OBSERVATIONS ON SOME JAW RELATIONSHIPS DURING SWALLOWING AS RELATED TO PROSTHETIC DENTISTRY

by

William Ronald Edwards Laird
B.D.S. (U. Glas.), H.D.D.R.C.P.S. (Glas.),
F.D.S.R.C.P.S. (Glas.).

THESIS

Submitted for the degree of Master of Dental Surgery

in the University of Glasgow Faculty of Medicine.

May, 1973

OBSERVATIONS ON SOME JAW RELATIONSHIPS DURING SWALLOWING AS RELATED TO PROSTHETIC DENTISTRY

VOLUME I

The illustrations and tables are contained in Volume II of this work, and are arranged in sequence as they are mentioned in the text.

ACKNOWLEDGEMENTS

I should like to record my gratitude to Professor T. C. White, Director of Dental Education, Glasgow Dental Hospital and School, for the facilities extended to me during the course of this study. To Professor A. R. MacGregor, Professor of Dental Prosthetics, I am grateful for encouragement and advice.

Part of this work was carried out at the Institute of Dental Surgery, University of London, in both the Prosthetics Department and the Department of Materials, and I should like to thank the respective Heads of these Departments, Professor A. O. Mack and Dr. J. A. von Fraunhofer for their guidance and advice.

The fluorographic apparatus employed in the major part of the investigation has been only recently acquired at Glasgow Dental Hospital, and I am indebted to Dr. W. N. Mason, Head of the Radiology Unit for introducing me to the equipment and for instruction in its use. In a study such as this a high quality of radiographic image is essential, and this was ensured by the skill and patience of Miss A. Carson, Superintendent Radiographer, Glasgow Dental Hospital.

For instruction and technical assistance in photographic techniques, and for the photographic prints in Volume II, I should like to thank sincerely Mr. J. B. Davies, Senior Medical Photographer, Glasgow Dental Hospital. For her excellent artistic work my thanks are due to Miss M. J. Wallace.

I should like also to express my gratitude to my friends and colleagues both dental and non-dental who assisted me in various ways. In particular, Mr. J.C. Thomson for posing pertinent questions from time to time which stimulated my search for answers, Dr. M.H. Hussey for his suggestions, constructive criticism and constant encouragement, and Mr. G. Manson who designed the transmitting and receiving apparatus to suit my requirements.

Mrs. K. Walker and Miss J. Johnstone gave invaluable assistance with draft typing. For the final typescript I am indebted to Miss I. Langdon.

Finally there remains a group of 70 persons without whose co-operation, this work could not have been performed. To the volunteer patients, students and members of staff of Glasgow Dental Hospital who participated in the study I extend my warmest thanks.

PREFACE

The work on which this thesis is based has been performed over the past three years at the Dental Hospital and School, University of Glasgow, and the Institute of Dental Surgery, University of London. Some of the material contained in the study has been published, accepted for publication, or presented to a scientific meeting.

<u>Publications</u>

1. Measurement of occlusal tooth separation by means of electrical field variations.
   Laird, W. R. E., Manson, G., Davies, E. H. and von Fraunhofer, J. A.
   Bio-med. Engng. <u>6</u> : 504

2. Intermaxillary relationships during deglutition
   Laird, W. R. E.
   J. dent. Res. (in press)

<u>Presented to a Scientific Meeting</u>

* Intermaxillary relationships during deglutition.
Annual Meeting of the British Society for the Study of Prosthetic Dentistry. March 1972.

---

* Awarded the Reckitt Prize of the British Society for the Study of Prosthetic Dentistry.

