided to treat him by resting in his bunk, with his head slightly lower than his feet. Recovery of his shock-like state took place over two hours and his shoulder discomfort was replaced by a mild low back ache. Next day his legs felt a little weak but examination disclosed no abnormality. This patient should have been recompressed but it was considered that recovery was probable in as short a period when treated by observation as by recompression. The case was of value in that it showed the possible progress of the untreated condition when improvement begins rapidly. If this case had occurred in the later stages of this trial he would have been rapidly recompressed. The immediate access to treatment chambers and an unwilling patient abetted the decision to observe the patient, but later experience of unpredictability of such cases led to recompression.

Diver BO carried out the same dive as Diver DR. During the stop at 20 feet, Diver BO complained of a mild ache in his right knee which eased, worsened, and then eased again but examination was negative. Decompression continued and within 5 minutes of reaching surface the ache in his knee spread throughout the whole right lower limb and up to the sacro-iliac region. He was then recompressed and as his symptoms had cleared before 60 feet was reached, Therapeutic Table I decompression was carried out (Recommended). After surfacing, he complained that the affected limb felt rubbery but after a nights' sleep, this sensation had cleared.

Diver FM and Diver CC twice repeated the dive of the two preceeding cases with an interval of 3 days. On the second occasion, Diver FM developed a mild right shoulder pain at the 20 foot stop which eased and decompression continued. At the surface, it worsened and radiated across to the left shoulder and early signs of shock appeared. Meanwhile Diver CC, on surfacing, complained of stiffness and mild aching in his hamstrings in both thighs. Both men were recompressed. Diver PM, apparently the more seriously affected was free of symptoms by a depth of 60 feet but Diver CC, after an initial improvement deteriorated again and eventually cleared completely only at 165 feet. Therapeutic Table III was then carried out and neither man had any residual symptoms on completion of the decompression (Recommended Diver PM. Longer Diver CC).

Diver MR and Diver WC also repeated the dive after a three day interval and again decompression sickness developed on the second occasion. The first signs appeared at 20 feet where Diver MR had a mild niggle in his right knee. Diver WC appeared restless and apprehensive and, although he protested he was well, he repeatedly asked for the chamber to be ventilated. On surfacing the latter complained of pain in front of both thighs; so he was asked to leave the chamber for a short period while wet diving suits were removed and a mattress was put inside prior to recompression. In this very short period he suddenly fainted. He was immediately put into the chamber and recompressed. Diver MR was also recompressed in case his complaint recurred later although he had no symptoms at the actual time. Diver WC did not improve till a depth of 165 feet was reached and then Therapeutic Table III was started (Recommended). At 40 feet, he developed dizziness, nausea, retching and vomiting with impalpable radial or brachial pulses. The occupants were again recompressed to 165 feet where Diver MR remained well but Diver WC did not improve as much as before, remaining very weak, lethargic and retching and weakly co-operative. Therapeutic Table IV was started (Recommended) but in addition a semi-closed circuit breathing apparatus was provided for him which used 30% oxygen/ 70% helium. He used this when he felt the need and his total spells amounted to 92 minutes each spell ending when the advantages of the less dense breathing medium were counteracted by the discomfort of the equipment. It was remarkable how his general condition improved while using the equipment initially. Any attempt to sit up however, restarted the nausea, retching and dizziness. When an intravenous infusion was about to be started to restore hydration, he began to retain fluids orally and generally to improve. On arriving at 50 feet, examination showed an exhausted patient with slight weakness of his right thigh. After surfacing and a night's sleep the weakness had cleared and his fatigue had improved. Diver MR was decompressed once 30 feet was reached to relieve him of attendant's duties; he developed mild aches in both knees, which cleared with rest and a night's sleep.

Diver MR dived in the chamber again to 300 feet for 10 minutes. 10 minutes after surfacing, he complained of numbness in the sacro-coccygeal area and a feeling of heat radiating down the left leg. This sensation changed character to severe pain which sapped the power of his legs, worse on the left. On recompression, his symptoms were relieved at 100 feet and Therapeutic Table II was used but on surfacing he felt stiff generally and later reported that this cleared with rest. (Shorter).

(ii) Second Period

Diver SD complained on surfacing after his very first experimental chamber dive, one to 300 feet for 10 minutes, of slight stiffness in his right shoulder but this cleared rapidly. 15 minutes after surfacing, he suddenly developed a sensation of loss of weight in both legs and examination disclosed a diminution of left knee jerk and loss of extensor power of his left thigh. During the examinations he complained of a sudden sharp pain in his left hip, and he was recompressed. His symptoms did not clear till 100 feet so he was further compressed to 165 feet and decompression on Therapeutic Table II started (Shorter). Although there was a short period when he complained of stiffness in his legs while at 80 feet decompression was concluded successfully.

Diver MR carried out a chamber dive to 450 feet for 10 minutes which followed the planned routine. On surfacing he reported an ache in both thighs which had just developed although he had had a mild ache in both forearms which had appeared at the 80 foot stop and each stop thereafter but which had cleared at each stop. While he was being questioned he felt faint and giddy and examination disclosed a hypotension and bradycardia which seemed to be recovering during the examination, so it was decided to keep him at rest under observation. Within an hour, he had recovered completely and he was allowed to join his messmates. 2½ hours after surfacing, he developed a slight ache in his right upper arm and in both knees which, over the next 3/4 hour before he reported, worsened and radiated to both thighs and hips. On examination, he was found not to be exerting full power of his limbs because of pain. Recompression commenced. His symptoms were not relieved when the pressure reached 165 feet so further compression was used and the symptoms cleared dramatically at 230 feet. Further compression to 250 feet was done before ad hoc decompression was commenced to 140 feet where standard therapeutic tables were joined. In view of his condition, Therapeutic Table II was used successfully to carry out the shallower stops (Special). Diver MR was not compressed initially as his vagal symptoms were improving and his muscular symptoms had cleared at each stop. With previous experience in mind, it was decided to try a greater depth to speed recovery.

Diver SD and Diver RS together carried out a work-up sea dive on air to 250 feet on the routine used in previous sea trips. Diver SD reported with aches in his left arm 25 minutes after reaching surface and in the next 5 minutes he reported blurring of vision in his left eye, pain in his right loin, buttock, and groin so he was immediately recompressed with his symptoms, other than visual, clearing at 30 feet and the visual ones at 60 feet. Diver RS surfaced with some itching and, when Diver SD reported, it was found that Diver RS had had an urticarial rash over his left arm and forearm which had flared and cleared over a period of 10 minutes. It was decided to put Diver RS in with Diver SD in case of further trouble although at the moment of recompression he had no signs or symptoms. Therapeutic Table I was used and after surfacing, after intensive questioning Diver SD mentioned a very slight stiffness of his right upper arm, 2 hours later this stiffness had increased and the mid humeral area was found to be swollen, painless, of normal colour and non-pitting. This tissue swelling cleared over the next 2 days (Shorter Diver SD. Longer Diver RS).

Diver SD and Diver RS were again partners one week later for a chamber dive to 400 feet for 20 minutes. On surfacing, Diver SD mentioned an ache in his left wrist while at depth which had eased on decompression: this had occurred in the site of an old known malunited scaphoid fracture. 40 minutes later, he complained of loss of power of his left arm as well as pain in both knees and upper legs, spreading to his left hip. His symptoms gradually cleared throughout the compression till at 165 feet, he had completely recovered. Diver RS developed fleeting niggles 10 minutes after surfacing which eventually settled as a dull steady ache in his legs. It was decided to try the effect of breathing 100% oxygen at atmospheric pressure and 20 minutes later he was sign and symptom free. However it was decided that once again Diver RS would be compressed with Diver SD and the niggles recurred as he was helping his colleague into the chamber. Decompression on Therapeutic Table II was uneventful for both men (Shorter Diver SD. Longer Diver RS). 9 hours after leaving the compression chamber, both men were permitted to go on a specially arranged bus trip as they insisted they were fully recovered. It was not realised that the bus trip would be at an altitude of more than 6,000 feet for some periods; at that altitude Diver SD developed blurring of vision and Diver RS developed mild niggles in both knees. Both men recovered completely on the rapid return of the bus to sea level.

Diver SE carried out the same dive as Divers RS and SD on the same day. 3 minutes after reaching surface, he developed a niggle in his right shoulder where a tender spot was found on the posterior aspect of the joint at the border of the deltoid muscle. This cleared in about 40 minutes. 2 hours after surfacing, a spasmodic stabbing pain developed in his left upper arm which recurred at longer intervals and less severe. It was decided to try the effect of 100% oxygen at atmospheric pressure and after 40 minutes the residual sensations were clearing rapidly and therapy stopped. 4 hours after surfacing, the left arm ache returned and 3 hours later after local heat and massage had been ineffective there was a sudden increase in the severity of his pain. He was recompressed but the relief at 165 feet was so slight that it was decided to compress him to 250 feet. The pain cleared leaving a sensation of bruising, and this remained while a similar routine was used to that tried with Diver MR (q.v.) which finished with the later stages of Therapeutic Table II (Special). Diver BR who had not dived that week was his attendant and 4 hours after surfacing, the latter was allowed on the bus trip, mentioned in the previous case, it being assumed that as he had only been an attendant there was no need to keep him on board. Because he had not been specifically ordered to remain on board Diver SE also went on the trip. It later transpired that two hours after surfacing Diver BR had developed a mild ache in his left knee with a sensation of weakness in his left thigh and that Diver SE had developed a very mild ache in his left knee as well as the persistent bruised feeling in his left shoulder. During the trip each man developed agonising pain in all limbs which was treated by rapid descent to sea level and intravenous morphine. In spite of printed slips in Spanish, language difficulties led to a 5 hour delay in transport to the nearest compression chamber (which was the ship) as the bus descended the other side of the mountain. Neither on arrival nor over the next 12 hours was any sign or symptom found to suggest the need for compression. This case showed that needless delay in therapy leads to decreased likelihood of complete and rapid success; that occasionally the attendants can develop decompression sickness; and that 250 feet may only alleviate rather than cure. Finally, it emphasizes that activities over the next 24 hours must be closely supervised both in their intrinsic nature and the distance from treatment facilities.

Diver SR dived in the sea to 300 feet for 10 minutes. He had previously carried out this dive uneventfully. This time he surfaced with a body rash and itching and an ache in his upper left thigh which eased over 10 minutes when an ache in his left upper arm stump was reported. This latter pain waxed and waned in severity over a period of 20 minutes, recurring at longer and longer intervals and no specific treatment was given. 17 hours after his dive - next morning - he reported because of a sharp pain in his left upper arm severe enough to bring tears to his eyes. This pain had lasted half-an-hour and he admitted that the previous evening he had a constant dull ache in the same area which he had not reported. On examination the area of the posterior border of the left deltoid was tender. It was decided to recompress him as a test of cure to 165 feet and initially all his signs and symptoms cleared but after half-an-hour the same troubles recurred undiminished in intensity and it was obvious that his condition was intermittent in character. He was decompressed on a routine diving table and treated thereafter with strong analgesics and hypnotics. The attacks returned 4 times over the next two days - it being of interest that the sensation of phantom fingers returned in their correct spatial relationship although the intervening forearm was not sensed. This case was undoubtedly decompression sickness but the long delay in recompression made that line of therapy valueless in this case.

Diver WS was considered to be very experienced and relatively resistent to decompression sickness so he was asked, as the 30th diver in the sea on the eighth schedule for 300 feet for 10 minutes to carry out an empirical test. It was intended in later dives to fill the submersible chamber with the breathing mixture so that the divers could rest from their equipment during this stage. Some work (11.94) suggested that helium had a rapid percutaneous diffusion and in such a delicate gas absorption situation as decompression was thought to be, this might possibly lead to complications. Accordingly, to avoid skin pinches his diving suit was kept inflated by an oxy-helium mixture instead of the customary air. About 1 hour after surfacing in good spirits and having had his midday meal with the measure of rum customary in the Navy, he felt tired and, as men were excused duties after such a dive, he turned in in his bunk. 3 hours later, it was decided to waken him to make certain that he remained well. There was some difficulty in wakening him and he immediately complained of severe aching pains in both knees and both shoulders. He was assisted to the compression chamber. On recompression, his knee symptoms cleared first and his right shoulder felt normal by 65 feet. His left shoulder did not clear till 100 feet so he was further compressed to 165 feet and then decompressed on Therapeutic Table II (Recommended).

Diver SB dived to 400 feet for 10 minutes in the sea with Diver BO as his partner. There was a slight error in the decompression when the submersible chamber was raised 10 feet past the 100 foot stop, but the error was corrected within one minute. Diver SB regularly complained of tightness in his chest after oxy-helium dives but this time both he and his partner requested to stay in the transfer chamber on arrival at surface because of vague generalised aches, slight difficulty in breathing and apprehension. The symptoms eased so both men were assisted over the 15 feet distance to a larger and more comfortable chamber to lie down. Diver SB then reported fleeting aches first in his right knee, then his left knee, then both shoulders and then steady dull aches in his right knee and then also in his left knee and he developed some nausea. Diver BO developed a burning sensation in his perineum which cleared rapidly, then niggles in both knees and a sensation of weakness in his left leg all of which cleared during examination leaving him symptom free. It was decided to recompress both men but Diver RO spiritedly requested that he be not so treated and he was kept under observation in the chamber lock with no deterioration in his condition. Diver SB was clear of all symptoms by 65 feet, so it was decided to try the effect of Therapeutic Table I from 100 feet (Shorter). $2\frac{1}{2}$ hours after surfacing, he reported with a mild dull ache in his left knee diagnosed as part of the residual bruised sensation which was to be expected and which would not respond to further recompression. In spite of hypnotics he had a restless night and had pain when weight bearing on that leg next morning so that his gait was affected. No abnormality could be found to locate the lesion and local heat was used as the condition cleared over the next three days. Without doubt this case was a genuine recurrence and would probably have responded to a further compression, in face of the obvious inadequate initial compression.

Diver WS and Diver RM formed one of the three pairs who carried out the final dives of this stage, to 450 feet for 10 minutes at depth. Both men surfaced tired but in excellent spirits as a result of their achievement and were permitted to move about the ship freely immediately after their dive. 15 minutes later Diver WS developed niggles in his left knee which rapidly became severe. Diver RM also developed niggles in his left knee in the same time interval but not so seriously and initially demurred at being recompressed with his partner. The symptoms cleared from Diver WS at 30 feet and from Diver RE at 45 feet and both men were decompressed from 100 feet on Therapeutic Table I with complete success - although Diver WS had a very mild niggle in his right knee 4 hours after surfacing which responded to mild analgesics and a night's rest. These cases showed the imprudence of allowing too much exercise too soon - as well as the unpredictability of the pressure required to relieve symptoms subjectively assessed in different individuals (Recommended for both men).

(iii) <u>Third Period</u>

(A) Laboratory Stage

<u>Diver RS and Diver SE</u> carried out a chamber dive to 160 feet for 16 minutes. 20 minutes after reaching surface, Diver RS developed a dull ache in his right shoulder, in both his forearms and in his right knee successively and all clearing fairly quickly. He then had a sharp pain behind his left knee which cleared with a sudden involuntary kick and one hour after reaching surface his only complaint was tiredness. 2 hours later he reported a peculiar sensation in the front of his left thigh when weight bearing and an apprehensive look had reappeared on his face. 1 hour later still his left knee jerk was found to be diminished. Diver SE, at this late stage developed waves of nausea and it was decided to recompress both men to 30 feet and to give them 100% oxygen for one hour at that depth and then to continue its use during 35 minutes decompression to surface. Diver SE had recovered after the initial 30 minutes but there was no dramatic

improvement in Diver RS. At surface, the latter had a sensation of tightness in his left thigh but his reflexes were brisk. Next day, Diver RS mentioned that he had had mild niggles in his elbow which he did not report as he wished to get to his bed; he now felt "worked over" but examination showed a pyrexial illness with pharyngitis and he was treated for this in the Sick Bay. These two men were puzzling in their progress and the recompression was carried out as much for the sake of doing something as for specific therapy (Shorter).

Diver MR dived to 160 feet for 16 minutes in the chamber. He had dived twice before to this depth uneventfully once on the same routine as his current dive, and the other occasion on the routine carried out by divers RS and SE. On surfacing, he reported a slight niggle in his right upper jaw and his right thigh which had appeared at the 10 foot stop and which persisted till arrival at the surface where it cleared during 5 minutes. 5 minutes later still he reported that his right eye was beginning to close - external examination did not confirm this - and that he had abdominal discomfort with nausea and dizziness. While the latter symptoms could be attributed to distension from swallowed gas - as had happened on previous occasions in minor degrees - the quickest way to provide relief was to recompress him and his symptoms cleared at 15 feet. He was kept at this pressure for 8 minutes and then pressure was slowly reduced over the next 28 minutes. He seemed fully recovered and examination disclosed no abnormality. He reported some days later that he had had difficulty climbing the stairs to his flat due to a mild niggle in his knees. This latter niggle then moved to give a low back ache and inability to stamp his feet - a state that lasted about 24 hours. The pressure to relieve the abdominal symptoms probably diminished the symptoms and signs of decompression sickness and as the patient concealed such symptoms as might be present, the treatment was not as effective as it appeared (Shorter).

Diver RS carried out a chamber dive to 185 feet for 16 minutes. On surfacing he developed an itch over the left costal margin and another over his left elbow. He then reported a dull ache in his right hip gradually becoming more severe and radiating to the low back area and down into both thighs. On recompression his symptoms cleared at 8 feet so a shallow therapy commenced from 20 feet where he stayed for 6 minutes and had 36 minutes decompression. On re-surfacing his left upper arm and both thighs felt weary but no abnormality was found on examination (Shorter).

Diver FS carried out his first helium and his first experimental dive in a chamber to 100 feet for 16 minutes when the only decompression was the ascent at 50 feet per minute, breathing 100% oxygen. 5 minutes after surfacing, he developed a sensation of numbness in his right thigh which increased while he walked to the therapeutic chamber for examination but only a small steadily decreasing area of diminished sensation to pinprick was found over the right calf. He began to feel that his right leg was becoming heavy and on re-examination weakness on resisted hip flexion was found, so recompression started. His symptoms cleared at

100 feet, but compression was continued to 165 feet and decompression carried out according to Therapeutic Table II (Shorter).

Diver SE carried out one of the first chamber dives to 340 feet for 16 minutes. On coming to 10 feet and again on coming to the surface, he developed slight niggles in his left shoulder and left knee. Although these disappeared while at 10 feet, and again at the surface, he slowly developed a rubbery feeling in his left leg with a sensation of stiffness on the lateral aspect of his left thigh. On examination, he was seen to have a rolling gait and while his only reflex disturbance was a diminished left knee jerk, he was found to have difficulty initiating straight leg raising in his left leg. Muscle power was normal. He was recompressed 1 hour after surfacing but his symptoms did not clear till he had spent 20 minutes at 165 feet. Decompression on Therapeutic Table II was successful (Shorter).

Diver JN dived to 340 feet for 16 minutes in the chamber on a schedule expected to be less testing than that used by Diver SE. During the stop at 70 feet he developed a prickly sensation over his right shoulder which became an ache on arrival at 50 feet where he started to breathe 100% oxygen and his ache cleared. At the 20 foot stop he developed itchiness over his left knee and at the next stop this became generalised over both thighs. 15 minutes after reaching surface he had a sensation of stiffness in both thighs and, 5 minutes later still, he complained of a burning sensation in the sole of his right foot. On examination both feet were thought to be unusually cold; while his arm and right leg reflexes were normal, his left leg reflexes were equivocal; his pulse was 65 per minute with frequent extra-systoles. He was recompressed to 30 feet and he was given 100% oxygen to breathe. Initially, he developed a patchy pallor of both feet but after 10 minutes this cleared and was replaced by paraesthesia and his pulse became regular at 60 beats per minute. After a further period of half-an-hour his only complaint was a tingle in the plantar aspects of both halluces and examination disclosed bilaterally equal reflexes. After one hour at depth, he was decompressed over the next hour and surfaced with no complaints or abnormalities (Shorter).