DEFINITIONS AND TERMS

The following is a list of certain general terms used in this study. Other relevant terms are defined and discussed in later sections.

articulator	an instrument to which maxillary and mandibular casts are fixed to simulate the relationship of the dental arches and certain movements of the jaws.
complete denture	a denture replacing the entire maxillary or mandibular dentition and part of the supporting tissues of the teeth.
partial denture	a denture replacing the missing teeth and part of the supporting tissues in a dental arch in which some natural teeth remain.
denture bearing area	the oral structures which bear the loads applied to a complete or partial denture.
occlusion	contact between the masticating surfaces of mandibular and maxillary teeth.
balanced occlusion	a condition in which there are simultaneous contacts of the occluding surfaces of the teeth on both sides of the opposing dental arches when the mandible is in lateral or protrusive occlusion.

intercuspation	the interdigitation of cusps or parts of the cusps of opposing teeth.
median plane	a vertical plane drawn through the midline of the body dividing the body into right and left halves.
sagittal plane	a vertical plane through the body parallel to the median plane.
coronal plane	a vertical plane at right angles to the sagittal plane dividing the body into anterior and posterior portions.

ABBREVIATIONS AND SYMBOLS

The following abbreviations and symbols are listed in their order of appearance in the text. The list does not include the statistical abbreviations which are presented in Chapter 9 (Statistical Analysis).

mm	millimetre(s)
a. c.	alternating current
swg	British standard wire gauge
mA	milliamperes or milliamperage
d. c.	direct current
min	minute(s)
kV	kilovolts or kilovoltage
^oC	degrees Centigrade
μH	micro-henry (unit of inductance)
MH_z	mega-hertz (unit of frequency, 10^6 cycles per second)
UV	ultra-violet
$k\Omega$	kilo-ohm(s)
cm	centimetre(s)
in	inch(es)
lbs	pounds
kg	kilogram(s)
kgf	kilogram force.

ABSTRACT

This work has investigated some of the jaw relationships which may occur during swallowing in both dentulous and edentulous persons. The study was stimulated by an appreciation of the problems which may be encountered in the registration of correct relationships between the mandible and the maxilla when constructing dentures for edentulous patients. These relationships exist in both vertical and horizontal planes. When they are recorded incorrectly, it is a common clinical experience that the comfort and function of complete dentures is adversely affected.

Numerous methods are used to determine and record jaw relationships, and the literature on the subject is extensive. This literature has been reviewed and discussed and the various methods for recording jaw relationships have been summarised as a) non-functional methods, and b) functional methods.

Non-functional methods may be used either before or after extraction of the natural teeth. In general, however, they do not appear very reliable.

Functional methods are based on movements of the jaws and associated parts, in the edentulous state. They include speech, mastication and swallowing. Of these functions, swallowing is a simple and natural procedure which most persons can perform, is not easily disturbed and appears to be a particularly suitable method for recording jaw relationships of edentulous patients. The rationale behind this method is based on the belief that in dentulous persons, swallowing is accompanied by contact of the occlusal surfaces of the opposing posterior teeth. It is also believed that

in the edentulous state, the relationship of the mandible to the maxilla during swallowing is similar to that which occurs with the natural teeth present. The recording of this position therefore would permit a clinician to construct complete dentures to natural jaw relationships.

Reports regarding jaw relationships in dentulous persons during swallowing reflect a diversity of opinion, whilst the information regarding jaw relationships during swallowing for edentulous persons and persons wearing complete dentures is sparse and inadequate. The present study therefore, was directed to the investigation of jaw relationships during swallowing with particular reference to the incidence and position of occlusal tooth contact in dentulous subjects, and the level of vertical jaw separation in edentulous subjects. In addition observations were made regarding jaw relationships during swallowing in subjects wearing complete dentures, and the effect which certain modifications of these dentures had on the jaw relationships.

The major part of the investigation employed fluorographic techniques, although some investigations on dentulous subjects were performed using an intra-oral transmitting coil linked to a potentiometric recorder. In the fluorographic study, subjects were exposed to X-rays while swallowing water. An image was produced on a fluorescent screen and photographed by a television camera which was built into the apparatus. Viewing was carried out as sequences were performed and the television picture was also recorded on video tape for later analysis. The apparatus incorporated an electronic image intensifier, which by increasing the brightness of the fluorescent screen resulted in a considerable reduction in radiation dosage. Investigations, which were restricted to the sagittal plane, were performed on 70 volunteer subjects, both dentulous and edentulous.

Analysis of the results used both visual and measurement techniques. As direct measurement from the video tape was impossible, each sequence was filmed from the television screen using a 35 mm camera with a motorised transport system. A frame analysis was performed and in order to obtain more detailed measurements, prints were made from relevant frames. All measurements were made relative to an established reference position.