Diver DW carried out the first chamber dive to 500 feet for 16 minutes. Due to a catarrhal condition he was under treatment with an oral anti-histamine "Eskornade" to enable him to dive. Generally his dive was unsatisfactory. While he was at the 30 foot stop he reported a slight pain in his right thigh which waned during his stay at that pressure but waxed and waned at 20 feet, at 10 feet and again at the surface. No abnormality was found on examination although he complained of residual stiffness in the thigh. Then the pain returned and gradually worsened so recompression was started. His symptoms cleared at 30 feet; he was further compressed to 100 feet; and decompression carried out successfully on Therapeutic decompression Table I (Recommended).

Diver FS carried out a similar chamber dive to 500 feet for 16 minutes as that done by Diver DW. He surfaced in good spirits but 8 minutes later while having a cup of coffee and a cigarette, he suddenly felt faint and giddy and he became very pale; his radial pulse was moderate in rate but almost imperceptible in volume. He was assisted to the therapeutic chamber where, as soon as he lay down, his colour improved and he felt better - his pulse was now 74 per minute and easily perceptible at the wrist. He developed a severe ache in his left leg down the whole lateral aspect so recompression was started 11 minutes after reaching surface. All his symptoms cleared at 21 feet, and as it was suspected that the syncopal attack was not due to decompression sickness, it was decided to treat the limb condition by recompression to 30 feet for 1 hour and then decompression over the next hour. At 3 feet, he reported an ache in his right knee but during the 2½ minutes the decompression stopped while the doctor was called, the ache cleared and 10 minutes later at the surface he had only a slight sensation of stiffness of his knee (Shorter).

Diver MR carried out a chamber dive to 500 feet for 16 minutes on a schedule presumed to be safer than that used by Diver DW and Diver FS. He developed a slight ache in his right knee at each stop from 40 feet to the surface which cleared during the stay at each stop. At the surface his symptoms progressed to flitting aches around his elbows and shoulders within half-an-hour and then cleared. 3 hours later, he suddenly felt faint and complained of a very severe pain behind his right knee and he became nauseated during his transfer to the therapeutic chamber. He admitted that he had had a persistent mild ache in the knee since surfacing but that he did not report it, in the hope he would be allowed home but salving his conscience by reporting it as short-lived. His symptoms cleared at 100 feet on compression, and he was decompressed on Therapeutic decompression Table II (Recommended).

Diver GI carried out his first helium dive in a chamber dive to 300 feet for 16 minutes on the schedule that was considered past the development stage and was expected to be the operational routine. At the 30 foot stop, he suddenly developed pain in his right hip spreading to his knee and rapidly becoming more severe. When the medical officer was locked through to examine him, he was found to be obviously in pain, sweating profusely, and there was slight tenderness in his right loin. No other abnormality was found. He began to improve so he was kept at the same pressure for 6 minutes longer than planned, then when it was decided to continue the original routine, he was decompressed to 20 feet. A further reduction in pressure led to aggravation of his symptoms at 18 feet so he was returned to 20 feet to continue oxygen breathing for 20 minutes. It was decided to decompress him slowly with the intention of transferring him to the large therapeutic chamber if this was indicated and again about 18 feet his symptoms deteriorated so he was rapidly transferred. On recompression, all his signs and symptoms cleared at 33 feet and, after compression to 100 feet, Therapeutic Table I was successfully used (Recommended).

Diver WS carried out the probable operational dive schedule to 400 feet for 16 minutes in a chamber. $3\frac{1}{2}$ hours after reaching surface, he developed - but did not report - slight twinges in his left knee which changed into a persistent mild dull ache. 2 hours later he became aware of rapidly developing numbness and weakness of his left arm and hand and some pain in his left shoulder - and then he reported. He was recompressed 10 minutes later with no relief on arrival at 165 feet - except for his knee ache which he had not noticed had disappeared till he was questioned. On examination he was found to have a glove anaesthesia up to his elbow; he had a partial motor paralysis below his left shoulder in that if his arm was raised, intense effort did allow him to maintain the position for a very short time. After 65 minutes, there was almost negligible improvement so it was decided to compress him further to 250 feet. Between 200 and 230 feet, the pain cleared completely first then full power and movement returned and on arrival at 250 feet only a residual small patch of diminished sensation on the lateral aspect of his left forearm remained - and that cleared quickly. After a 30 minute stay at this pressure, he was decompressed to join the therapeutic tables, the decision on whether to use Therapeutic Table II or III being delayed till 30 feet when it would be taken as indicated by the diver's condition. His condition was excellent so Therapeutic Table II was selected (Special). However 14 minutes before he was due to be decompressed from 20 feet he developed an extremely severe pain in his left knee and he was immediately recompressed. When his symptoms cleared at 70 feet decompression was then transferred to Therapeutic Table IV and eventually he reached surface in a rather exhausted state (Recommended for recurrence). 3 hours later he developed stiffness in both legs which progressed to pain over the next 2 hours and he was recompressed again. His symptoms were relieved at 155 feet while on his way to 165 feet and decompression was commenced after 30 minutes at 165 feet on Therapeutic Table IV (Recommended). On reaching 155 feet, Diver WS felt apprehensive about his legs so decompression was halted for $1\frac{1}{2}$ hours and he was given 20% oxygen/80% helium to breathe during this pause. As usually happens under such prolonged therapies under pressure, the diver's psychological attitude became one of reluctant co-operation and irrascibility. At 50 feet his left leg reflexes were equivocal and his arm reflexes were bilaterally absent. He was treated by hypnotics and mild analgesics and he eventually surfaced 3 hours over 4 days after he started his original dive. As he was weak and unsteady, he was put to bed for a rest and re-examined the next day. He complained of aching in both thighs and fairly severe pain in his knees on movement. He was found to have weakness on resisted movements of both lower limbs; diminished proprioception of both his big toes but more so on his left side where there was also diminished vibration sense; and a shuffling gait. Further recompression was rejected as suitable treatment. After one week with hydrotherapy followed by one week of active physiotherapy, he was fully recovered. This case showed the problems that can arise if a delay occurs in reporting and how a recurrence may occur in the less prominent sites even if more dramatic signs and symptoms are completely cleared.

(B) Sea Stage

Diver FZ and Diver HD carried out a sea dive to 400 feet for 16 minutes. Diver HD developed a niggling ache in his right shoulder on ascending to 40 feet which cleared at that depth; this pattern was repeated at 30 feet, 20 feet and 10 feet. It recurred on reaching surface, but this time it did not clear and was joined 12 minutes later by an ache in his right hip. Diver FZ reported an ache in his left knee which started as a niggle at the 10 foot stop and which became more severe during the first 10 minutes at the surface. It then began to improve. It was decided to recompress both men. Diver FZ was clear of all symptoms at 15 feet where the shoulder pain cleared in Diver HD but the latters' pain in his hip did not clear till 28 feet. Both men were further compressed to 100 feet and Therapeutic Table I was used successfully (Recommended).

Diver CI dived in the sea to 400 feet for 15 minutes on the same decompression schedule as Divers HD and FZ. On reaching surface, he complained of such severe pain in both knees that he could not move them, let alone stand up. A niggle had appeared in both knees on breaking down to 30 feet, 20 feet and 10 feet and had cleared at the first 2 of these stops. However at 10 feet it had persisted and became very severe on breaking down to surface. He was transferred to a more comfortable chamber and he was recompressed within 2 minutes of reaching surface. His symptoms cleared dramatically at 23 feet and a sensation of discomfort in his left knee disappeared at 30 feet. At his request, it was decided to use 100% oxygen as his breathing medium for 1 hour at this depth and for one more hour that it would take to decompress him to surface. This routine was successful (Shorter).

Diver GR was one of the first pair to dive in the sea to 500 feet for 16 minutes. On surfacing, he complained that he had been having spasms of giddiness since leaving the 60 foot stop when he also had noticed a sensation of disorientation in space of his body. No physical abnormality could be found but his personality was subdued, lacking his normal wit and humour and with startling loss of interest in food or a cigarette. When he complained of a headache, it was concluded that his depressed personality was due to decompression sickness and he was recompressed. At 60 feet, he recovered as if he was being unveiled. He was further compressed to 100 feet and decompression on Therapeutic Table I started (Shorter). As a precaution it was decided to increase his tissue oxygenation by giving him 100% oxygen to breathe for the last half hour at 30 feet and 20 feet and for the last hour at 10 feet. On examination 10 minutes after surfacing, there was diminished sensation to pinprick on the back and front of his right forefinger which improved overnight. This case emphasized the protean manifestations of decompression sickness.

Unusual Case

Diver FS dived in the sea to 500 feet for 15 minutes. He surfaced in very good spirits which allayed the worries of the observers while he sat in a chair with a cigarette and a hot cup of coffee. During this

10 minute period of observation while at rest, he had a second cigarette. He and his partner had just been told they could remove their rubber suits prior to an examination and their midday meal, when Diver FS had an epileptiform convulsion. He was immediately rushed to the compression chamber and the supply valves opened. No compressed gas was delivered because permission had been given by the doctor for the supply to be diverted for a minor task. Permission had been given in view of the first-class appearance of the men. In the short time before the supply was restored, Diver FS recovered and recompression was not started pending examination. There were no symptoms and no signs other than a short duration amnesia from seconds before his fit. He remained in the chamber under close attention for 4 hours and he remained well. He had had a light breakfast an hour before his dive which had lasted $5\frac{1}{2}$ hours. Hypoglycaemia and chain smoking seemed to be precipitating factors. At a later date, a fasting electroencephalograph showed some slow activity largely within normal limits which disappeared after glucose administration. This attack and his two earlier episodes (q.v.) seemed to be similar and not basically due to decompression sickness although in the other two attacks he had signs and symptoms at least of minor cases. He carried out 18 experimental helium dives altogether.

(iv) Fourth Period

Diver PT carried out a chamber no-stop experimental dive to 72 feet for 2 hours. His previous dive had been of a similar duration to a depth of 51 feet, 5 weeks earlier when he had had minor pain symptoms in his left knee. This particular dive was carried out deliberately with his full knowledge to see the effects of a lay-off period without subsequent work-up as it was a dive which his colleagues had carried out without incident. 10 minutes after reaching surface, he felt some pain over his xiphisternum which worsened. 7 minutes later, when he was recompressed he was having some difficulty in breathing and he was sweating profusely. At 34 feet all his symptoms cleared, but he was found to have a slight typical trunk rash. He was kept at this depth for one hour breathing air, and he was slowly decompressed over the next hour (Shorter). One hour after surfacing, he developed nagging aches deep in both knees which he bore for 3/4 of an hour before reporting. He was again compressed with relief at 50 feet and subsequent decompression was on Therapeutic Table I (Shorter). Next day he had a sensation of stiffness in his right knee but no further treatment was required.

Diver BF dived in the chamber on an experimental no-stop dive to 75 feet for 2 hours. At each of the 3 preceeding dive depths he had had minor incidents. 15 minutes after surfacing, while having a shower, he felt some pain in his left shoulder which made drying himself difficult. Due to pain, there was some weakness of resisted movements of the shoulder on examination 5 minutes later. He was recompressed with relief of all his signs and symptoms at 14 feet. He was then taken to 30 feet for one hour and decompressed over the next hour, air being breathed throughout (Shorter). Next day his shoulder felt as if he had slighly strained a muscle.

<u>Diver HI</u> carried out an experimental no-stop dive in the chamber to 60 feet for 4 hours. At depth, he mentioned some sharp transient pains in his right knee but examination when he surfaced was negative. 15 minutes later he developed severe sharp pains in his right knee of a different character to the earlier ones. The new pains became constant and radiated up the right thigh and 30 minutes after surfacing he was recompressed. His pain was relieved at 37 feet but he was taken to 100 feet and then decompressed on Therapeutic Table I (Recommended). Next morning, an initial stiffness in his right knee on leaving his bed, cleared with walking.

<u>Diver PF</u> carried out a similar dive to Diver HI. As on a previous occasion, he developed tightness in his chest about 10 minutes after reaching surface. This progressed to complaints of difficulty with respiration, particularly on inspiration but observation did not confirm this. He was recompressed with relief of his symptoms at 15 feet. He was taken to 30 feet for 1 hour and then decompressed over one hour with air as the breathing medium, with no after effects (Shorter).

<u>Diver BF and Diver WF</u> dived in the chamber to 300 feet for 4 hours, both men surfacing on the planned decompression schedule after a total time at high pressures of 9 hours 17 minutes. Diver BF had a slight pain in his left shoulder at this time which flitted to both ankles and within 5 minutes had settled in his left knee where it gradually became more severe. Recompression started 15 minutes after he had reached surface

and at 50 feet he was relieved of his symptoms. At this moment, Diver WF watching the recompression, developed pain in his right knee and rapidly took on the appearance of shock, so he was locked through to the main compartment where he too recovered. Both men were then taken to 100 feet and decompression on Therapeutic Table I started (Recommended Diver BF. Shorter WF). On arriving at the 30 foot stop, Diver BF complained of a recurrence of the niggle in his left knee and slight tightness across his chest and shoulders which had been constant from the first stop. This condition persisted and the doctor on duty decided to increase the pressure again, first to 40 feet, then to 50 feet and in view of the lack of response, eventually to 165 feet to carry out decompression on Therapeutic Table IV (Recommended) as his knee was now slightly better. Abnormal sounds were present in the chests of both men with scattered rhonchi and altered vocal responses. Eventually they reached surface where Diver BF still had pain but now in his right knee which affected his gait. Radiographic examination disclosed lower right mid zone patch of pneumonitis in Diver WF who was clinically much better than Diver BF. Over the next few days both men tired easily on exertion. It was one month before Diver WF was radiologically clear, although he felt and was clinically completely recovered in about one week. The routine of this dive is given in Appendix 4.

<u>Diver BF</u> again dived in the chamber to 300 feet for 4 hours after an interval of 1 month. The dives were similar for the first 8 hours but thereafter the second decompression schedule was designed for a

further 8 hours instead of 1½ hours thus there were more decompression stops. Diver BF first reported a slight pain in his right knee on arrival at each stop from 65 feet but clearing while at the stop. At 25 feet the pain only eased a little during the 3 hours at this depth. On ascending to 10 feet the pain became more severe and did not alleviate much over the next hour. He then claimed that he had improved rapidly so an attempt was made to reduce the pressure but at 6 feet, his pain recurred severely. He was recompressed with complete relief of his symptoms at 18 feet and he was taken to 30 feet with the intention of staying there for one hour and then slowly decompressing over the next hour. On arrival at 16 feet, Diver BF reported a pain in his right ankle and in his right knee and decompression was halted for a pause of 10 minutes. He also complained of nausea and tightness of his chest on inspiration. Due to a power cut affecting the lighting system, the pause lasted one hour during which all his complaints eased. Decompression was then restarted with an extremely slow bleed till 8 feet was reached when there was a recurrence of his right knee pain. After a pause of 30 minutes an even slower bleed was started without telling him. This was halted at 4 feet because the patient became restless. The chamber doors at this depth are not airtight and the excess pressure was slowly vented. On examination his gait was affected by aching in his right knee and ankle; his chest had an increase in fine moist sounds on auscultation; during the observation period at rest in a chair, he seemed to be in considerable pain and it was decided to recompress him again. However on walking to a bigger chamber, his pain eased and his gait improved so it was decided to let him have a hot shower while continuing the observation. His improvement continued to complete recovery. The routine of this dive is given in Appendix 4.

<u>Diver LS and Diver FE</u> carried out a chamber dive to 800 feet for 2 hours, the greatest pressure to which any man had ever been exposed for such a period of time. At depth, the men reported that food tasted terrible; that they had some difficulty in moving; that sudden or rapid movements were painful; and that they had impairment of control of their legs on walking. 6 minutes were taken in decompressing to the first stop at 490 feet, - well within the expected safe pressure drop. After 1 hour, Diver LS complained of nausea and of a spinning sensation of his head and shortly afterwards he vomited. It was decided to continue the decompression routine with Diver LS remaining flat and taking sips of water. Whenever he moved, he developed an attack of giddiness which led to some retching. At the 340 foot stop, there was some suspicion of his hearing and shortly afterwards Diver FE reported that he was also feeling a little giddy if he moved around. It was now decided to recompress the men and they were taken back to 400 feet 5 hours and 20 minutes after the start of the dive. Diver FE was cleared of symptoms and Diver LS seemed to improve and went into a peaceful sleep. After 2 hours, decompression to 340 feet was carried out to repeat that stop. Diver LS still had some dizziness and a tendency to retch if he moved too much. Decompression was carried out to 260 feet after 2 hours

and the oxygen was enriched to 10% in the helium chamber atmosphere which was breathed for 2 hours. On decompression to 190 feet, - a drop in pressure planned in the original schedule, - both men developed pain; Diver FE had twinges in both elbows and a more persistent pain in both knees; Diver LS developed pain in his right knee to add to his other symptoms. Both men were recompressed to 220 feet and their pains disappeared at 204 feet. After 30 minutes, both men were decompressed again to 190 feet this time without aggravation or reappearance of symptoms. After 90 minutes, decompression to 165 feet was carried out. Both men had a short recurrence of pain in both knees on arrival at this depth, at 140 feet, at 120 feet, at 110 feet and at 100 feet. Over 5 hours after leaving 165 feet, an attempt to reach 90 feet had to be stopped at 93 feet and both men were returned to 100 feet because of severe pain in both knees especially of Diver FE. After another hour, 90 feet was achieved and after 2 hours 80 feet and then after a further period this time 6 hours, 70 feet was reached. His pain recurred in an extremely severe form in Diver FE, so both men were recompressed to 165 feet with relief of pain at 100 feet for Diver FE and relief of giddiness for Diver LS. Both men gradually became aware of a mild persistent dull ache in their knees which eased during the decompression to 140 feet after 2 hours at 165 feet. Decompression continued with 1 hour at 140 feet, at 120 feet, at 100 feet, at 80 feet, at 70 feet, and at 50 feet where Diver FE became restless because of discomfort in his right knee. On moving to 40 feet, this discomfort became a niggling pain which lasted 3 minutes. At this depth, the oxygen content of the chamber atmosphere was increased to 40%. After 1 hour, both men were decompressed to 30 feet and after some initial restlessness, they settled down for a stay of 6 hours at that depth. On subsequent bleed to 20 feet and again to 10 feet, where the stops were 1 hour long there was a recurrence of discomfort in the right knee of Diver FE. On the last bleed to surface, this reappeared at 5 feet for Diver FE and Diver LS reported a soreness in his right knee at 2 feet. On leaving the chamber Diver FE was much more exhausted than Diver LS but he was free of signs or symptoms (Fig. 17). Diver LS was found to have a lesion of the right cochlea and vestibule. The cochlear lesion cleared in the course of a few days with the vestibular lesion improving more slowly. The therapeutic decompression was an empirical mixture of reducing pressure to keep the symptoms constant but minimal; of return to pressures higher than required for relief of symptoms; and of prolonged stays at pressures to equalise the saturation of the tissues at the new ambient levels. The depth at which signs and symptoms appeared is one to or beyond which very few men have dived and it is remarkable that the whole episode took less than 50 hours. The routine of this dive is given in Appendix 4.