Errors in the materials used, the techniques employed and the methods of analysis were examined. It was concluded that errors in the materials used and measurement and observer errors in the techniques employed were small, and unlikely to have any appreciable effect on the results. The methods of analysis, however, occasionally demonstrated some bias towards the reference measurement and where present this has been stated. Random errors were also examined, and although they could not be entirely eliminated were controlled and considered to be minimal.

The results of the investigation on the selected sample of subjects confirmed the opinion that, in dentulous subjects, occlusal tooth contact does occur during swallowing. It was not present in all subjects however, and some subjects demonstrated contact in some swallowing sequences and not in others. The position of contact when present was normally with the teeth in the intercuspal position as defined in the study.

Edentulous subjects demonstrated a reproducible vertical jaw relationship during swallowing. This finding confirmed the rationale of using the action of swallowing to establish jaw relationships in the vertical plane.

In the majority of subjects wearing complete dentures swallowing was accompanied by occlusal tooth contact. The position of contact was normally with the teeth in maximum intercuspation. The modifications which were made to the dentures were found to be associated with a lower incidence of tooth contact.

The interpretation of these findings indicated that in many cases swallowing might be a suitable method of determining both vertical and horizontal jaw relationships when constructing complete dentures. It was also considered that use of the action of swallowing might be extended to permit continuous evaluation of the vertical dimension of complete dentures, as lack of tooth contact appeared to be associated with a reduction in vertical dimension.

In association with this study, investigations were performed regarding the suitability of waxes as a medium for recording jaw relationships by swallowing. The methods of investigation, results and discussion are presented in an Appendix to the study. An account of the technical problems encountered in obtaining photographic prints from the television screen is also presented as an Appendix.

SECTION 1

INTRODUCTION

CHAPTER 1

Background and Aims

BACKGROUND & AIMS

1.1 Background

Dental prosthetic treatment, in the form of complete or partial dentures, is designed to provide both visual and functional replacement for lost teeth and tissues. Successful visual replacement, although desirable, is of doubtful worth without an associated successful functional replacement. It is of little benefit to a patient to be aware that his dentures have a pleasing appearance, if he is unable either to eat or to speak without discomfort, when he is wearing them.

In order to ensure comfort and efficiency from a denture, it is important to make correct records of the relationship between the mandible and maxilla both vertically and horizontally. An incorrect recording may affect adversely both comfort and function of the finished denture, and it is a common clinical experience that a large number of complaints regarding dentures can be attributed to this.

A variety of techniques may be used to determine the correct jaw relationships of patients. It would appear, however, that if dentures are to be functionally satisfactory then a greater degree of success can be expected if these relationships are recorded with reference to natural movements of the jaws. Such movements include swallowing, speech and mastication. Of these swallowing is a simple and natural procedure which most patients can perform and when used as a clinical technique does not require any complicated instructions which may be associated with other techniques. Conflicting evidence has been produced in the literature, however, regarding jaw relationships during swallowing and for this reason the present study has been undertaken.

1.2 Aims of the Present Study

The aims of the present study were as follows :

i) to determine the incidence of occlusal contact of natural teeth during swallowing and the position of contact if and when it occurred;

ii) to determine whether or not a reproducible vertical level of jaw separation was present in edentulous subjects during swallowing;

iii) to determine the incidence of occlusal tooth contact of complete dentures and the influence of a reduction in the vertical dimension of occlusion;

iv) to observe the mandibular position in the sagittal plane at the end of the swallowing sequence.

Associated with the present study the properties of some materials used to record jaw relationships during swallowing were investigated to assess their accuracy and reliability.

CHAPTER 2

Jaw Relationships

JAW RELATIONSHIPS

2.1 Terminology

It is not uncommon in dentistry to find a variety of terms which lend themselves to the same definition. Such a situation gives rise to confusion and misunderstanding. In an attempt to avoid this, the terminology used in the present study is based on that recommended by the BRITISH STANDARDS INSTITUTION (1969), with a number of modifications which are discussed below.

The jaw relationship of a person is any relationship of the mandible to the maxilla in either a vertical or horizontal plane.

The rest jaw relationship is the relationship of the mandible to the maxilla when a person is in the upright posture, and the muscles controlling the mandible are in relaxed equilibrium.

Vertical jaw relationship in both sagittal and coronal planes is termed the vertical dimension, and is defined as a vertical measurement of the face between any two arbitrarily selected points which are located, one above and one below the mouth, usually in the midline. For each person, measurements of vertical dimension are infinite, dependent upon the degree of separation of the jaws. For practical purposes, however, they are reduced to two in number, one when the mandible is in rest jaw relationship, and one when the posterior teeth are in occlusion with maximum contact and intercuspation. The former is termed the rest vertical dimension and the latter as the vertical dimension of occlusion. The rest vertical dimension normally exceeds the vertical dimension of occlusion, the difference being accounted for by the presence of the interocclusal clearance (Fig. 1, 1a and 1b) which is the space between the maxillary and mandibular occlusal surfaces when the mandible is at the rest jaw relationship. This clearance has been estimated to be between 2 and 4 mm. (OSBORNE 1949, BERRY 1960, POSSELT 1968, MACK 1964) but may be as great as 8 mm. (ANDERSON and STORER 1966, VIERHELLER 1968). Its presence contributes to the success of complete or partial prostheses. If the vertical dimension of occlusion of complete dentures is excessive then the interocclusal clearance will be insufficient or even completely eliminated. Conversely, if the vertical dimension of occlusion is insufficient, the interocclusal clearance will be excessive.

Horizontal relationships of the mandible to the maxilla occur anteroposteriorly in the sagittal plane and laterally in the coronal plane. No general term exists to describe these horizontal relationships and it is difficult to define any specific or constant anatomical references. The range of anteroposterior and lateral mandibular movements is limited only by the temporomandibular joint, and associated muscles and ligaments. The BRITISH STANDARDS

INSTITUTION (B. S. I.) has described the horizontal relationships of the mandible as centric occlusion, centric jaw relation and eccentric jaw relation.

Centric occlusion is the relation of opposing occlusal surfaces which provide the maximum intercuspation and contact (B. S. I. 1969). It is dependent upon the presence of tooth contact, either natural or artificial, in the molar and/or premolar region of both the maxilla and mandible. It is essentially a relationship of the upper and lower teeth and may be better described by the term intercuspal position. As this term limits confusion by the elimination of the word "centric", it is the one which shall be used throughout the text to be synonymous with the definition of centric occlusion which is given above.

Centric jaw relation exists when the condyles are in the most posterior position in the glenoid fossae at the occluding vertical dimension (B. S. I. 1969). This has been described as the ligamentous position of the mandible (BRILL et al. 1959) as it was believed to be limited by the ligaments of the temporomandibular joint. Because of the permanency of the limiting joint structures it is repeatedly reproducible and is considered to be a reference which remains constant for each patient. BOUCHER (1961, 1962) did not agree that limitation of posterior mandibular movements was controlled by ligaments. He concluded, after examining patients who had their temporomandibular and capsular ligaments severed, that the posterior mandibular movements were controlled by the musculature.

Therefore the term "ligamentous position" might be questioned. ATWOOD (1968) observed that the importance of centric jaw relationship lay in its use as a reference for restoration of the occlusion. He was of the opinion that the movement of the temporomandibular joints was not controlled by ligaments alone, but by a combination of ligaments and muscles. Accordingly, he suggested that a more descriptive term might be the retruded contact position, as centric jaw relationship had no significance without occlusal contact. In the present study many jaw positions are recognised by occlusal contacts and the term retruded contact position will be used in place of the term centric jaw relation.

Eccentric jaw relation is any relation which is lateral, protrusive, or retrusive to centric jaw relation (B.S.I. 1969). It is generally accepted that these relationships are reproducible with a lesser degree of accuracy than either the intercuspal position or the retruded contact position.