Diver CR and Diver HI carried out a chamber dive to 700 feet for 2 hours. The decompression schedule to be used was the one prepared for the 800 foot dive so it was expected that the initial pressure drops should be safely carried out. All went well till the men left the 190 foot stop, 10 hours from the start of the dive and 4 hours after the oxygen had been enriched to 20% from 5%. During this decompression change, Diver HI slowly developed severe pain in both knees and Diver CR was dramatically sudden at 150 feet in reporting pain in both his knees. Both men were recompressed, Diver HI recovering by 185 feet but Diver CR not till 260 feet was reached. Both men were decompressed in stops of 2 hours duration and reached the surface with only an occasional reminder of pain in their knees which appeared on reaching each stop and this cleared at that stop. Both men had retrosternal pain on deep inspiration with fine râles scattered throughout the lung areas. In addition Diver CR had diminished sensation of the pads of the terminal phalanges of all digits of both hands - an abnormality which prevented the differentiation of coins. (This has been reported as occurring in prolonged oxygen breathing). These men had had twinges from the beginning of decompression which they had not reported and their painful episode was dealt with by a great increase in pressure and then a steady monitor of their symptoms to regulate each succeeding pressure drop. The routine of this dive is given in Appendix 4.

Diver FK and Diver MM dived to 55 feet in a chamber for 2 hours at depth using 10% oxygen/90% helium for the dive and 100% oxygen for the direct ascent to the surface at 50 feet per minute. 20 minutes after surfacing Diver MM reported with a mild ache of the flexor aspect of his right forearm which cleared within the next hour. Diver FK had an ache in the lateral aspect of his left upper arm distal to his shoulder and reaching his elbow. Over the next 2½ hours it eased to a mild dull ache in the region of his left elbow. It then gradually became more severe again and in a further 3 hours developed a "bite". Recompression was effective at 7 feet, he was taken to 30 feet and a bleed decompression was carried out using air as the breathing mixture with complete success (Shorter).

Diver LC and Diver CW dived to 300 feet in a chamber for 4 hours at depth. Diver LC reported on arrival at the 45 feet stop that he had a severe pain in the medial side of his left knee which had been present at the previous stop of 70 feet. Both men were recompressed to 70 feet with relief of symptoms at 57 feet. The decompression continued with stops of 1 hour at 70 feet and 60 feet but the pain appeared again at 55 feet where there was a pause of 1 hour. On resuming the decompression the pain recurred at 45 feet and the chamber pressure was raised to 50 feet. After 2 hours, decompression was restarted with a recurrence of symptoms at 33 feet, 22 feet, 8 feet and 2 feet there being a very slow bleed to the next point of 30 feet, 20 feet, and 8 feet where the pressure was maintained for 1 hour before proceeding. On the surface Diver LC was walking well and both men had retrosternal tightness on deep inspiration but no clinical or radiological abnormalities on examination. This case was treated by an increase in pressure beyond that required for relief and by stops of 1 hour duration monitored by the patient's response, and changes in pressure were carried out by a slow bleed. The routine of the dive is given in Appendix 4.

Comments

There were many lessons learnt and relearnt in this trial. The variability of response among individuals is shown by the fact that the first sea dives resulted in 1 permanent cripple, 3 men successfully treated and two men apparently unaffected. The value of keeping in reasonably regular practice and of an adequate work-up after a lay-off is apparent. The chronic effects of pure dry oxygen, so often over-shadowed by the acute convulsive effects, had to be recognised and borne in mind when considering prolonging a therapeutic routine. The points of decompression theory assumed from work done elsewhere or many years before, coupled with animal experiment results were found to be misleading. In fact many misconceptions had to be shed and the initial euphoria became eventually a planned attack. Even then there was the surprise that extrapolation of curves and extension of tentative theories was not straightforward in spite of an ultra conservative approach. There is some suggestion from the case histories that once decompression sickness occurred, there was no real benefit to be gained by the patient breathing oxygen enriched mixtures, even pure oxygen at 30 feet, instead of a gas mixture intended to maintain the partial pressure of oxygen equivalent to normal atmospheric levels. While there is doubt whether pure oxygen or dry gas caused pulmonary discomfort, it is better to keep the oxygen level down. The concept of using the depth of relief as the pressure required for therapy was not entirely satisfactory it being of value to add an increment to this figure. It is difficult to assess the effect of long pauses at various depths and it is possible that shorter duration at shallower intervals might be more effective. The use of discomfort as a guide to therapy was never satisfactory but in such an empirical situation there was little choice. The fact that some cases recovered without recompression may disguise one asset of such action in that patients are more rapidly relieved of all signs and symptoms; this in turn means that one has a fit energetic young man as a patient who remembers the subsequent boredom and irksome confinement of his therapy; this then leads to a reluctance to accept recompression therapy at a later date. The spectre of aseptic bone necrosis is always present in deep diving, but never more than around cases of decompression sickness because of queries on the adequacy of any therapeutic regimen. Finally it is obvious that this type of deep diving will always require to be a major undertaking and not to be tackled by a small ill-equipped team.

CHAPTER XII

DISCUSSION

Inevitably several aspects have already been mentioned in the preceeding chapters. Broadly, it is submitted that the established compression treatment of decompression sickness of whatever origin, diving or tunnelling, commercial, military, or for sport, must be reviewed. It is tempting to include aviator's decompression sickness but there is very little experience recorded as yet by men who have seen cases in both low pressure and high pressure situations. In essence the evolution of the theories leading to measures for the prevention of decompression sickness also led to measures for the treatment of decompression sickness. The response of various species has not enabled a reliable experimental animal to be found except perhaps, in some limited aspects for the goat. There is a great tendency amongst workers in this field to promote for use with man, treatment routines based on their animal cases whether the animals be dogs, or goats. This proferred work appears to be unusual first in the number of cases in divers, cases which were the responsibility of one individual, sometimes in collaboration with less experienced colleagues; and second in the variety of types of exposure to high pressures which resulted in such cases.

Criterion for Diagnosis

It is probably apparent that there has only been one criterion required to establish a prima facie diagnosis of decompression sickness and that has been the complaint of unusual symptoms or signs from a man who had a recent history of exposure to pressures greater than atmospheric pressure. The diagnosis has been separated into two groups depending on the duration of exposure and to some degree on the development of the case. By this is meant that cases arising after a fairly rapid return to atmospheric pressure after a short exposure to maximum pressure and which then presented symptoms of neurological disturbance, motor or sensory, were regarded from the start as "air embolism" consequent on lung damage rather than as classical decompression sickness. The classical label was considered when the cases developed after prolonged exposures to pressures with a decompression routine and were more often associated with symptoms and signs of the locomotor system. The coincidental development of both types is always possible as is the possible occurrence of one type when the other is more likely. One wonders if cases showing lung cysts as reported in men from tunnel sites although arising after long pressure exposures are not really cases of pulmonary barotrauma rather than decompression sickness, as indeed is suggested by Campbell Golding and his colleagues (28).

Differential Diagnosis

The question of differential diagnosis from conditions not caused by pressure changes is sometimes difficult. Hysteria used to be put forward commonly in submarine escape training cases and was difficult to refute when no radiological, clinical, or electro-encephalographic evidence of the lesion was present. In diving, muscle and joint injuries are always possible as well as malingering and, again in the absence of positive signs, some alternative diagnosis to decompression sickness may be made. An example was given in the chapter on deep diving of a case that almost certainly had a hypoglycaemic cause but the same man on earlier occasions, (also recorded) probably had a hypoglycaemic attack as well as decompression sickness. Griffiths (67) has described a tunnel worker with classical clinical signs and symptoms of perforated peptic ulcer a short time after he had completed a shift but who on recompression recovered dramatically and remained well. As there is no evidence or expectation that patients not suffering from decompression sickness will dramatically improve on recompression while those so afflicted do improve the diagnosis can always be checked by a test of cure by recompression. This is particularly the case where the prospect of permanent disability due to decompression sickness may occur as there is no record, so far, of a person dying of another condition when recompressed for possible decompression sickness. A case has been described (1) where a patient died while in a compression chamber from multiple causes when a mistaken diagnosis of air embolism was made without a history of decrease in ambient pressure, the immediate cause of death being oxygen poisoning complicating septic abortion.

Problems of Treatment

Having advanced to the point where the diagnosis is presumed because of the history and where recompression as the correct treatment is indicated directly, or after a test of cure, for the prevention of serious disability of a temporary or a permanent nature, an explanation must be given for the fact that the majority of cases are not recompressed. To this end the circumstances of treatment must be considered. A compression chamber is a confining cell of such a size that very rarely can an occupant stand up inside it and, due to the cylindrical shape of narrow diameter, even a comfortable sitting position is not always attainable (Fig. 3). Great strides have been made in comfort for example in providing mattresses so that lying down is the most acceptable activity. The patient is not "ill" and once his signs and symptoms are relieved he is once more a healthy active individual. The temperature inside the chamber varies with the season and environment there being a marked increase on compression followed by a sharp drop each time the pressure is subsequently released. The cold is aggravated by cloud formation as the temperature drops below the dew point of the chamber atmosphere (Fig. 15). In a minor way, replenishing the atmosphere also has a cooling effect on the internal conditions of the chamber.

Associated with temperature is the problem of noise. The release of gas from a higher pressure to a lower pressure is always noisy: this varies with the volume involved and the rate of release. A skilled operator can change the atmosphere with only a slight sibilant sound and, if the decompression is a bleed, at a very slow rate, he can sometimes carry out a fairly silent progression to lower pressures. In addition, the metal construction of the chambers transmits noise to the inside, especially such scratching or tapping sounds which may be carelessly made by attendants on the chamber itself. Lighting is important so that the patients may be observed but by switching off all but a soft light, it is possible to encourage relaxation and remove the uncomfortable sensation of being "on the spot", but still observe such important indications as restlessness or restricted movements. In any long period in a compression chamber, enmity can be generated fairly easily towards the attendants who regularly observe through the portholes - as they must - but who thus deprive the occupants of privacy even for natural functions; this emotion is aggravated by visitors, however well-intentioned.

The patient and his attendant may pass the time reading, playing board games or dozing and they can carry out normal activities such as feeding and attending to personal hygiene. The depressant effect of high pressure attributed to nitrogen - but also noticed to a lesser extent when helium is the inert gas - leads to a lack of concentration so that reading requires too much concentration and is usually abandoned. Games played are simple ones with cards or ludo but never chess or other games requiring high intellectual performance - perhaps because the men cannot play such games. Food tends to be unappetising however well-prepared and the taking of fluids has to be actively encouraged. Because of the inflammability risks of high oxygen tensions, smoking in a chamber is banned and in smokers this can become a troublesome matter.

Some people may consider that no action should be taken till the man volunteers a complaint, thus avoiding a dilemma in diagnostic skill and treatment. This was not the practice, first because of the risks of delay when examination disclosed signs of which the patient was unaware, and second, because of the experimental nature of so much of the work when the number of cases of varying severities formed the main part of the assessment of success or failure. In addition, questioning could lead to continuous observation of the man so that any deterioration was rapidly spotted. In at least two men who reported, the benefit of the doubt was not given because of personality clashes causing suspicion of "financial" decompression sickness but the case records show the error in retrospect.

Alternative Treatment

Alternative therapy to recompression was usually labelled "symptomatic". A deep hot bath was often the first measure in suspected or minor cases and was always welcomed as the men wanted to clean themselves after their work. It was hoped that the traumatic bubble might expand in such a situation causing aggravation of symptoms thus confirming the diagnosis; and that such heat could ease the muscle aches and strains sometimes occurring in helmeted diving. Rest was more a gentle pastime of sitting with friends, eating, talking, smoking, and similar activities rather than bed rest; this routine often led to permanent as well as temporary improvement. Analgesics were not used often to avoid masking of any developing signs and symptoms but if they were used then it was usually after several hours had passed with a nuisance type of pain remaining constant. If the patient wished to sleep he was allowed to do so under observation.

Pressure Required for Recompression

Once the decision to recompress was taken, the minimum pressure required was that where relief of symptoms and signs occurred. Sometimes, the improvement of the presenting symptoms was so marked that the patient was temporarily unaware of minor discomforts that might remain but these often led to subsequent trouble. This principle was well established in the past in divers and in tunnel workers but it had fallen into disrepute because of suggestions that if prolonged exposure to 6 Ats.Abs. did not result in improvement the diagnosis was wrong. It is true that as a rule pressures greater than 6 Ats.Abs. are unlikely to be required except for cases that appear after dives to greater pressures but this is by no means invariable. Thus in deep diving, therapeutic chambers should at least match in maximum working pressure the pressure of the dive. It is important that the considerable improvement in the patient be due to increasing the pressure and not to pausing at a pressure. It was remarkable how often the persistence of signs or symptoms, for however short a period, at the pre-selected depth of recompression seemed to lead to trouble during the subsequent decompression. Equally in cases of submarine escape training air embolism, high initial pressures were always required even if the subsequent decompression was curtailed. In practice an increment of pressure was usually added to the pressure of relief - not as a fixed amount but by increasing the pressure to 2 Ats.Abs., 4 Ats.Abs., 6 Ats.Abs., or $8\frac{1}{2}$ Ats.Abs. whichever was the next greater figure. During the decompression of deep diving cases, it seemed to be of benefit to increase the pressure again whenever the symptoms recurred or became persistent or became unbearable.

Duration of Stay at Pressure

As well as the pressure of relief, and the increment of pressure, three points had to be considered, the stay at maximum pressure, the gas to be breathed; and any adjuvant therapy before decompression commenced. All previous work in divers and compressed air workers had suggested that a period of half-an-hour was the minimum required at maximum pressure and this recommendation is endorsed by the experience in these various trials. This duration seemed to permit a stabilising of the patients' condition - or it was long enough for signs and symptoms to reappear. For the routines involving an increase in pressure to 2 Ats.Abs. it became standard practice to wait there for 1 hour and this seemed satisfactory.

Breathing Gas

Air was the gas usually selected as the breathing mixture because it was the atmosphere in the chamber for most treatments and because no breathing equipment was needed to use it, in spite of the effects of nitrogen and density. In some of the experimental chamber deep dives, the chamber atmosphere contained helium and in those cases that developed during the decompression, the patients continued to breathe oxygen and helium mixtures. On two occasions, when cases occurred after deep dives but which were treated with air breathing, oxygen and helium was administered intermittently by mask with improvement in the morale of the patient. 100% oxygen was used in half of the cases treated with the shallow routine as well as in some cases with prolonged therapy. In addition two men used it at atmospheric pressure in an attempt to see whether improved oxygenation led to alleviation of their symptoms but in one of them temporary improvement led to a more resistant case later so that no further cases were so treated. In the cases following deep dives and needing prolonged recompression there were physical signs of lung irritation in men confirmed once only by X-ray. This effect was possibly due to prolonged inspiration of high partial pressures of oxygen although successful attempts to keep these low indicated that the dryness of the gas supply might have been as important as the oxygen content in producing chest symptoms. In the shallower and shorter routines, there was no difference in the success of treatment as judged by the incidence of residual mild discomforts after decompression, whether air or 100% oxygen was used.

The impression was obtained that whereas a high oxygen content - and thus a low inert gas content - in inspired gas enhanced the rate of elimination of the inert gas during a routine decompression, once the diver reported signs or symptoms this physical process was considerably slowed. This might have been due to tissue reaction to the noxious agent and the consequent local oedema postulated then led to impaired circulation and thus impaired gas exchange. It was thought that the partial pressure of oxygen in the mixtures at high pressures was adequate to maintain oxygenation without incurring the risks of using 100% oxygen.

/It was assumed - perhaps unjustifiably - that the tissue oxygen tensions would reflect the inspired levels in the saturation situation of diving/ Experience tended to confirm opinions that the use of 100% oxygen during the decompression of developed cases did not accelerate recovery and, because of equipment limitations, often was an added stress to the patient. With these views, it is not surprising that so few of the cases reported here were actively treated with this gas. Comparison of cases treated at some stage with pure oxygen with the other cases is not of value because of small numbers.

The early deep dives suggested that air was undesirable as breathing mixture for decompression following oxygen and helium dives without an intermediate period of oxygen breathing. This opinion arose out of ideas that helium formed multiple micro bubbles whenever decompression started, bubbles which cleared quickly, when the pressure steadied again unless nitrogen was breathed. The diffusion and solubility characteristics of the two inert gases are such that it is feasible that nitrogen diffuses into the helium bubble to make it more stable whereas the oxygen content decreases as it is used up in metabolism. In later dives, the treatment on air always followed a period of oxygen decompression so that there was no repeat of the routine used in the one case that resulted in permanent neurological damage. Thus for routine air diving, it is suggested that air is the best therapeutic breathing medium, with the oxygen and helium mixtures being kept available for intermittent administration at the wish of the patient to lighten his depression.

After deep dives, the main therapeutic breathing mixtures should be the various oxygen and helium mixtures unless 100% oxygen has already been used for a reasonable period during the decompression in which case air may be used. 100% oxygen would seem to have little place as a breathing mixture of choice in therapy as its efficiency is doubtful and its dangers under high pressures are real. In addition there is the discomfort of administration of any mixture which depends on the type of equipment used.

Therapeutic Adjuvants

The use of other therapeutic agents at pressure, other than breathing gases and pressure has to be considered when signs and symptoms are not entirely relieved by such recompression as may be carried out. This situation may arise in one of two ways, either the treatment chamber is limited in its maximum working pressure or the treatment may be delayed deliberately or, more often, because of transport difficulties, both these latter causes producing a more resistent case. It has happened that cases have been treated in chambers where the maximum working pressure of 2 or 3 Ats.Abs. was inadequate to relieve symptoms rapidly (67. 154) but the routine used then was to keep the patient at the maximum pressure possible till eventually signs and symptoms cleared before successful decompression. The situation did not arise in the diving trials as the working limits were always adequate even if not fully used although such a situation could arise in submarine escape training. As mentioned earlier hypothermia has been used inside chambers in cases grossly damaged by transport delays, and in the later deep diving periods, facilities to carry out this adjuvent therapy were prepared but were not required. The use of saline or dextran infusion was considered in one case but an improvement in his condition made this operation unnecessary. The use of plasma volume expanders in a most unusual case of decompression shock (31) was of great interest and shows the sort of situation where benefit can be expected. It is understood that intravenous urea to reduce cerebral oedema was tried in a case, which had had a long delay to reaching treatment facilities, with considerable recovery but opinion on the efficiency of this mechanism is doubted by some neurophysicians and credit is given to recompression, time, and nursing (154). It is instinctive in some doctors to gild the lily by using drugs or some other evidence of their expertise, even when recompression has been successful; the intention being presumably to encourage gas - and theoretically bubble - elimination. If there is a risk of masking of recurrence of signs and symptoms, it is better to avoid unnecessary measures in the absence of specific indications. It is worth remembering at this point, that the patient should always be asked to carry out active full movements including weight-bearing on his legs at several points in the decompression lest the confining effect mask signs and symptoms by imposing restrictions on mobility (145). Where there are indications, then suitable drugs may be used e.g. paraldehyde in the case with epileptiform fits and sodium amytal during a prolonged stay at a constant pressure on Therapeutic Tables III and IV (especially recurring cases) thus allowing the patient to rest more effectively. Such drugs should be selected as far as possible for rapidity of action, shortness of duration, and minimal respiratory depression. Similarly, mild analgesics may be used.