2.2 The Significance of Jaw Relationships for Edentulous Patients

2.2.1 Vertical Dimension

The construction of complete dentures to an incorrect vertical dimension of occlusion is one of the most common causes of their failure (YOUNG 1949, MORRISON 1959, FENN et al. 1961, SWERDLOW 1965). It has been further observed (DOWNS 1963), that the establishment of the correct vertical distance between the maxilla and the mandible is one of the most perplexing problems in complete denture construction. It has been noted already that the vertical dimension of occlusion may be either excessive or insufficient.

Excessive Vertical Dimension

If the vertical dimension of occlusion of complete dentures is excessive, the patient may suffer discomfort in the load bearing area under the denture, and in severe cases traumatic bruising or ulceration may occur. If the interocclusal clearance is completely eliminated, muscle fatigue and clicking of the teeth on speaking is often observed. The general appearance of the patient is one of strain (Fig. 1, 2a and 2b). Difficulties of speech arise, especially in formation of the consonants "Th" where the tongue must move between the maxillary and mandibular teeth, "P, B, and M" where the lips must make contact, and "C, Z, S, J, and Ch" where teeth clicking may be extremely audible. This situation, if left untreated, may sometimes be resolved due to resorption of the supporting alveolar ridge (NISWONGER 1934, MCGEE 1947, OSBORNE 1949, SMITH 1958, NAGLE and SEARS 1962, BOUCHER 1963) and attrition of the acrylic teeth of the dentures (THOMSON 1967). Few patients, however, can tolerate the discomfort over the period of time necessary for this to occur. Resorption of bone in the denture bearing area may also occur, together with displacement of dentures into the mucosa of the denture bearing areas resulting in irritation and muscosal hyperplasia.

Insufficient Vertical Dimension

If the vertical dimension of occlusion is insufficient, the patient may experience muscular inefficiency (KOVATS 1967) as the muscles of mastication suffer some loss of power when they contract beyond normal occlusal level (BOOS 1940, THOMPSON 1946). Cheek biting may also occur as the cheeks may collapse into the space resulting from the excessive interocclusal clearance. In severe cases the patient exhibits an abnormal appearance (Fig. 1, 3a and 3b) with the forward posturing of the mandible necessary to achieve contact between the maxillary and mandibular teeth (CHICK 1949, LANDA 1954). At the angles of the mouth folds develop and become constantly bathed in saliva leading to breakdown of the skin, soreness and inflammation (MCGEE 1947). An insufficient vertical dimension of occlusion which persists for any length of time may also give rise to pain in the region of the temporomandibular joint (POSSELT 1962, NAGLE and SEARS 1962).

2.2.2 Horizontal Jaw Relationships

In the natural dentition the retruded contact position does not commonly coincide with the intercuspal position

(BRILL et al. 1959, POSSELT 1968). This discrepancy is considered to be a "minor malocclusion" (BOUCHER 1964) but can result in damage to supporting tissues of the teeth, damage which will become more apparent with age. In complete dentures, however, this discrepancy is avoided. The retruded contact position is recorded and casts are mounted in this position on an articulator. Teeth are then set in the intercuspal position, to coincide with the retruded contact position already recorded.

Eccentric jaw positions may be recorded by means of waxes or similar substances placed between the occlusal surfaces of the teeth or record blocks. These occlusal records are transferred to the articulator which can then be adjusted to simulate some of the condylar movements particular to that person (CHRISTENSEN 1905).

Incorrect Horizontal Jaw Relationships

In the construction of complete dentures the basic reproducible horizontal jaw relationship which is recorded is the retruded contact position. This recording is used to position casts on an articulator. Dentures constructed to this jaw relationship have teeth set to allow maximum intercuspation in the intercuspal position. In this way the recorded retruded contact position and the intercuspal position will always coincide on the articulator. If the retruded contact position is recorded incorrectly both positions will still coincide on the articulator, although they will not coincide in the mouth. If complete dentures are constructed to such a recording any attempt to retract the mandible to the retruded contact position will be resisted by the teeth at the intercuspal position. This can result in trauma and pain to the underlying mucosa, or varying amounts of displacement or shift of the dentures. Similar faults would be apparent in eccentric mandibular excursions, as a correctly balanced occlusion is firstly dependent on a correctly recorded retruded contact position.