In the cases described, one patient was not completely relieved by recompression in that he progressed to a paraplegia. His case was the major stimulus to investigation of therapeutic routines and later he would have been treated by much higher pressures. It would appear that he had multiple air emboli in his spinal cord, relieved by the initial pressure increase but hypoxic effects then appeared when the emboli grew again and this sequence was repeated a second time. No drugs were used and the condition did not deteriorate during decompression - although hypoxic areas might well have been rendered completely anoxic. Oxygen and helium mixtures might have been used during his therapeutic decompression to make life less miserable and perhaps increase tissue oxygen and reduce tissue carbon dioxide levels. In two cases in which it was decided to continue routine decompression after symptoms appeared there was a disappearance of the symptoms and a negative examination at the next lower pressure; again both were in the deep diving programme. There was no explanation for this unusual progression. When a case developed signs referable to the balancing mechanisms while at very great depths during decompression it was decided to continue the decompression as long as the signs remained constant till more familiar pressure levels were reached using the experience of the first case as a guide and hoping for an improvement as in the other two. Eventually the appearance of other signs at much shallower depths led to an increase in pressure to an intermediate level with improvement in the impaired sense of balance, suggesting that the hypothetical bubble had in fact been kept fairly constant in size as planned. No other therapeutic agents were used and the patients condition remained good.

Therapeutic Decompression Tables

As a rule the greater the pressure required for treatment, the longer the decompression routine will take. As oxygen does not seem to have much effect in speeding up the process compared with air or oxygen and helium mixtures, there does not appear to be anything to be gained by using potentially toxic concentrations; this means however that higher quantities of inert gas are available for absorption or to retard elimination. Thus one must be aware of the gas tensions in the body as a whole as well as at the site of the lesion. These tensions may differ because of circulatory impairment locally. This may be important in deep prolonged diving where it is possible to reach lower pressure levels during a therapeutic routine quicker than intended for the original dive and usually with a longer period at much greater intermediate pressures as well. (This situation arises when the decompression is carried out using the signs and symptoms as a guide and not using the calculated tissue levels). Previous diving therapeutic tables used the stage method of decompression as against the bleed of compressed air workers and, for the more serious cases, the stages could be prolonged so that the body could reach equilibrium with the inert gas partial pressures at each stage. It is suggested that once decompression sickness occurred the assumptions on equilibration no longer hold. The occurrence of decompression sickness in previously uninjured attendants suggest that these assumptions might have been falsely based in any case. The first departure from standard routines was to reduce the 12 hour duration of the 30 foot stop of Therapeutic Table III to the 2 hours of Therapeutic Table II although the indications for the use of the table remained. In effect, Therapeutic Table III fell into disuse. The next development occurred in the treatment of submarine escape training accidents where the vital point of adequate initial pressure exposure on recompression became obvious but, in the special pressure history, where it was found that the use of the standard diving table provided an adequate therapeutic decompression routine in selected cases. The next departure was to treat all cases, irrespective of the symptoms, on the depth of relief and to use the appropriate tables so that cases at one time treated on Therapeutic Table III could be treated on Therapeutic Table I. After 2 dramatically successful cases treated thus, there came the case of Diver WN which was not really a failure of this approach as in fact he did not start the Therapeutic Table I decompression but was further compressed from his initial depth of relief plus increment to what would have been the recommended depth, although perhaps not as quickly as he might have been. The development then continued by instituting the routine of depth of relief and a little bit more for cases relieved at shallow depths, followed by a bleed decompression as used in tunnel workers. There was some adjusting of times at pressure and rates of bleed before simple instructions were devised. In the same period, there were occasions when a need arose to use higher pressures than previously recommended up to $6\frac{1}{2}$ Ats.Abs. and which was initially devised on the spot with the first case. The table, developed in emergency, very quickly reached the shallower stages of Therapeutic Table II was fairly successful on the 4 occasions it was used. For later trials tables were prepared at leisure in readiness for cases which required such pressure levels and which either responded quickly or which had a longer resolution. Neither prepared table was used. These results suggested that either Therapeutic Table II was excessively long for most occasions or that a decompression routine did not have to have longer and longer stages the lower the pressure levels reached.

The stage was now set for the really deep dives and some principles had been established as guide lines for therapy. It was decided not to prepare a complete range of therapeutic tables but the scientists were asked to produce a decompression routine to cover slips in drill, equipment failure or other error at the maximum depth which could also act as a framework for the therapy. In the result, this table was used for emergencies twice but never, not even as a framework, for therapy. The evolution of a recommended routine is still not complete but the cases in the fourth deep diving period show the following points and modifications to illustrate the principles established. Pain was used as a guide in that a mild bruised sensation was noted but any increase in severity was an indication for recompression to depth of relief. Recompression usually occurred if any other signs or symptoms developed. The rate of decompression between stages was a slow bleed and each stage tended to be of similar duration rather than longer than the preceeding one. The pressure interval between stages was variable, depending on the appearance of or change in symptoms and signs. Any subsequent increase in pressure varied from considerable to minimal and the decompression started again from whatever new level was reached. It is still a matter for trial and error whether recurrence of trouble should be treated by recompression only to depth of relief or to depth plus increment. Experience would suggest that the addition of an increment followed by a pause might allow a more comfortable and a more rapid subsequent decompression than one being guided by signs and symptoms; and that the continuous "bleed" descent is an advantage compared with fixed stage intervals. [The reason for the attempt to speed up the process is the fear of respiratory abnormalities already discussed]

Signs and Symptoms

There has been little discussion or comment on the aetiology of the signs and symptoms in this thesis. In the absence of special investigative procedures ranging from X-rays and ultra sonics to blood coagulation studies, the eyes and hands can only have a limited value. The symptoms have been mainly pain but the flitting nature both in site and timing sometimes accompanied by local signs of tenderness and swelling, suggested a central focus at one time and a peripheral one at another. The localised swelling is mysterious in that the bilateral malar swelling should suggest a serious intra-cranial venous lesion belied by the condition of the patient although compatible with restricted venous return when it occurs in a limb. As a practitioner, one is forced to accept multiple gas bubbles intra-vascular and extra-vascular, central and peripheral, and get on with treating the patient so that the evidence disappears as quickly as possible.

Double-Blind Trial

At one stage in the deep diving trials, suggestions were made that symptoms might be due to increased apprehension on the part of the divers as the depth of the chamber dives increased. Equally, it was thought that the assessment of success and the choice of treatment was influenced by knowledge of the pressure of the traumatic dive. The programme that was being prepared at that time involved dives on oxygen and helium to depths shallower than 300 feet - a possible psychological barrier as few divers have been deeper than this level. There were also intended to be several fluctuations in depth in several depth ranges so that some departure was possible from the normal progression of dives gradually getting deeper. A medical officer took part in the actual preparation of the dives so that a qualified opinion was available in the planning stages. The divers did not know the depth of their dive and the assessing medical officer, also in ignorance, remained outside the chamber house till the final few minutes unless he was required earlier. The system failed because the divers could estimate the time of compression at a steady rate and compare it with their own trained subjective feelings and thus be aware of their depth within narrow limits. The doctor deliberately had to exclude the estimation of depth by the total duration of the dive and, in the event, his assessments were made with a fair idea of the depth obtained by several stray clues. It was perhaps relevant that all those taking part, had misgivings from the start about the practicability of such a trial.

Acclimatisation

This phenomenon has been noticed by medical men and others who have worked with compressed air undertakings and has been often described in the literature. An attack of decompression sickness may occur in a man in one of his first three shifts, or after a break such as a holiday or a strike. The man can thereafter tolerate pressure exposures thought to be more strenuous or causing attacks in newer employees. In this work, the dives during the several air-breathing trials and the first three stages of the oxygen-helium trial, were carried out with a rapid frequency of diving for each individual so that he might dive daily or every second day. The last deep diving stage required that the man dived less often than once a week. No clear effect was noticed in the air dives but this possibility was one of the reasons for the recommendation that divers should remain in regular practice or should steadily work-up to a desired level of operational readiness after a lay-off. There was a strong feeling that about one man in ten diving for the first time with helium had a likelihood of a dramatic major attack of decompression sickness. With the numbers involved and the interruptions for leave and travel, no clear evidence for or against this impression was obtained. The analysis was complicated by the abandonment of any decompression schedule which resulted in a major case. Over the two years, the first helium dive became an indoctrination dive and as the occasional case appeared, succeeding candidates carried out shallower dives of the same duration for the same decompression schedule. When a trial air routine was promulgated for use by the operational teams, certain minor changes were incorporated to take into account less accurate depth-keeping or possible errors in drill and to simplify the routine as much as possible. As these teams are in constant practice, acclimatisation may be as good or better than in the trials team. Little controlled work has been done on divers in this aspect and some research is indicated to determine the optimum interval between dives and thus the appropriate size of a diving team for a particular task.

CHAPTER XIII

CONCLUSIONS AND RECOMMENDATIONS

Diving will always carry a risk to those who choose this activity for their sport or employment. This risk can be reduced considerably. The need for economical use of manpower on the productive and preventive phases of a dive often compromises the best advice. As retribution is not as frequent as a doctor might wish for those who ignore his recommendation, there is a tendency, to consider rules as unnecessarily restrictive till it is too late. Even the sportsman often adopts this attitude to his subsequent regret.

There is no evidence which might lead to better selection of divers on physical or psychological grounds. Volunteering is a reasonable way to become qualified in the basic skills. For experimental work, this action is vital and must be made in as full knowledge as possible of the risks and without direct or indirect pressures. The status of being a member of a select group is obviously attractive, but direct financial inducements are not necessarily helpful. One suggestion, that these should take the form of "income protection" insurance in the event of disability causing loss of earnings, has some advantages in these days of hire purchase and easier credit without the penalties of volunteers more interested in money than the work - and avoids the problem of assessing the magnitude of an incentive payment.

The reasons for the variability between individuals and in the same individual from day to day are not understood at present. This means that the risk of decompression sickness, pulmonary barotrauma, or oxygen toxicity is always present in any dive. This risk may be ignored for short and shallow exposures to raised pressures but as the exposure is prolonged or is to higher pressures the risk will increase for each condition at different rates depending on the basic physiological mechanism. Greater attention may have to be paid to such factors as changes in circulatory and respiratory dynamics with immersion of the individuals. It is only recently that plans have been developed to investigate with modern techniques and equipment the physiology of man under pressure to discover any alterations from his functions at atmospheric pressure. There is a case for suspending further research on decompression and on prolonged exposures to pressures till such investigations have been made into that part of the field already explored.

While decompression sickness occurring in standard air diving may often be satisfactorily treated by recompression under the supervision of an experienced diver, this is not always the case. When the condition arises in deep diving especially if helium is being used or the possibility of pulmonary barotrauma is present then the presence of a medically qualified individual is important and, he should be experienced in the field. Most doctors have a very vague idea on causation and almost no idea on treatment; even those with a little knowledge may misdiagnose a case; while those with several years experience have each their own records of mistakes. It is important for any diver to know the whereabouts of the nearest treatment facilities, the nearest source of skilled advice, and the quickest way to reach and obtain these services. When in doubt, any signs and symptoms arising after an exposure to higher pressures must be assumed to be due to that activity. Very few conditions are aggravated by recompression therapy - and most of these should have been diagnosed before the initial dive. In this situation the best treatment is recompression, whoever is supervising, and to keep the patient at adequate pressures till further advice can be obtained. Such action may save life or disablement and be more comfortable for the patient; if it is wrong, the penalty is a little inconvenience and wasted time. When skilled advice is present, less dogmatic therapeutic routines may be instituted always with the possibility of recompression as more positive treatment if indicated initially or subsequently.

For ordinary diving, the therapeutic routines in the various diving handbooks are usually adequate. Often they may be unnecessarily prolonged, but they will suffice for the rare case occurring in ordinary supervised operations and treated by experienced lay divers. It is suggested that these routines could be augmented by another for those cases which respond to small increases in pressures. It is further suggested that in all these routines only air should be used as the standard breathing mixture for the patient. If an experienced medical officer is available then various departures may be possible, even in routine air diving. These departures include the use of greater pressures than those recommended in the manuals; the use of oxygen and helium mixtures to relieve the narcosis of nitrogen; and the use of 100% oxygen where the doctor considers the theoretical advantages outweigh possible toxic manifestations. It follows that these departures are used where the affected person has not made or sustained a complete recovery with the initial procedures.

In deep diving and submarine escape casualties, recompression therapy can be complicated and even skilled medical aid may be handicapped by pressure limitations of treatment equipment or by delay in treatment. In pulmonary barotrauma an initial adequately high pressure is the most important need; thereafter fairly rapid decompression may be carried out - as rapid as a dive decompression schedule instead of a therapeutic decompression schedule. In deep diving decompression sickness the subsequent decompression is unlikely to be straight-forward so that a detailed schedule is of little value. The need for a high initial pressure to relieve signs and symptoms is still vital but thereafter a very slow release of pressure between stages of such duration and depth as is considered wise (and always one hour or more) will be dependent on the appearance or aggravation of further trouble. In addition, the partial pressure of oxygen has to be carefully watched. This means that other problems such as dehydration, temperature control, and carbon dioxide accumulation must also be considered as the therapeutic routine might be prolonged.

Many individuals consider the treatment automatic for specified signs and symptoms and should follow "tables" - on whatever basis these tables were devised. A plea is made that the cases are treated as human beings; that the published tables be not regarded as the invariable right answer; and that fundamental research is needed into the illness and its treatment as well as into its aetiology.

CHAPTER XIV

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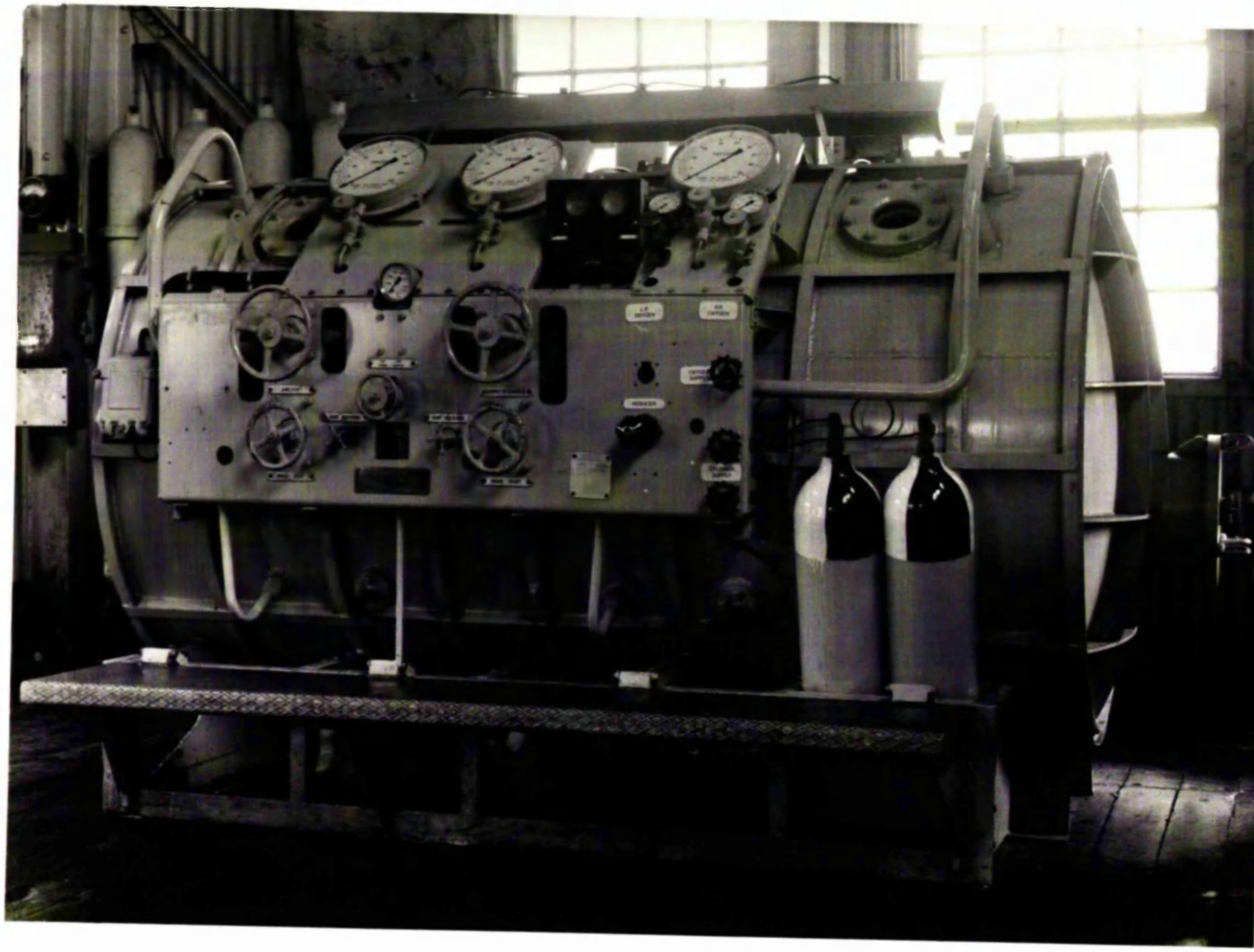
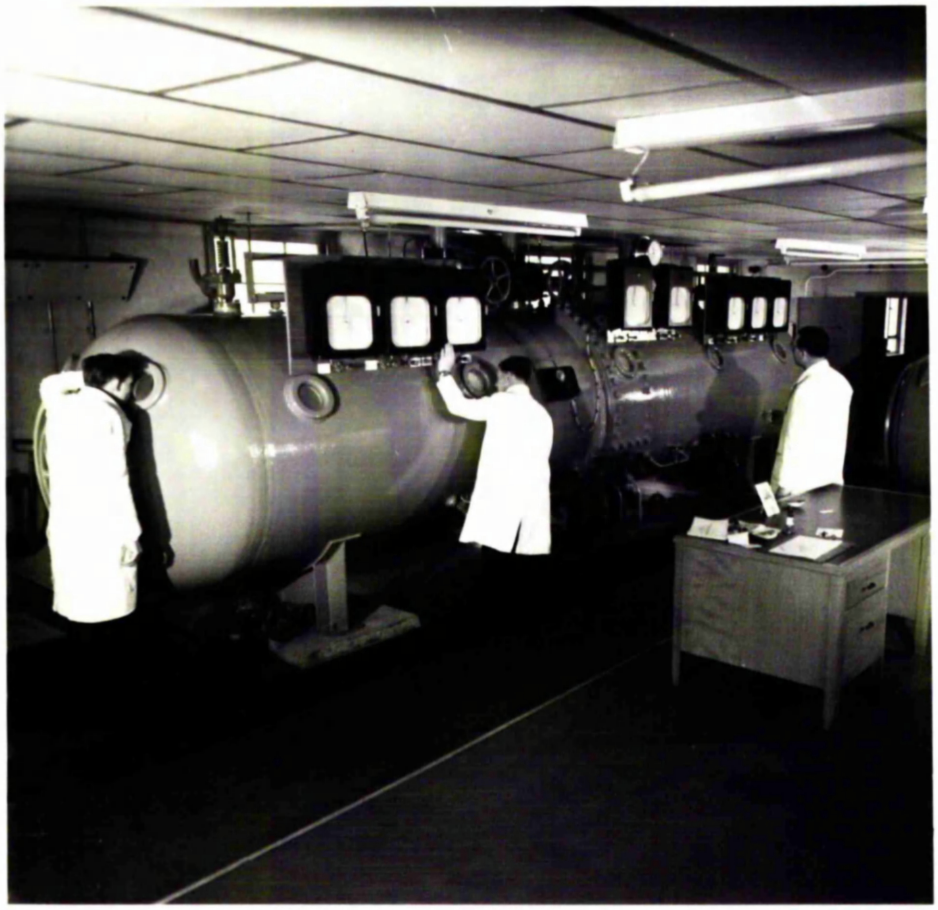
LIST OF FIGURES



A.E.D.U.