It has already been noted that eccentric occlusal jaw records can be used to adjust the settings of an articulator. If complete dentures are made in this way, then the eccentric occlusion is more likely to be balanced than when the articulator has not been so adjusted. A balanced occlusion will reduce cuspal and incisal interference during mandibular excursions, interference which may cause instability of both maxillary and mandibular dentures, and traumatic lesions to the denture bearing mucosa.

2.2.3 Rest Jaw Relationship

It is only when the mandible is in rest relationship to the maxilla that the amount of interocclusal clearance can be determined. The rest relationship is not recorded by the clinician, but is used as a reference from which, according to the degree of interocclusal clearance present, he can assess the accuracy of the recording of the vertical dimension of occlusion.

The value of such a method of assessment is dependent upon the constancy of the rest relationship. The view in favour of constancy has been expressed by THOMPSON and BRODIE (1942), THOMPSON (1946) and LAST (1955). More recent studies, however, using radiographic and electromyographic techniques (OLSEN 1951, TALLGREN 1957, FISH 1961, 1964, HICKEY, et al. 1961, ATWOOD 1966) have demonstrated a variability in the rest relationship which renders it unsuitable for use as a reference.

2.3 Comment

There is little doubt regarding the importance of recording correct jaw relationships in prosthetic dentistry. The situation is well summarised by BERRY (1960) who stated that "more dentures fail from wrong jaw relationships than from any other cause", and observed that the procedures used in 1960 for recording jaw relationships were no more scientific or precise than they were 100 years ago. This statement could well be repeated today.

It seems reasonable to state therefore, that in order to construct dentures which satisfy the basic requirements of comfort, appearance, and function, more attention should be given to finding a precise method of recording vertical and horizontal jaw relationships.

SECTION 2

REVIEW OF THE LITERATURE

CHAPTER 3

Recording Jaw Relationships

INTRODUCTION

The review of the literature is divided into three chapters, the first is a general description of the methods available for recording jaw relationships, whilst the second comprises a detailed review of the correlation between swallowing and jaw relationships. The final chapter is a brief account of methods of obtaining data regarding mandibular movements and jaw relationships.

RECORDING JAW RELATIONSHIPS

3.1 Introduction

The recording of jaw relationships for edentulous patients involves the use of record blocks, which are constructed on casts of the maxillary and mandibular denture-bearing areas. These blocks should have firm well-fitting bases which will not distort in the mouth. Bases are commonly formed in acrylic resin, although many clinicians use wax or shellac resin for reasons of speed and simplicity. The occlusal rims of the blocks may be formed in impression compound, a mixture of pumice and plaster of Paris or, most commonly, wax.

When recording the jaw relationships for a patient, the rims of the maxillary and mandibular blocks are carved until they meet evenly at what is considered to be the correct vertical and horizontal jaw relationships. They are then sealed together to provide a record. This stage in the construction of dentures is subject to a certain degree of error, and it is not surprising to find reported a variety of techniques which are available to achieve a similar end result.

3.2 Vertical Dimension

KURTH (1959) has stated that if any one method for the determination of vertical dimension for the edentulous patient were the most accurate, then that would be the technique which should be used. When one considers the large variety of techniques which are used to record the vertical dimension, it is apparent that no single approach has, as yet, been considered absolutely reliable. A technique found satisfactory by one operator may be considered unsatisfactory by another, or alternatively may be satisfactory when used for one patient and unsatisfactory when used for another. Combinations of techniques are often used in the search for accurate results.

Aids in the determination of vertical dimension include facial measurements (both pre- and post-extraction), functional mandibular movements, and facial appearance. A further method exists whereby a patient may select his own vertical dimension according to memory or comfort. Recordings of vertical dimension by these methods are with respect to the vertical dimension of occlusion.

3.2.1 Facial Measurements

A. Pre-extraction

Accurate facial measurements may be obtained from records made prior to extraction of teeth, and it has been advocated that this should be a regular procedure (TURRELL 1955).

Earlier workers (WILLIS 1930, WRIGHT 1939, BOYLE 1947) suggested that pre-extraction photographs of patients should be taken, reference being made to these at a later date in the construction of complete dentures.

A photograph of an anterior facial view could be enlarged to natural size by locating specific anatomical references, measuring the distance separating them, and reproducing this in the photographic print. The references suggested were the pupils of the eyes, their distance apart being known as the interpupillary distance. Dentures were constructed for the patient in order that the brow-chin distance on the patient equalled the brow-chin distance on the photograph. If smaller prints were used the same result could be achieved by the application of arithmetical proportion between similar anatomical references on the patient and on the photograph.

Photographs could also be taken in profile at the vertical dimension of occlusion, accurate enlargement being achieved by including a ruler at the time of exposure (BOUCHER 1970). Other methods of recording the facial profile of a patient included lateral radiographs (WILLIS 1930, DOUGLAS and MARITATO 1967) moulding galvinized iron or soft lead wire to the face from the forehead to the chin (MERKELEY 1953, FENN et al. 1961) a cardboard profile tracing (TURNER 1969) or by making a profile impression in hydrocolloid using contoured plumber's pipe strapping to simulate a tray (SMITH 1971). The latter technique could be extended to include an impression of the whole face, a cast poured from this impression being used to construct a face mask in clear acrylic resin. This had an advantage over the other techniques as it not only registered a brow to chin profile recording, but also provided a guide to the restoration of appearance if the clinician was later presented with a collapsed facial contour.

From all profile work, an anatomical template of the pre-extraction profile of the patient may be constructed, and subsequent dentures designed to restore the facial contour to this profile.

Direct measurement of the vertical dimension of occlusion together with the position of the upper central incisors may be made using the dakometer (Fig. 2,1). This instrument consists of a carrier to convey impression compound to the bridge of the nose, an adjustable chinpiece, and an attachment to record the position of the mesio-incisal point of the upper central incisors. The latter two components are adjustable along a vertical scale calibrated in millimetres. The readings obtained are entered in the patient's treatment card and the compound impression is preserved. Subsequently, dentures can be constructed to these dimensions, by re-assembling the instrument and using it for guidance.

An instrument (Fig. 2,2) which used principles similar to the dakometer was the Willis gauge (WILLIS 1930), which consisted of a scale graduated in millimetres with a fixed arm (A) and a movable arm (B). The fixed arm was placed at the base of the nose and the movable arm in contact with the skin of the lower border of the mandible and the intervening distance was measured. The vertical dimension of occlusion was thus recorded and reproduced later in complete dentures.

Permanent references have been produced by intra-epithelial injection of Indian ink into the labial mucosa of both the mandible and the maxilla, occlusal to the mucogingival junction (SILVERMAN 1950). This technique was modified by TURRELL (1955) who marked the most occlusal point of attachment of the labial mandibular and maxillary frena with an indelible pencil, which avoided permanent marking. It was claimed that the permanency of the frena allowed the marks to be reproduced accurately at any time. In both these methods measurement of the distance between the points at the vertical dimension of occlusion was recorded, and dentures could be constructed in the future with a vertical dimension of occlusion which corresponded to the recorded measurements.

One method which did not involve complex procedures or instrumentation made use of dental casts in occlusion. Impressions, together with a wax record of the teeth in the intercuspal position, were taken prior to extractions. Casts of the patient's mouth were poured from these impressions and mounted in the intercuspal position on an articulator. This method provided not only a record of the vertical dimension of occlusion, but also a guide to the positioning of the artificial teeth. A refinement of this technique has been described by HEINTZ and PETERS (1959) who mounted teeth from the casts directly on to record blocks and claimed to reproduce accurately both vertical dimension and tooth position.

Comment

Photographic techniques are time consuming and subject to considerable error. Enlargement of prints and comparison between photographs and face requires reliable stable anatomical references. The variability of the soft tissues of the face resulting from age changes, emotion, illness or trauma, coupled with the difficulty in obtaining a straight line measurement over a contoured surface suggest that references on the face are neither reliable nor stable. The suggested use of the pupils of the eyes, which are movable references, would appear to be even less reliable.