Fig. 1.

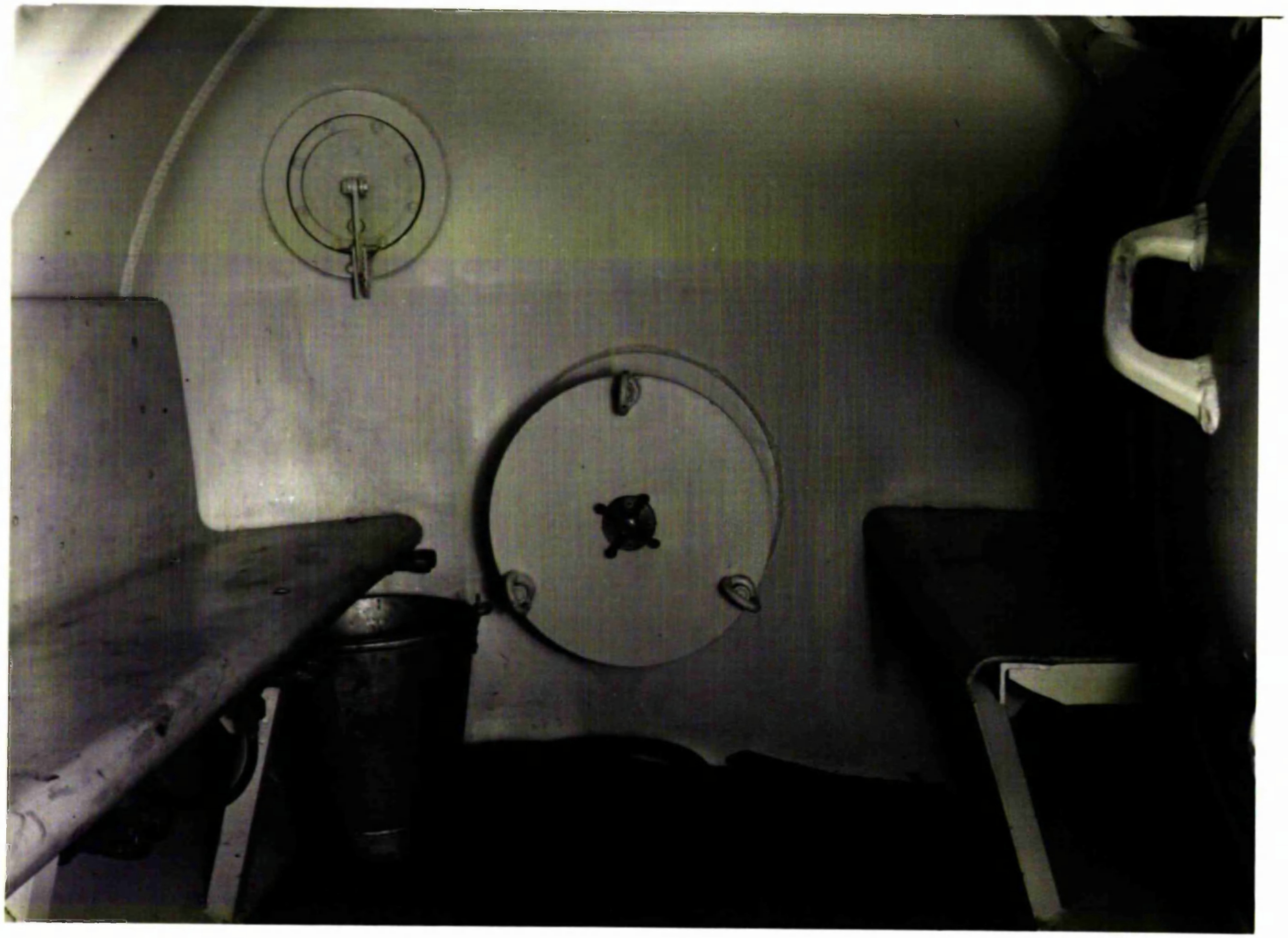
Standard 2-compartment Compression Chamber



R.N.P.L.

Fig. 2.

3-Compartment Compression Chamber for Experimental Work at the Royal Naval Physiological Laboratory



A.E.D.U.

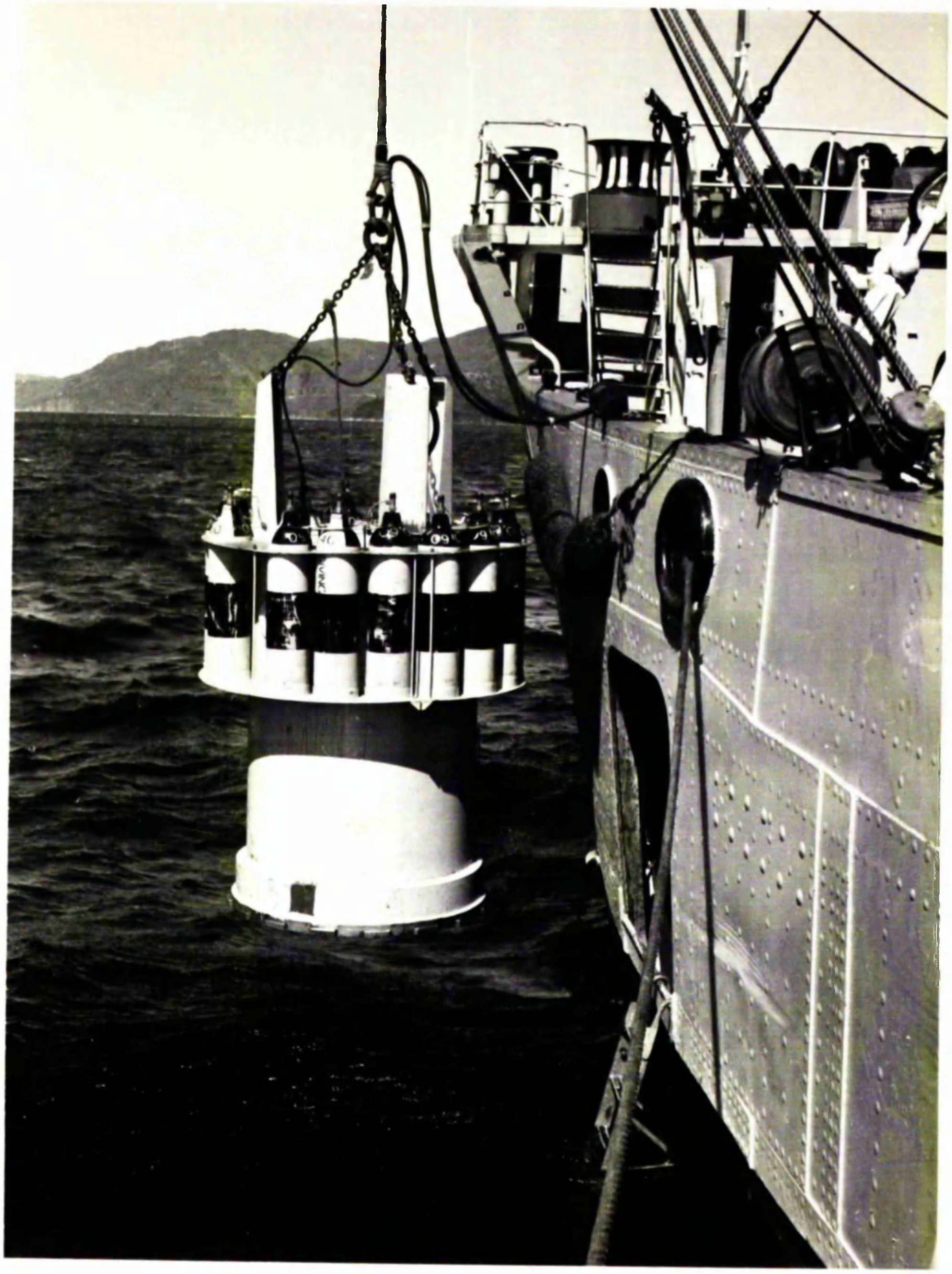
Fig. 3.

Interior of Main Compartment of Standard Compression Chamber shown in Fig. 1.

R.N.P.L.

Fig. 4.

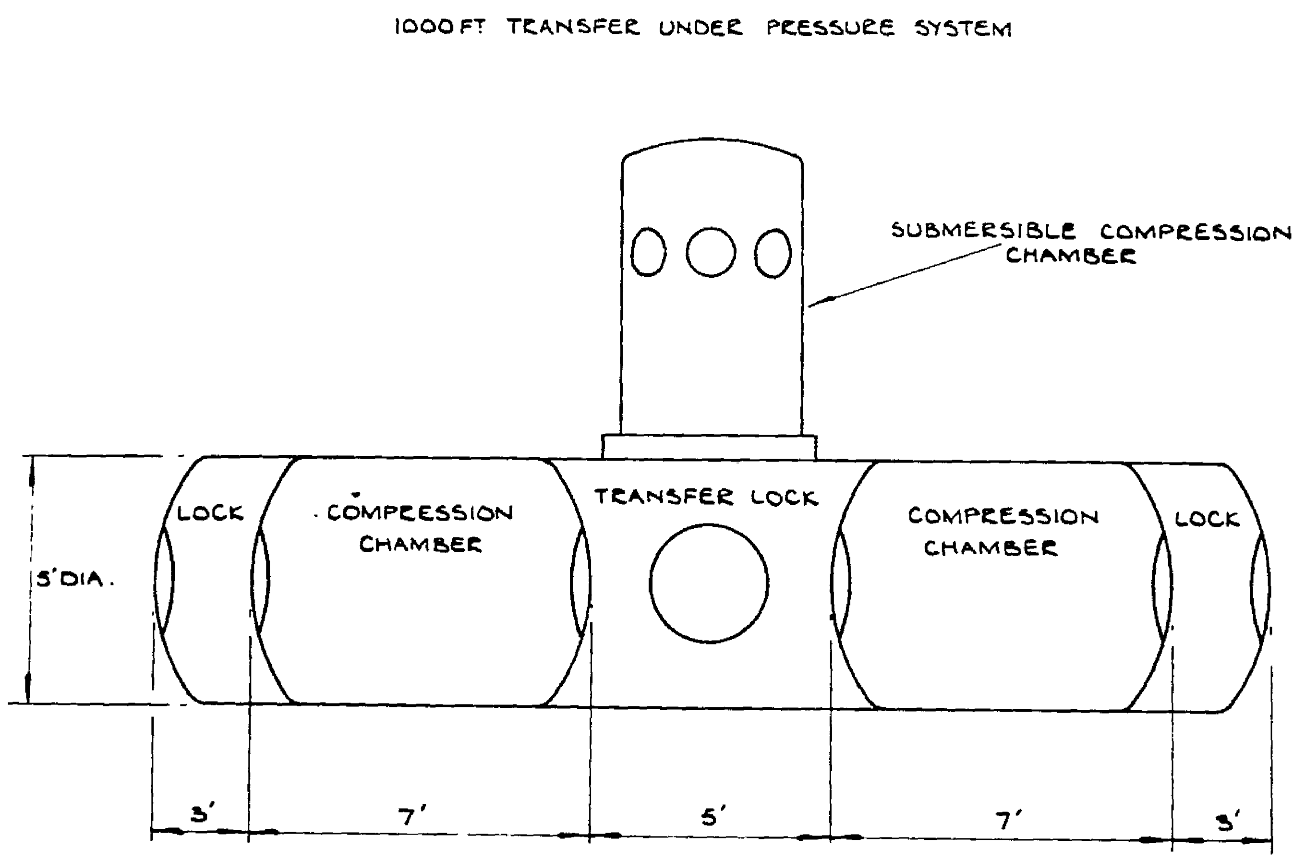
Breathing Equipment and Rowing Machine
in Compartment of Compression
Chamber shown in Fig. 2.



A.E.D.U.

Fig. 5.

Submersible Compression Chamber suspended opposite access to diving flat H.M.S. Reclaim

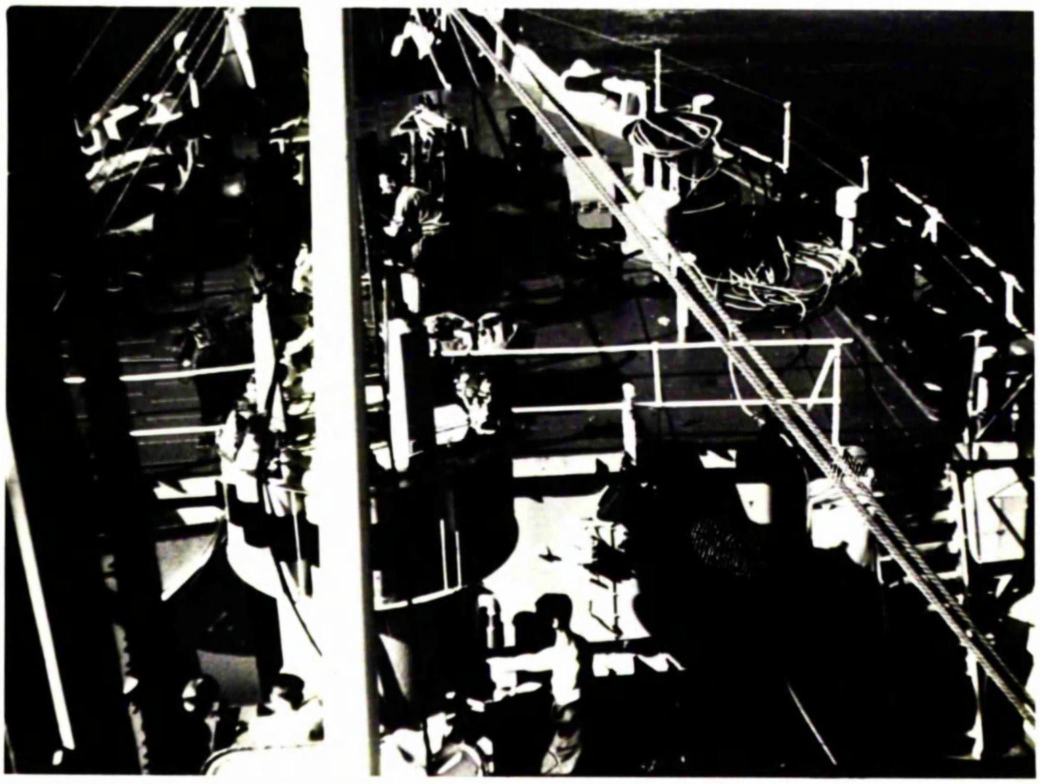


A.E.D.U.

Fig. 6a.

Diagram of a Transfer Under Pressure System.

At present the only system in operation consists of a submersible compression chamber on a modified standard 2-compartment compression chamber, equivalent to one end of the system illustrated



A.E.D.U.

Fig. 6b.

Submersible Compression Chamber being lowered on to Compression Chamber aboard H.M.S. Reclaim

A.E.D.U.

Fig. 7.

Diver dressed in Standard Equipment

A.E.D.U.

Fig. 8.

Men dressed in Surface Demand Diving Equipment

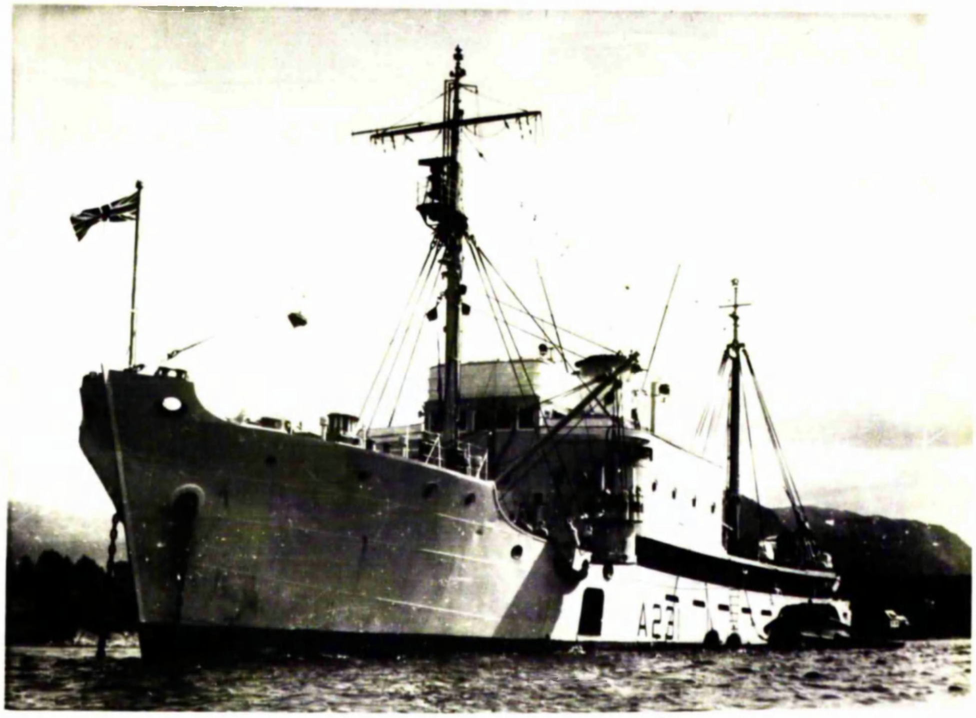


Fig. 9.

H.M.S. Reclaim at Diving Station with Submersible Compression Chamber hoisted outboard and Diving Door open

(Scotsman Publications)

Fig. 10.

Diving Flat H.M.S. Reclaim

Diver KA being dressed by Diver MR in Standard Equipment. Controls for Compression Chamber on the right.

R.N.P.L.

Fig. 11.

Rash following air dive in a Compression Chamber

a: Back view b: Front view

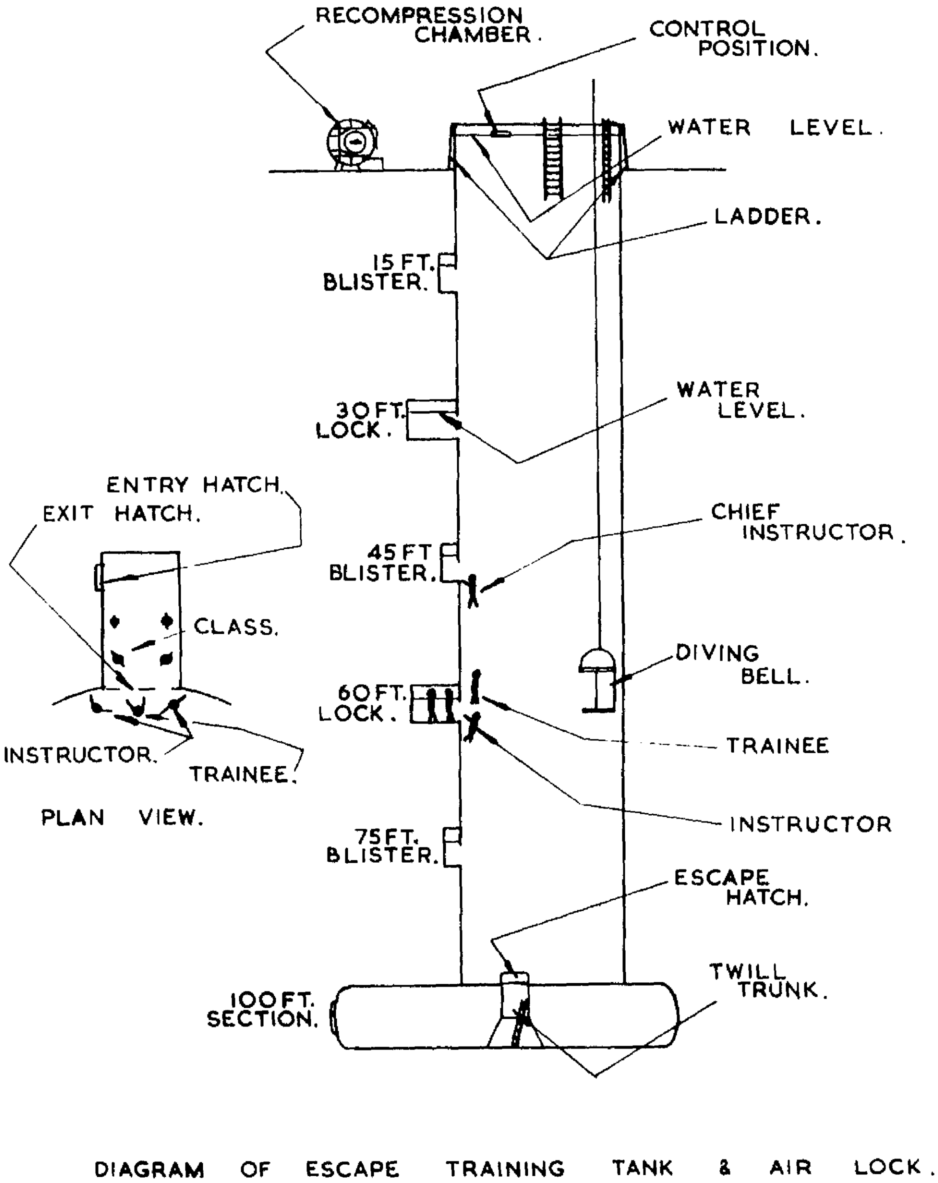


Fig. 13.

Submarine Escape Training Tank

at H.M.S. Dolphin

S.E.T.T.

Fig. 14.

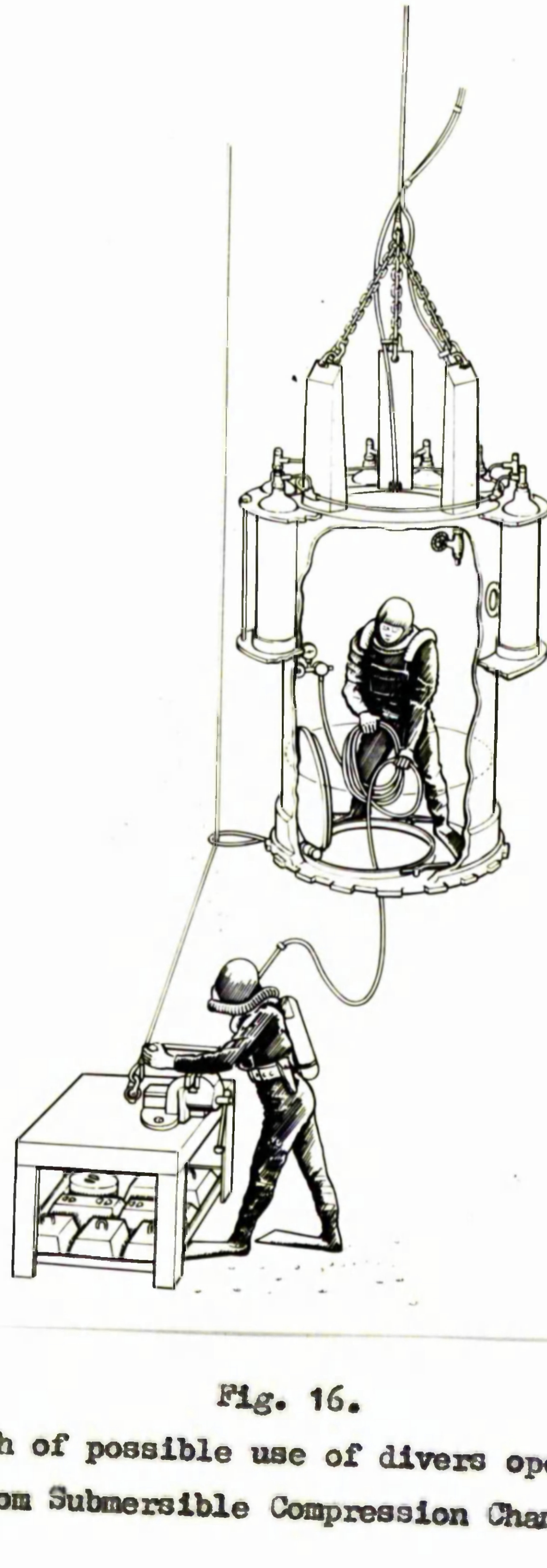
Submarine escaper showing life jacket fully inflated with escape valve to permit expansion of gas during ascent; and exposure suit inflated as it would be after arrival at surface.

R.N.P.L.

Fig. 15.

Below the dew point

Diver FE wrapped in blanket during decompression to keep warm: Note mist in the chamber

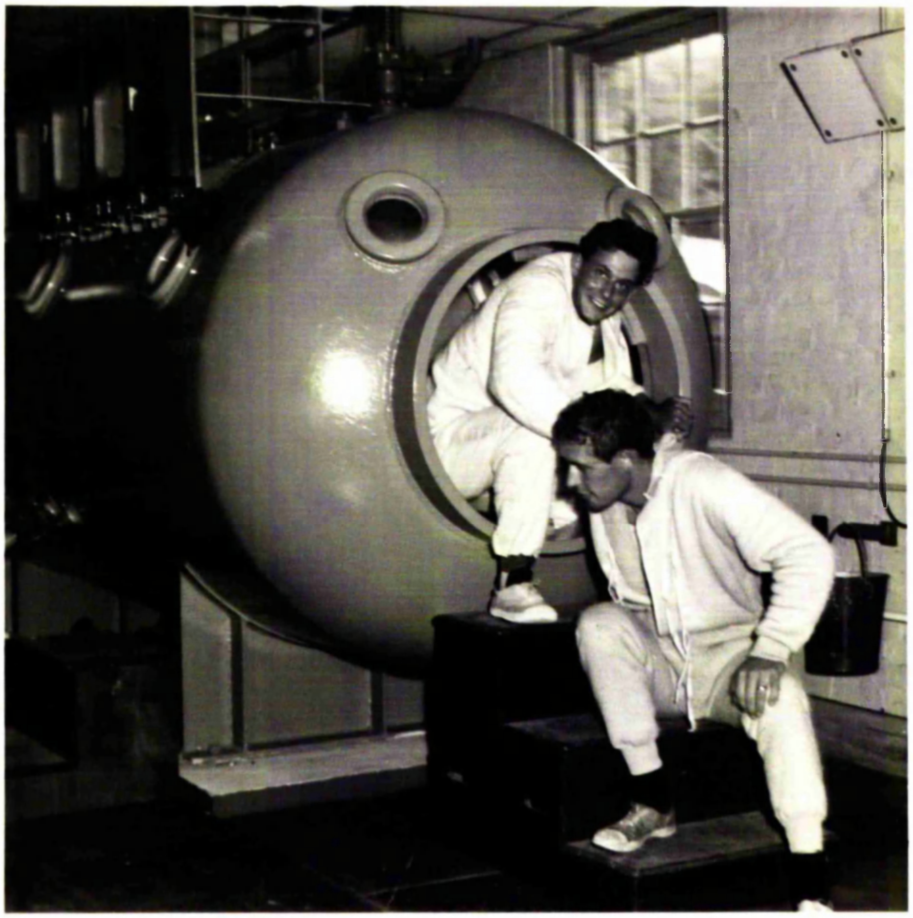


S.D.C.

A.E.D.U.

Fig. 16.

Sketch of possible use of divers operating from Submersible Compression Chamber



R.N.P.L.

Fig. 17.

After the deepest "bend" ever
Diver LS follows Diver FE out of the Compression
Chamber at the end of compression therapy

APPENDIX I

Statement by Surgeon Commander D. E. Mackay with reference to paragraph 2 (a) of Appendix A to U.P.S. 213 dated 12th October 1962. (for Med. Res. Coun. R. Naval Personnel Research Committe Underwater Physiology Sub-committee)

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1. Signs and Symptoms of Decompression Sickness

The problem is best described in the following quotation: "Decompression sickness manifests itself in a variety of symptoms each ranging from mild to severe. The evaluation of these or any symptom is subjective by nature. The measure is influenced by the subject's description and the examiner's observation and evaluation of the ailment ... Severe symptoms and signs of decompression sickness must be considered relatively objective and valid indices of decompression adequacy. However, both objectivity and validity decrease with the decrease in symptom severity so that the transient pain, the dull muscle ache, etc. is almost always open to question". (Kiessling & Wood) (1).

Behnke (2) has described the nascent gas bubble as replacing the spirochaete as the "great imitator" and this property of the bubble causes difficulty in accurate diagnosis when symptoms are fairly mild in character and no signs are present or can be detected. If signs and symptoms are present in combination then the total picture may be more serious than any single item might indicate and the following list of symptoms and signs should be considered with this point in mind.

Itching

The significance of this symptom is controversial. However it is definitely minor in character, rarely lasting more than 15 minutes after a dive (which is usually one in a dry chamber) and no treatment is needed though a hot shower reduces the duration.

Rash

This blotchy lesion distributed mainly on the upper trunk is a fairly serious sign when allied to other troubles (other than itching). Again no specific treatment is indicated for rash alone - although recompression leads to its disappearance - as it fades fairly quickly, and even faster if a hot bath is taken.

Fatigue

The degree of severity of this symptom is important and only an undue tiredness unexplained by diving conditions and state of training should be considered as a form of decompression sickness. On its own, treatment is rest under observation and rarely does recompression have any place in treatment of fatigue.

Pain

This is the most common symptom and requires experience both of decompression sickness and the individual diver to assess its importance, from the transient nagging pain of 10 - 15 minutes duration, through the dull constant type completely cleared by aspirin tablets, to the worsening ache which may or may not cause secondary signs such as collapse. The differential diagnosis from strained muscles or other injuries is not easy in inexperienced men and local heat may help in sorting out cases. In the more severe cases therapeutic recompression is essential and as in other cases any deterioration in the patient's condition, or increase in severity of the pain is a clear indication for recompression.

Pain is commonly located in the limbs in the region of joints and may radiate or even migrate and may be either single or multiple in location. Pain elsewhere such as low back ache, or pain in the perineum, abdominal pain or colic due to distension is unusual and so is regarded with more suspicion in the assessment of a case although recompression is not mandatory. In the case of abdominal pain, recompression is perhaps the quickest way of relieving symptoms due to intestinal gas but this is not a reason for enforcing a long therapeutic recompression. Great care has to be taken to diagnose the severe pain in the segmental distribution at the level of the lesion sometimes met in cases of paralysis; immediate recompression is the vital step in treatment.

Paraesthesia

Like pain, this symptom may be present in minor or major form.

The sensation of hot-and-cold must be closely watched. I have usually treated such cases by recompression without waiting for any worsening but where there has been the possibility of pressure damage to a nerve - such as excessive tight cuff on the radial nerve - then I have doubted the diagnosis of decompression sickness.

Central Nervous System

All lesions are serious when they involve cerebral structures, the spinal cord, cranial nerves, and the roots or peripheral nerves. While recompression as soon as possible is the normal treatment, it is not invariable. For example visual disturbance which improves during examination may be treated by a policy of waiting as long as improvement is occurring. Behaviour abnormalities are more difficult to detect but they also may respond to treatment, even 48 hours later. Vestibular damage is a less rare manifestation of decompression sickness and must always be recompressed.

Cardio-respiratory Systems

The problem here is that known as "chokes" where substernal distress and difficulty in breathing may lead to asphyxia or the "shock" syndrome. Some cases have occurred of tightness of the chest on respiration which have not needed recompression. Some cases closely resemble the straightforward vaso-vagal attack and respond to simple measures.

As a rule this group of symptoms and signs however should be recompressed rapidly.

There may be other symptoms or signs in decompression sickness but the guide would always be the condition of the patient after his dive. If he had little trouble, rest and constant skilled observation would be adequate; if his symptoms deteriorate or cause him distress or anxiety then recompression is the best treatment.

2. Criteria for Treatment

a) If there is doubt as to the diagnosis:

The routine should be to keep the patient under close observation at rest or else gentle exercise and measures such as local heat or baths could be used to determine the effect on the symptoms and signs. Any worsening of old symptoms or the appearance of new symptoms or signs would indicate that the patient should be assumed to have decompression sickness. The history of the dive and diver should be rechecked for possible injury, wrong gas etc.

b) If the diagnosis is substantiated or assumed:

(i) Cases with minor symptoms only e.g. itching, rash, niggles and other symptoms not causing the patient any distress, these cases would be treated by close observation and local measures such as heat and massage and perhaps mild analgesics. If the symptoms worsen or change then the case would be regarded as serious.

(ii) Cases with serious symptoms such as show involvement of the central nervous system or the cardio-respiratory system, these cases would usually be treated by recompression on the therapeutic tables published in the diving manual. If this were not adequate then consideration would be given to increasing the pressure even to the maximum the recompression chamber will take; to changing the gas mixture being breathed from air to oxy-helium, pure oxygen, or even oxygen enriched air; or to a combination of greater pressure and different breathing mixture.

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APPENDIX II

THERAPEUTIC TABLES

SECTION I

Extract from: U.S. Navy Diving Manual NavShips 250 - 538 January 1959

"General Principles of Diving"

Notes of Recompression

Explanation: All references to TABLES indicate parts of Table 1 - 21 "Treatment of Decompression Sickness and Air Embolism".

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1. GENERAL CONSIDERATIONS

   a. FOLLOW TREATMENT TABLES (table 1 - 21) accurately.

   b. Permit no shortening or other alteration of tables except on advice of trained diving medical officer or in extreme emergency.

2. RATE OF DESCENT IN CHAMBER

   a. Normal rate is 25 feet per minute.

   b. Serious symptoms: rapid descent is desirable.

   c. If pain increases on descent: stop, resume at a rate tolerated by patient.

3. TREATMENT DEPTH

   a. Go to full depth indicated by table required.

   b. Do not go beyond 165 feet except on decision of medical officer.

4. EXAMINATION OF PATIENT (see article 1.6.2. (14)).

   a. If no serious symptoms are evident and pain is not severe, examine thoroughly before treatment.

b. If any serious symptom is noted, do not delay descent for examination or for determining depth of relief.

c. In "pain only" cases where relief is reported before reaching 66 feet, make sure it is complete before deciding on TABLE 1.

d. On reaching maximum depth of treatment, examine as completely as possible to detect,

1) Incomplete relief

2) Any symptoms overlooked

NOTE:- At the very least, have patient stand and walk length of chamber.

e. Recheck before leaving bottom.

f. Ask patient how he feels before and after coming to each stop and periodically during long stops.

g. Do not let patient sleep through changes of depth or for more than an hour at a time at any stop. (Symptoms can develop or recur during sleep).

h. Recheck patient before leaving last stop.

5. PATIENT GETTING WORSE

a. Never continue bringing a patient up if his condition is worsening.

b. Treat as a recurrence during treatment (see 6).

c. Consider use of helium-oxygen as breathing medium for patient, (see 8).

6. RECURRENCE OF SYMPTOMS

a. During treatment:

1) Take patient to depth of relief (but never to less than 30 feet; and not deeper than 165 feet except on decision of medical officer) (If recurrence involves serious symptom not previously present, take patient to 165 feet).

2) Complete the treatment according to TABLE 4.

b. Following treatment:

1) Recompress to depth giving relief.

2) If depth of relief is less than 30 feet,

a) Take to 30 feet.

b) Decompress from 30-foot stop according to TABLE 3.

3) If relief occurs deeper than 30 feet,

a) Keep patient at depth of relief for 30 minutes.

b) Complete remaining stops of TABLE 3.

NOTE. - If original treatment was on TABLE 3, USE TABLE 4.

4) Examine carefully to be sure no serious symptom is present. If the original treatment was on TABLE 1 or TABLE 2, appearance of a serious symptom requires full treatment on TABLE 3 or TABLE 4.

7. USE OF OXYGEN

a) Use oxygen wherever permitted by tables unless:

1) Patient has not had oxygen tolerance test, or

2) Is known to tolerate oxygen poorly.

b. Be sure mask fits snugly.

c. Take all precautions against fire.

d. Tend carefully, being alert for symptoms of oxygen poisoning such as

   1) Twitching

   2) Dizziness

   3) Nausea

   4) Blurring of vision

e. Know what to do in event of convulsion. Have mouth-bit available.

f. If symptoms appear, remove mask at once.

g. If oxygen breathing must be interrupted -

   1) on TABLE 1, proceed on TABLE 1-A.

   2) on TABLE 2, proceed on TABLE 2-A.

   3) on TABLE 3, continue on TABLE 3 using air.

h. At medical officer's discretion, oxygen breathing may be resumed at 40-foot stop. If this is done, complete treatment as follows:

   1) Resuming from TABLE 1-A: breathe oxygen:

      at 40 feet for 30 minutes

      at 30 feet for 1 hour

   2) Resuming from TABLE 2-A: breathe oxygen:

      at 40 feet for 30 minutes

      at 30 feet for 2 hours

3) In both cases, then surface in 5 minutes still breathing oxygen.

4) Resuming from TABLE 3: breathe oxygen:

at 40 feet for 30 minutes

at 30 feet for first hour

(then finish treatment with air)

8. USE OF HELIUM-OXYGEN

a. Helium-oxygen mixtures (ratio about 80:20) can be used instead of air (not in place of oxygen) in all types of treatment and at any depth.

b. Use of helium-oxygen is especially desirable in any patient who

1) Has serious symptoms that fail to clear within a short time at 165 feet.

2) Has recurrence or otherwise becomes worse at any stage of treatment.

3) Has any difficulty in breathing.

Table 1-21. Treatment of Decompression Sickness and Air Embolism.

Stops		Bends—Pain only				Serious Symptoms	
Rate of descent—25 ft. per min. Rate of ascent—1 minute between stops.		Pain relieved at depths less than 66 ft. Use table 1—A if O_2 is not available.		Pain relieved at depths greater than 66 ft. Use table 2—A if O_2 is not available. If pain does not improve within 30 min. at 165 ft. the case is probably not bends. Decompress on table 2 or 2—A.		Serious symptoms include any o of the following: 1. Unconsciousness. 2. Convulsions. 3. Weakness or inability to us arms or legs. 4. Air embolism. 5. Any visual disturbances. 6. Dizziness. 7. Loss of speech or hearing. 8. Severe shortness of breath c chokes. 9. Bends occurring while still under pressure.	
						Symptoms relieved within 30 minutes at **165 ft.** Use table 3	Symptoms not re lieved within : minutes at 165 ft. Use table 4
Pounds	**Feet**	Table 1	Table 1-A	Table 2	**Table 2-A**	**Table 3**	**Table 4**
73.4	**165**	----------	----------	30 (air)	30 (**air**)	30 (air)	**30 to 120 (air**
62.3	140	----------	----------	12 (air)	12 (**air**)	12 (air)	**30 (air)**
53.4	120	----------	----------	12 (air)	12 (**air**)	12 (air)	**30 (air)**
44.5	100	30 (air)	30 (air)	12 (air)	12 (air)	12 (**air**)	**30 (air)**
35.6	80	12 (air)	12 (air)	12 (air)	12 (**air**)	12 (**air**)	**30 (air)**
26.7	60	30 (O_2)	30 (air)	30 (O_2)	30 (**air**)	30 (O_2) or (**air**)	**6 hrs. (air)**
22.3	50	30 (O_2)	30 (air)	30 (O_2)	**30 (air)**	**30 (O_2) or (air)**	**6 hrs. (air)**
17.8	40	30 (O_2)	30 (air)	30 (O_2)	30 (air)	**30 (O_2) or (air)**	**6 hrs. (air)**
13.4	30	↓	60 (air)	60 (O_2)	2 hrs. (air)	12 hrs. (air)	**First 11 hrs. (a Then 1 hr. (O_2 or (air)**
8.9	20	5 (O_2)	60 (air)	↓	**2 hrs. (air)**	**2 hrs. (air)**	**First 1 hr. (air Then 1 hr. (O_2 or (air)**
4.5	10	↓	**2 hrs. (air)**	5 (O_2)	**4 hrs. (air)**	**2 hrs. (air)**	**First 1 hr. (air Then 1 hr. (O_2 or (air)**
Surface		↓	**1 min. (air)**	↓	**1 min. (air)**	**1 min. (air)**	**1 min. (O_2)**

Time at all stops in minutes unless otherwise indicated.

SECTION II

Extract from: R.N. Diving Manual, 1956, B.R. 155C

"0314. Procedure for treatment of Decompression Illness.

It has been found in practice that if a diver gets decompression illness and is recompressed to enable any nitrogen bubbles to re-dissolve, his subsequent decompression must be at a rate slower than the normal or there is every chance that the bubbles will re-form. This longer decompression is known as THERAPEUTIC DECOMPRESSION.

(1) PROCEDURE FOR THERAPEUTIC DECOMPRESSION

(a) The patient should be instantly placed in a Recompression Chamber and the pressure should be run up at a rate of 25 feet per minute.

(b) The pressure at which pain is relieved should be noted and from this figure the correct Therapeutic Decompression Table to use can be discovered. The pressure should then be allowed to mount to the maximum figure indicated by the correct table, and decompression should be carried out according to the prescribed stages.

(c) The diver should be treated in this way even if the symptoms are only suggestive of Decompression Illness. Recompression can do no harm and it may prevent serious results".

(2) The Medical Officer should examine the patient as soon as possible and satisfy himself that the correct table is being used. He should not hesitate to change from Table 1 or 2 to Table 3 or 4 if he suspects that

bubble formation has caused a lesion of the Central Nervous System.

0315. RECURRENCE OF SYMPTOMS

If symptoms return DURING treatment, recompress to depth of relief but never to a depth of less than 30 ft., and complete decompression from this depth according to Table 4.

If symptoms return FOLLOWING treatment, recompress the diver to a depth giving relief.

(a) If relief occurs at a depth of less than 30 ft., take the diver to 30 ft. and decompress from the 30 ft. stop according to Table 3.

(b) If relief occurs deeper than 30 ft., remain at the depth of relief for 30 minutes and then complete remaining stops of Table 3 using air throughout.

It is highly improbable that the attendent as a result of being under pressure with the patient, will himself develop decompression illness. Should however, the symptoms be such that the Medical Officer decides to place the attendent under pressure within 12 hours of arriving at surface his subsequent decompression must be on the Therapeutic Table. Cramp is commonly experienced after a long period in the confined space of a recompression chamber.

0316. USE OF OXYGEN

Oxygen should be used when indicated by the tables, if available. The use of oxygen should not be allowed to shorten the total therapeutic decompression time. Oxygen should not be administered unless a Medical

Officer or qualified Diving Officer is in attendance.

If dizziness, nausea, muscular twitching or blurring of vision occur while breathing oxygen, remove mouthpiece and complete the rest of the treatment on air.

[illegible] Ascend 5 min. between stops.

		"BEND"-PAIN ONLY		SERIOUS SYMPTOMS	
		Pain relieved at depths LESS than 66 ft.	Pain relieved at depths GREATER than 66 ft. If pain does not improve within 30 mins. at 165 ft. the case is probably not bends.	1. Spinal "bends"-weakness or numbness of limbs. 2. "Staggers"-staggering, vomiting, dizziness, vertigo nystagmus. 3. "Chokes"-pain in chest with shortness of breath, cyanosis, collapse, unconsciousness.	
				Symptoms RELIEVED within 30 mins. at 165 ft.	Symptoms NOT RELIEVED within 30 mins. at 165 ft.
STOPS		TABLE 1	TABLE 2	TABLE 3	TABLE 4
Lb.	Ft.		Time in minutes unless otherwise indicated		
73.4	165		30 (Air)	30 (Air)	30-120 (Air)
62.3	140		12 (Air)	12 (Air)	30 (Air)
53.4	120		12 (Air)	12 (Air)	30 (Air)
44.5	100	30 (Air)	12 (Air)	12 (Air)	30 (Air)
35.6	80	12 (Air)	12 (Air)	12 (Air)	30 (Air)
26.7	60	30 (Air)	30 (Air)	30 (Air)	6 hrs. (Air)
22.3	50	30 (Air)	30 (Air)	30 (Air)	6 hrs. (Air)
17.8	40	30 (Air)	30 (Air)	30 (Air)	6 hrs. (Air)
13.4	30	60 (Air)	2 hrs. (Air)	12 hrs. (Air)	First 11 hrs. (Air). Then 1 hr. (O_2 or Air)
8.9	20	60 (Air)	2 hrs. (Air)	2 hrs. (Air)	First 1 hr. (Air). Then 1 hr. (O_2 or Air)
4.5	10	2 hrs. (O_2 or Air)	2 hrs. (O_2 or Air)	2 hrs. (O_2 or Air)	First 1 hr. (Air). Then 1 hr. (O_2 or Air)
SURFACE		1 minute (O_2 or Air)	1 minute (O_2 or Air)	1 minute (O_2 or Air)	1 minute (O_2 or Air)

SECTION III

Extract from: R.N. Diving Manual, 1964, B.R. 155C

"0313. THERAPEUTIC DECOMPRESSION - TABLE 5

1. Any diver who has decompression sickness or even symptoms not directly attributable to some other cause is to be treated strictly in accordance with the instructions in this article except on the advice of a medical officer or in extreme emergency. Recompression is most unlikely to do harm and it may prevent serious consequences.

2. If a Medical Officer is available and no serious symptoms are present, the patient is to be thoroughly examined before entering the recompression chamber. If, however, no Medical Officer is available or if serious symptoms are present, the patient is to be immediately placed in the chamber, with an attendant whenever possible, and the chamber pressurised as follows:

(a) IF THE SYMPTOMS ARE PAIN ONLY. The chamber is to be pressurised at a normal steady rate of 25 ft. per min. until the patient's symptoms are relieved, subject to a maximum recompression of 165 ft. which must not be exceeded except on the advice of a Medical Officer. The pressure at which relief is complete is to be noted and the chamber pressure increased at the same rate to the depth of the first stop given in Part A or Part B of Table 5 according to whether relief is experienced at a depth of less than 66 ft. or at a depth of 66 ft. or more. If pain is not relieved within 30 min. at 165 ft. (Part B), the case is probably not 'bends'.

(b) IF THE SYMPTOMS ARE SERIOUS:

(i) 'Spinal bends'. Weakness or numbness of the limbs.

(ii) 'Staggers' Staggering, vomiting, dizziness, vertigo, nystagmus.

(iii) 'Chokes'. Pain in chest with shortness of breath, cyanosis, collapse, unconsciousness.

For such symptoms the chamber is to be pressurised to the maximum depth of 165 ft. at the highest rate that can be tolerated by the patient and the patient then decompressed receiving the stops given in Part C or Part D of Table 5 according to whether or not the symptoms are relieved within 30 min. at this depth. If pain increases on descent, the descent must be halted and then continued at a rate acceptable to the patient. The maximum depth of 165 ft. is not to be exceeded except on the advice of a Medical Officer.

3. Rate of Ascent and Timing Stops. The time for the ascent between all successive stops is to be 5 min. The time for the first stop is to commence on leaving maximum pressure and the time for each subsequent stop is to commence when the diver leaves the preceeding stop.

4. Treatment in the Chamber. The Medical Officer is to examine the patient as soon as possible and satisfy himself that the correct table is in use. He must not hesitate to change from one table to another if he suspects that bubble formation has caused a lesion in the Central Nervous System. While in the chamber, the following checks are to be

applied by the Medical Officer or by the attendant if no Medical Officer is present:

(a) On reaching the maximum depth of treatment the patient is to be examined as completely as possible to detect incomplete relief and any symptoms previously overlooked. The patient must, at least, be stood up and made to walk the length of the chamber.

(b) A re-check as in (a) is to be made before commencing the ascent.

(c) The patient is to be asked how he feels before and after arrival at each stop and periodically during long stops.

(d) The patient must not be allowed to sleep through changes in depth or for more than an hour at any time during a stop (symptoms can recur during sleep).

(e) The patient is to be re-checked as in (a) before leaving the last stop. If the patient's condition worsens during the ascent, the ascent must be stopped and the patient treated as for a recurrence of symptoms (para. 5). The use of a helium-oxygen mixture as a breathing medium (para. 7) should be considered.

5. Recurrence of Symptoms. If symptoms return:

(a) DURING TREATMENT. The patient is to be recompressed to the depth at which relief of the symptoms occurs but never to a depth less than 30 ft. or to a depth greater than 165 ft.

except on the advice of a Medical Officer. Decompression is then to be carried out on Part D of Table 5.

(b) FOLLOWING TREATMENT. The patient is to be recompressed to a depth giving relief and:

(i) If relief occurs at a depth LESS than 30 ft. Take the patient to 30 ft. and decompress from the 30 ft. stop in accordance with Part C of Table 5.

(ii) If relief occurs at a depth GREATER than 30 ft. Remain at the depth of relief for 30 min. and then complete the remaining stops of Part C, Table 5, or, if the original treatment was on Part C, then Part D is to be used.

6. Use of Oxygen. Oxygen should be used as indicated in the Tables whenever it is available but must not be administered unless a Medical Officer or Qualified Diving Officer is in attendance.

If dizziness, nausea, muscular twitching or blurring of vision occurs while breathing oxygen, the mouthpiece is to be removed and the rest of the treatment given breathing air.

7. Use of Helium-Oxygen. When available, helium-oxygen mixtures (ratio about 80:20) can be used instead of air (not in place of oxygen) in all types of treatment and at any depth but only in the presence of a medical officer. The use of helium-oxygen is especially desirable in any patient who:

(a) has serious symptoms which fail to clear within a short time at 165 ft.

(b) has recurrence, or otherwise becomes worse at any stage of treatment.

(c) has difficulty in breathing.

8. Attendant - Decompression Sickness. It is highly improbable that the attendant will develop decompression sickness as a result of being under pressure with the patient, but should this occur and the symptoms be such that the Medical Officer decides to place the attendant under pressure within 12 hours of arriving at surface, his subsequent decompression must be therapeutic. It should be noted that cramp is commonly experienced after a long period in the confined space of a recompression chamber.

TABLE V

THERAPEUTIC DECOMPRESSION

STOPPAGES IN HOURS AND MINUTES AT DIFFERENT DEPTHS BREATHING AIR OR OXYGEN (O_2)												
Depth of Stops (ft.) Chamber Pressure lb./sq.in.	165 73.4	140 62.3	120 53.4	100 44.5	80 35.6	60 26.7	50 22.3	40 17.8	30 13.4	20 8.9	10 4.5	Surface -
Part A Pain relieved at depths LESS than 66 ft.				30 min. air	17 min. air	35 min. air	35 min. air	35 min. air	60 min. air	60 min. air	2 hrs. air or O_2	1 min. air or O_2
Part B Pain relieved at depths GREATER than 66 ft. (See Note)	30 min. air	17 min. air	17 min. air	17 min. air	17 min. air	35 min. air	35 min. air	35 min. air	2 hrs. air	2 hrs. air	2 hrs. air or O_2	1 min. air or O_2
Part C Symptoms RELIEVED within 30 min. at 165 ft.	30 min. air	17 min. air	17 min. air	17 min. air	17 min. air	35 min. air	35 min. air	35 min. air	12 hrs. air	2 hrs. air	2 hrs. air or O_2	1 min. air or O_2
Part D Symptoms NOT relieved within 30 min. at 165 ft.	30 min. to 2 hrs. air	35 min. air	35 min. air	35 min. air	35 min. air	6 hrs. air	6 hrs. air	6 hrs. air	First 11 hrs. air Then 1 hr. air or O_2	First 1 hr. air Then 1 hr. air or O_2	First 1 hr. air Then 1 hr. air or O_2	1 min. air or O_2

Note. Part B. If pain is not relieved within 30 min. at 165 ft., the case is probably not 'Bends'.

SECTION IV

Therapeutic Tables devised during trials

A. Shallow Therapy Table

Table X

Assumptions

1. Symptoms and signs were relieved rapidly and before 30 feet was reached.

2. The symptoms and signs were minimal in severity.

3. 100% oxygen is available and can be easily given.

4. The patient does not object to breathing from breathing apparatus.

Routine

1. Compress to 30 feet.
2. Patient breathes 100% oxygen or air for 1 hour.
3. Decompress the chamber at 1 foot per minute to 20 feet.
4. Decompress the chamber at 1 foot per 2 minutes from 20 feet to 10 feet.
5. Decompress the chamber at 1 foot per 3 minutes from 10 feet to atmospheric pressure.

B. Long Deep Therapy Table

Table Y

Therapeutic Recompression for exceptional cases of decompression sickness

Assumptions

1. The diver has been to 165 feet for 30 minutes and there has been no appreciable improvement in his condition, and it is considered that

further recompression to a deeper depth would be beneficial.

2. No depth less than 265 feet is worthwhile as the next pressure to be used. At 165 feet the bubble is reduced to 1/6th its initial size and at 265 feet to 1/9th its initial size.

3. The diver will not remain longer than 30 minutes at the new depth.

4. The U.S.N. system of therapy is reasonably satisfactory and the same ideas are capable of extension to 265 feet.

NOTES

(i) As ½ hour has been spent at 165 feet and ½ hour has been spent at 265 feet, together with 1 hour (approx.) at depths in excess of 165 feet during the decompression, it is clear that joining up with Table 5D may well be inadequate.

(ii) Table 5D is itself not adequate and has been known to give the attendant an attack of decompression sickness.

(iii) In a recent case, residual troubles were still present after the treatment. These may have been due to tissue damage and therefore unavoidable by any decompression routine, or they may display an inadequacy in the decompression. As there is doubt, and in view of (i) and (ii) above it is clear that some additional safety must be added to Table 5D.

(iv) Experience with therapy at 250 feet has, of necessity, been limited, but recurrences are too frequent. Attempts to join up with the accepted therapy tables don't appear to succeed.

(v) In view of the narcotizing effect of air at 265 feet and the possibility of errors of judgement occurring both in the diver and attendant, it is especially beneficial to breathe an oxy-helium (20/80) mixture whilst at depths in excess of 165 feet.

(vi) In view of the density of air at 265 feet and the possibility of breathing difficulties it is also beneficial to breathe the oxy-helium gas, whilst at depths in excess of 165 feet.

(vii) Unless the diver is in a state of complete exhaustion the breathing of oxygen at the lower depths cannot be other than beneficial, provided always that there is no risk of oxygen poisoning.

(viii) Prolonged breathing of dense air at depths of 60 feet and over can cause distress. It is desirable to breathe the oxy-helium as much as possible.

THE SCHEDULE

1. Raise pressure from 165 feet to 265 feet at 25 feet per minute.

2. Commence breathing oxy-helium mixture (20/80) immediately upon reaching 265 feet and continue oxy-helium breathing until arrival at 140 feet. Change to air.

3. Rate of ascent, 1 minute between stops.

DEPTH	TIME
265 feet	30 minutes
230	12
200	20
170	20
140	30
120	40
100	1 Hour
80	2 Hours
60	6 Hours
50 *	8 Hours
40 *	10 Hours
30 *	12 Hours
20 *	2 Hours
10 *	2 Hours

Total Time 45 Hours 46 Minutes.

* OXYGEN BREATHING at the end of each stop as follows:-

50 feet last 10 minutes

40 feet last 20 minutes

30 feet last 40 minutes

20 feet last 60 minutes

10 feet last 60 minutes

C. Short Deep Therapy Table

Table Z

Shorter alternative version for decompression from 265 feet.

Assumptions

1. The diver has been taken to 165 feet for a short period (less than 10 minutes).

2. Symptoms (or signs) were not relieved at 165 feet.

3. No more than 30 minutes is to be spent at 265 feet when it must be assumed that all troubles have ceased.

4. The diver's initial 'bends' were not accompanied by chokes or C.N.S. involvement - this is the U.S.N. classification i.e. pain or serious symptoms.

Schedule based on U.S.N. table 2-A which it must be realised is NOT the same as R.N. Table 5B.

DEPTH	TIME
265	30
230	12
200	12
170	12
140	12
120	30
100	30
80	30
60	30

DEPTH	TIME
50	60
40	90
30	120
20	180
10	240

Total Decompression time 15 hours 28 minutes.

NOTES

(i) Table 5B has 9 hours 14 minutes decompression time and Table 5C has 19 hours 44 minutes decompression time. As may be seen this table is intermediate but more towards Table 5C. This tendency towards extra time could be checked if the R.N. Table 5B principles were adopted instead of the U.S.N. Table 2A, which it must be noted is 10 hours 30 minutes in duration.

(ii) It is advisable to breathe oxy-helium (20/80) at 265 feet, and all stops deeper than 140 feet.

APPENDIX III

SHORT THERAPEUTIC RECOMPRESSION FOR S.E.T.T. ACCIDENTS

Statement by Surgeon Lieutenant Commander D. E. Mackey, 7th March 1962 and 4th December 1962 to Command Escape Officer, Flag Officer Submarines and his medical advisers.

Some confusion has arisen both about the reasons that I had for introducing a shortened form of therapeutic recompression, for the few accidents that occur during submarine escape training; and about the routine used.

2. I arrived at the training tank with some experience of decompression sickness and its treatment. I was aware that there was a recurrence rate; that treatment was unpleasant in so far as sleeping, feeding, and hygiene were concerned; and that there were residual troubles such as exhaustion and sensations of bruising.

3. Cases at the tank were quite different in their symptomatology to the majority of cases of decompression sickness as one would expect theoretically; in fact they resembled either the very rare severe cases obviously involving the central nervous system or they had signs in the chest or under the skin (or of course various combinations of these signs) which are not seen in decompression sickness.

4. The causation of all these cases is assumed to be the presence of a bubble in the appropriate areas to produce the relevant signs and symptoms. However, one must try and find the source of the bubbles as

treatment is aimed at making the bubbles regress and disappear. It is accepted that bubbles may arise in situ in a tissue which becomes supersaturated with a gas to such an extent that bubble formation may occur (there is a degree of supersaturation of the order of double saturation which is allowable for all tissues - some may have more - and other variations may occur but this doubling factor is a cornerstone in that bubble formation will only occur if supersaturation exceeds this amount). It is also accepted that gas may be rapidly introduced to a tissue through the surrounding membrane (usually alveolar) and once through, it will take up the form of any gas so introduced to a fluid i.e. a bubble.

5. For decompression sickness two things are important - the time of exposure to the gas and the ambient pressure: these determine the amount of gas absorbed and hence the degree of saturation of the tissues. Previous work has shown that the risk of decompression sickness after 20 minutes at 100 feet (i.e. 4 atmospheres absolute) is infinitesimal, in fact 30 minutes is accepted by many as quite safe: i.e. the degree of saturation of the tissues is such that a person can return to atmospheric pressure without much worry about bubble formation in situ. True, there is the question of speed of return to atmospheric pressure but consideration of circulation times and volumes of blood through the lungs would show that the difference in quantities released in 20 seconds or 100 seconds is not of such great significance as to affect tissue saturation materially.

6. In the case of the introduction of gas as bubbles through a lining membrane, the duration of exposure is immaterial as it is thought that the cause is a local area of gas causing distension of the containing membrane and either rupturing it or otherwise passing through it and so forming bubbles in the tissues (regarding blood as a tissue). The vital points here are the rate of expansion and route of escape of the gas.

7. In training for submarine escape, the duration of exposure for the man with the longest exposure is of the order of 12 - 15 minutes and the maximum ambient pressure is equivalent to 100 feet of sea water. Thus the likelihood of decompression sickness occurring is extremely remote. As the rate of ascent may be up to 7.5 feet per second (or as slow as 2.2 feet per second) the expansion of gas in the lungs may be great enough to cause alveolar rupture and any of the main forms of pulmonary barotrauma (air embolism) pneumothorax, or interstitial emphysema) may occur. It is always possible that a case may occur where decompression sickness and pulmonary barotrauma develop concurrently.

8. As has been said before, treatment aims at regression of the bubble. Some forms of pulmonary barotrauma need more than this simple aim as pneumothorax and interstitial emphysema do not reabsorb rapidly and other means of treatment may be needed. Air embolism however responds on the theory that Boyle's Law applies and if enough pressure is used the volume of the bubble will decrease till either the bubble continues on in the circulation and is trapped in the lungs or else the bubble tends to

dissolve in the blood stream - in either case the presumed blockage is relieved. This routine of shrinking the bubble is the idea behind treatment in decompression sickness also, but here one is starting with tissues supersaturated with the same gases and as such the resolution of the bubble is bound to be slower for comparable pressures; subsequent release of pressure must make certain that such supersaturation is not increased.

9. At this point, let me restate the position. There are two serious conditions due to a decrease in ambient pressures, which have different mechanisms for producing the same result. I considered that it was justified for the general benefit of the patient to apply two types of treatment depending on my interpretation of the symptoms as a clue to the mechanism involved. There are several other benefits but these are in the form of bonuses and in my opinion should never influence the treatment used.

10. The standard method of treatment is to regard the patient as suffering from decompression sickness and treat him on the appropriate therapeutic table i.e. 19 hours 51 minutes for one table, or a minimum of 37 hours 33 minutes on the other. My experience with the method has been detailed earlier, in particular with regard to the condition of the patient at the end of such manoeuvres.

11. Recompression to 6 atmospheres absolute would reduce the volume of the bubble to about 1/6th of its size at the surface. As this pressure is 2 atmospheres in excess of any exposure in the S.M.T.T., it is assumed

that the gas is encouraged to go into solution in the tissues. The speed of such an action would depend a great deal on the amount of gas already present in the tissues. In the case of decompression sickness one would anticipate a slow rate but as this possibility is most unlikely, (under the training conditions) in the case of air embolism a fast rate can be expected. In fact, I presumed that a rate similar to one in a dive to those depths would be reasonable, and hence adequate decompression for such a dive would suffice. As time at maximum pressure is important, 30 minutes at least should be spent at 165 feet so that there is a reasonable period for absorption of the bubble.

12. Therefore I advised a shorter therapeutic regime for cases which I considered to be due to pulmonary barotrauma. In the cases with interstitial emphysema, the deciding point was the appearance of subcutaneous bubbles in the neck as this usually relieved mediastinal signs and symptoms; if they did not appear then long decompression was indicated to prevent cardiac embarrassment. Those cases with pneumothorax varied whether there was a possibility of a tension pneumothorax or not; if present then paracentesis thoracis enabled fairly rapid decompression; if it was not a tension type then decompression depended on the effects of the pneumothorax acting as a guide. In the third broad type, air embolism, again the short routine was used unless it became obvious that a local lesion persisted as shown by the continued presence of any signs or symptoms by the time of arrival at 165 feet in which case the full routine was used. (A clinical observation is that

the original injury very rarely persists i.e. the lesion is self sealing on most occasions).

13. The procedure entailed automatic recompression to 165 feet where the patient was examined. (There did not seem to be any purpose in stopping at a shallower depth as treatment would always involve a descent to 165 feet). Depending on the results of examination, advice was given on the use of a full therapeutic table or the requirements for a shorter technique. If the latter was indicated, the R.N. Diving Manual was consulted in the schedule for 170 feet for a duration equal to the sum of a) the time the man had been under pressure that day; b) the time from his last exposure to reaching 165 feet on treatment; and c) an addition of 30 minutes. This would entail a decompression of at least 2 hours and probably nearer 3 hours.

14. During the shorter decompression, the patient was kept under close observation by a doctor who re-examined him at every stop. Any recurrence of symptoms was a definite indication for a full therapeutic routine. If there was no recurrence, the patient would be kept under observation for two hours and then sent to R.N. Hospital, Haslar, for X-rays of chest and E.E.G. and admission for observation. It should be emphasized that this routine is only applicable to cases whose symptoms are completely cleared on recompression to 165 feet, as any persistence would indicate that the bubble had not disappeared.

15. Following some experience of such methods, it is fair to say that the victims left the chamber relatively fresh, without any residual aches,

and frequently only a little subcutaneous emphysema of the neck to prove that pulmonary barotrauma had occurred. The bonuses consisted of (1) the good effect on the morale of other trainees; (2) the reduction in requirements of the staff; and (3) the minimal interruption of training; but again, the patient's needs have complete priority over any advantage to others. It is essential that constant medical observation is kept, that recurrence of symptoms - usually of neurological origin - be treated on a long table without delay; and that a period of observation at the tank be maintained post-treatment.
of observation at the tank be maintained post-treatment.

APPENDIX IV

SOME INTERESTING THERAPEUTIC-ROUTINES

A. Special Routine 1.

Divers BF and WF. — Chamber dive

Exercise - rowing machine.

Position		Time	Notes
Left	surface	00.00.00	
Arrived	300 feet	00.07.35	Breathing 10% oxygen/90% helium
Left	300 feet	04.00.00	Ascend $2\frac{1}{3}$ min. Change to 20% oxygen/ 80% helium on arrival at first stop.
Left	170 feet	06.03.00	Ascend $1\frac{1}{3}$ min. Change to 40% oxygen/ 60% helium on arrival at next stop.
Left	100 feet	08.05.00	Ascend 2 min. Change to 100% oxygen on arrival at next stop.
Left	40 feet	09.16.00	
Arrived	surface	09.17.07	BF complained of niggle L.Shoulder.
At	surface	09.22.00	Niggle moved to both ankles and then settled in L. knee.
Left	surface	09.33.00	Therapeutic recompression started.
Arrived	50 feet	09.34.00	BF sign and symptom free. WF at surface suddenly had severe pain R.Knee and looked in shock. Recompressed and locked through to Main compartment to join BF at 50 feet. Recovered.

Position		Time	Notes
Left	50 feet	09.35.00	
Arrived	100 feet	09.36.00	Decided to use Therapeutic Table I.
Left	100 feet	10.06.00	
Left	80 feet	10.23.00	
Left	60 feet	10.58.00	
Left	50 feet	11.33.00	
Left	40 feet	12.08.00	
Arrived	30 feet	12.13.00	DF complained of slight niggle in L.knee on arrival. He also reported slight tightness across chest present since first therapeutic stop. Examination - no abnormality either man. Niggle persisted - recompression decided to ease pain.
Left	30 feet	13.26.00	
Arrived	40 feet	13.28.00	
Left	40 feet	13.41.00	
Arrived	50 feet	13.43.00	
Left	50 feet	13.56.00	No change in pain or chest complaint.
Arrived	165 feet	14.01.00	Knee recovered. Chest no change. Decided to use Therapeutic Table IV. Diver WF - continue as attendant.
Left	165 feet	14.31.00	
Left	140 feet	15.06.00	
Left	120 feet	15.41.00	
Left	100 feet	16.16.00	

Position		Time	Notes
Left	80 feet	16.51.00	
Left	60 feet	22.51.00	Examined 23.20.00. BF - altered voice sounds in chest on auscultation. WF - abnormalities. Both men irritative cough.
Left	50 feet	28.51.00	
Left	40 feet	34.51.00	Examined 46.00.00. BF - chest clear, but still complained of tightness on very deep inspiration. WF - scattered rhonchi but no complaint. Cough persists in both men.
Left	30 feet	46.51.00	
Left	20 feet	48.51.00	
Left	10 feet	50.51.00	
Arrived	surface	50.56.00	
Doors opened		50.57.00	

After a short period of observation, both men had full plate X-rays. BF - no abnormality. WF - "small area pneumonitis present lower aspect R.M.Z. peripheral occlusion left costo - phrenic angle not present ... (6 weeks earlier)". Continued under direct observation and seemed recovered. Permitted to return to their own messes 6 hours after surfacing. After 4 days, BF stated that later in the day of his surfacing, he had had a pain in his right knee which had affected his gait but which eased with several hot baths - he had in fact warned his friends to be ready to take him to the chamber but he had refused to report to any responsible individual; over the next three days he had had only a rapid tiring on exertion. (He had been examined daily). WF had no complaints and felt fully recovered but his X-ray plate did not show resolution of the shadow till 5 weeks later - without any treatment.

D. Special Routine 2

Dviers BF and LB. Chamber dive

Exercise - rowing machine

Position		Time	Notes
Left	surface	00.00.00	
Arrived	300 feet	00.05.36	Breathing 10% oxygen 90% helium.
Left	300 feet	04.00.00	Ascend 2½ min. then change to 20% oxygen 80% helium.
Left	170 feet	06.00.00	Ascend 1½ min. Change to 40% oxygen 60% helium at 07.30.00.
Left	100 feet	08.00.00	Ascend 1 min.
Left	65 feet	10.00.00	Ascend 1 min. Change to 100% oxygen at 11.45.00.
Left	40 feet	12.00.00	Ascend 1 min. Change to 40% oxygen 60% helium at 12.06.00.Then to 100% oxygen at 14.30.00. At 12.08.00 Diver BF reported slight transient niggle in right knee.
Left	25 feet	15.00.00	Ascend 1 min. Diver BF reported ache in right knee. (Diver LB continued dive routine) Diver BF examined, no abnormality found.
Left	10 feet	16.12.00	Slow decompression started.

Position		Time	Notes
Arrived	6 feet	16.14.00	Pain unbearable, recompressed.
Arrived	18 feet	16.19.15	Recovered.
Left	30 feet	17.20.15	
Arrived	15 feet	17.42.00	"Bleed" halted as mild recurrence of pain in right knee, development of pain in right ankle, nausea and tightness of chest on respiration.
Left	15 feet	18.50.00	All gradually eased. Slow bleed.
Arrived	8 feet	20.17.00	Recurrence of ache in right knee. Bleed halted till eased.
Left	8 feet	20.50.00	Bleed restarted.
Arrived	4 feet	21.15.00	Restless. Pressure could not be maintained and "bleed" to surface. Exact time not known.
Opened doors		22.06.00	Examined, gait affected; basal râles; seemed in pain. Reported transient pains on arrival at every stop from 170 feet. Decided to recompress but on walking to chamber all signs and symptoms (except râles) cleared completely.
At	surface	22.30.00	

C. Special Routine 3

Divers FE and LS.

Chamber dive

Exercise - rowing machine

Position		Time	Notes
Left	surface	00.00.00	
Arrived	800 feet	00.23.15	Breathing 5% oxygen 95% helium.
Left	800 feet	02.00.00	
Arrived	490 feet	02.06.12	02.58. Diver LS nausea and vertigo then vomited several times in next hour after moving.
Left	490 feet	04.00.00	Condition unchanged 04.34 deafness suspected 04.40. Diver FE complained of giddiness on rising and later vomited.
Arrived	340 feet	04.03.00	
Left	340 feet	05.20.00	Recompressed.
Arrived	400 feet	05.21.20	FE recovered. LS improved steadily and went to sleep. Before ascent both seemed recovered.
Left	400 feet	07.22.00	
Arrived	340 feet	07.24.00	
Left	340 feet	09.22.00	
Arrived	260 feet	09.23.30	Changed to 10% oxygen 90% helium at 09.33.30.
Left	260 feet	11.33.00	

Position		Time	Notes
Arrived	190 feet	11.34.24	Change to 20% oxygen 80% helium FE 11.35 reported twinges both elbows, both knees; LS pain in right knee. Both shivering. Pain in LS persisted. Recompressed.
Left	190 feet	11.50.00	
Arrived	220 feet	11.51.07	LS relieved at 204 feet.
Left	220 feet	12.21.00	
Arrived	190 feet	12.26.00	
Left	190 feet	13.56.00	
Arrived	165 feet	14.01.00	FE twinges both knees.
Left	165 feet	14.31.00	
Arrived	140 feet	14.36.00	Both divers pain in knees. 15.32 both divers pain free. LS still has dizziness on rapid movement of head.
Left	140 feet	16.36.00	
Arrived	120 feet	16.42.00	Both men twinges in both knees, which cleared rapidly.
Left	120 feet	17.41.00	
Arrived	110 feet	17.47.00	Both men twinges in both knees which cleared rapidly.
Left	110 feet	18.46.00	
Arrived	100 feet	18.51.30	Similar episode. 1905 LS vomited
Left	100 feet	19.51.00	
Arrived	93 feet	19.54.00	Twinges recurred and became severe.

Position		Time	Notes
Arrived	100 feet	19.56.00	
Left	100 feet	20.56.00	
Arrived	90 feet	21.01.30	Twinges again present and cleared in about 1 hour.
Left	90 feet	23.01.00	
Arrived	80 feet	23.06.00	Similar episode. Examined 26.00.00.
Left	80 feet	29.06.00	
Arrived	70 feet	29.16.00	Recurrence of severe pain. Recompressed
Arrived	165 feet	29.21.55	Relieved at 100 feet.
Left	165 feet	31.22.00	
Arrived	140 feet	31.27.00	
Left	140 feet	32.27.00	
Arrived	120 feet	32.32.00	Both divers well except for slight dizziness in IS.
Left	120 feet	33.32.00	
Arrived	100 feet	33.37.00	
Left	100 feet	34.37.00	
Arrived	80 feet	34.42.00	FE suspicious of right knee.
Left	80 feet	35.42.00	
Arrived	70 feet	35.47.00	
Left	70 feet	36.47.00	
Arrived	60 feet	36.52.00	
Left	60 feet	37.52.00	

Position		Time	Notes
Arrived	50 feet	37.57.00	FE still restless after each reduction of pressure.
Left	50 feet	38.57.00	
Arrived	40 feet	39.02.00	FE reported niggle right knee which cleared in 3 minutes. Changed to 40% oxygen 60% helium.
Left	40 feet	40.02.00	
Arrived	30 feet	40.08.00	Both men trouble with knees - FE in right, LS in left but cleared rapidly.
Left	30 feet	46.08.00	
Arrived	20 feet	46.30.30	FE conscious of his right knee.
Left	20 feet	47.28.00	
Arrived	10 feet	47.49.00	
Left	10 feet	48.48.00	
Arrived	surface	49.11.00	
Doors opened		49.21.00	Both had niggles. LS unsteady gait. Examined by ENT. specialist - Right cochlear and vestibular damage.

D. Special Routine 4

Divers CR and HI.

Chamber dive

Exercise - rowing machine

Position		Time	Notes
Left	surface	00.00.00	
Arrived	700 feet	00.17.14	Breathing 5% oxygen/95% helium
Left	700 feet	02.00.00.	
Arrived	480 feet	02.04.24.	
Left	480 feet	04.00.00.	
Arrived	350 feet	04.02.36	
Left	350 feet	06.00.00	
Arrived	260 feet	06.01.48	Changed to 20% oxygen/80% helium
Left	200 feet	08.00.00	
Arrived	190 feet	08.01.24	
Left	190 feet	10.00.00	
Arrived	150 feet	10.01.48	HI developed pain in both knees steadily and CR suddenly hit by pain. Recompressed HI relieved by 185 feet, CR by 240 feet.
Arrived	260 feet	10.06.50	
Left	260 feet	12.06.00	
Arrived	225 feet	12.11.30	CR transient pain during ascent
Left	225 feet	14.11.00	
Arrived	185 feet	14.18.00	
Left	185 feet	16.11.00	

Position		Time	Notes
Arrived	155 feet	16.16.00	
Left	155 feet	18.11.00	
Arrived	125 feet	18.17.00	19.15 CR twinges in both legs
Left	125 feet	20.11.00	
Arrived	100 feet	20.16.00	21.54 changed to 60% oxygen/40% helium.
Left	100 feet	22.11.00	
Arrived	75 feet	22.16.00	
Left	75 feet	24.11.00	
Arrived	55 feet	24.16.00	CR tingly both hands became numbness.
Left	55 feet	26.11.00	HI slight tightness in chest before ascent.
Arrived	35 feet	26.21.00	HI niggle during ascent in left ankle.
Left	35 feet	28.11.00	
Arrived	20 feet	28.21.00	HI slight ache left knee radiating down to ankle. Chest tightness eased a little. CR slight ache right knee on arrival at each stop. Hands still reduced sensation.
Left	20 feet	30.11.00	
Arrived	10 feet	30.21.00	HI similar but a little more severe. CR similar in severity as previous.
Left	10 feet	32.11.00	
Arrived	surface	32.24.45	

Position		Time	Notes
Doors opened		32.30.00	HI very slight niggles in both knees which cleared in ½ hour. Chest hurts on coughing. CR fairly severe pain both knees steadily easing, loss of fine touch and thermal sense both hands. Chest hurts on coughing.
		34.30.00	HI dull ache both knees. CR limping on right leg. Numbness cleared to palmer aspects distal phalanges all fingers.
		48.00.00	HI minimal tightness in chest also in CR whose numbness i s q.

E. Special Routine 5

Divers IC and CW.

Chamber dive

Exercise - rowing machine

Position		Time	Notes
Left	surface	00.00.00	
Arrived	300 feet	00.07.50	Breathing 10% oxygen/90% helium
Left	300 feet	04.00.00	
Arrived	170 feet	04.02.36	Changed to 20% oxygen/80% helium.
Left	170 feet	06.00.00	
Arrived	100 feet	06.01.00	07.30 changed to 40% oxygen/60% helium.
Left	100 feet	08.00.00	
Arrived	70 feet	08.01.00	

Position		Time	Notes
Left	70 feet	10.00.00	
Arrived	45 feet	10.01.00	LC reported not too severe pain left knee but looked in severe pain.
Left	45 feet	10.17.45	Examined. Recompressed.
Arrived	70 feet	10.21.00	Pain relieved 57 feet.
Left	70 feet	11.22.00	
Arrived	60 feet	11.32.30	LC pain recurred but tolerable.
Left	60 feet	12.32.00	Slow bleed commenced with pauses.
Arrived	54 feet	13.00.00	
Left	54 feet	13.48.00	
Arrived	45 feet	14.05.30	LC slight increase in pain.
Left	45 feet	14.12.00	Increase in pressure to ease pain.
Arrived	50 feet	14.14.00	
Left	50 feet	16.15.00	In fact 48 by leak.
Arrived	40 feet	16.27.00	
Left	40 feet	16.27.00	
Arrived	34 feet	17.43.00	LC reported pain had moved round knee and more of an ache.
Arrived	30 feet	17.53.00	Bleed by leak.
Left	30 feet	18.53.00	
Arrived	20 feet	19.18.00	LC slightly worse but tolerable and cleared by 19.36.
Left	20 feet	20.18.00	
Arrived	10 feet	20.46.00	Slight leak. LC moving easily and weight bearing.

Position		Time	Notes
Left	8 feet	21.22.00	
Arrived	2 feet	22.02.00	LC slight increase in pain.
Arrived	surface	21.54.00	By leak.
Doors open		22.02.00	Both men slight chest pain on deep inspiration, otherwise well.