Radiographic techniques will provide anatomical references on bone from which measurements can be made (BJÖRK and PALLING 1955, NYLÉN 1961). It may be difficult, however, to ensure that the head of the subject is in exactly the same position if repeated exposures are required. Practical complications also exist with regard to radiation hazards to patients, although the use of intensifying screens results in a considerable reduction in dosage. The method is inaccurate, however, as bony reference points cannot be located to the surface of the face with any certainty.

All measurements of facial profile suffer from the fact that recordings are made on soft tissues, and these are subject to displacement by the recording apparatus, which may be as great as 2 mm in the vertical plane (TURRELL 1972). In an investigation into the accuracy of the Willis gauge (MCMILLAN and IMBER 1968) it was demonstrated that from 53 clinicians, not one was able to record three identical measurements on a patient with her mandible at the vertical dimension of occlusion. Variations between measurements were often greater than the expected interocclusal clearance. It is possible that the dakometer might produce a more accurate recording as the carrier and chinpiece are positioned at the bridge of the nose and at the lower border of the mandible, areas with relatively little soft tissue coverage. FENN et al. (1961) stated the error of the dakometer to be only $\pm$ 1 mm, which is perhaps misleading, as when compared to an interocclusal clearance of 2-4 mm, it represents anything from a 25% to 50% error.

Intra-epithelial markings may be useful provided the attached mucosa remains tightly bound to the underlying bone. If the bone undergoes resorption the problem of locating references on movable tissue will again arise. Frenal markings have been admitted by TURRELL (1955) to be less accurate than intra-epithelial markings.

The simplest and most reliable method of making pre-extraction records appears to be the mounting on an articulator of casts of the teeth in the intercuspal position, so eliminating some of the variability resulting from recordings on movable tissues.

In spite of the considerable attention given to methods of recording pre-extraction measurements the final point of evaluation considers not so much the reliability of the techniques described, but whether or not it is desirable to construct complete dentures to pre-extraction measurements. From the literature reviewed it is clear that there is a school of thought in favour of this, but more recently other investigators (OLSEN 1951, TALLGREN 1957, HICKEY et al. 1961, ATWOOD 1966, NAIRN and CUTRESS 1967) have demonstrated that changes in facial vertical dimension commonly occur after extraction of the teeth. In the light of these disclosures it would appear that routine construction of complete dentures to pre-extraction measurements may be contra-indicated.

B. Post-extraction

Other methods of recording vertical dimension must be employed if the patient is already edentulous when presenting for treatment. It has been suggested (WILLIS 1935) that when the distance from the base of the nose to the lower border of the mandible was equal to the distance from the pupil of the eye to the parting line of the lips, the correct vertical dimension had been reached. KANTOROWICZ (1932) considered vertical dimension to be correct when the lower third of the face was equal to the length of the nose. The use of either of these techniques requires modification of the dentures or record blocks until the suggested situation is reproduced at the vertical dimension of occlusion.

NAGLE and SEARS (1962) suggested that the correct distance between the maxilla and mandible at the vertical dimension of occlusion was often present when parallelism existed between the edentulous alveolar ridges of the maxilla and mandible. Although difficult to determine with record blocks in the mouth, the presence of parallelism could be verified after the casts had been mounted on an articulator.

A further method of obtaining the vertical dimension was put forward by MCKEVITT (1957), who advocated that the maxillary record block should be carved until the desired lip contour was obtained and then reduced until it was 1 mm short of the upper lip line with the lip in repose. The maxillary occlusal plane was determined by trimming the posterior rim of the block parallel to a line from the ala of the nose to the tragus of the ear. The lower rim was similarly marked and trimmed and the blocks were sealed together in the mouth.

Several authors (CRADDOCK 1956, LAMMIE 1956, FENN et al. 1961) have suggested that the vertical dimension of occlusion may be obtained by reference to the rest vertical dimension. In this method a vertical distance between the jaws was first measured at the rest vertical dimension. The occlusal rims of record blocks were trimmed until they contacted evenly at that dimension. By then reducing the lower occlusal rim by 2-3 mm, the interocclusal clearance and the vertical dimension of occlusion was established.

Comment

All the post-extraction techniques described are rather haphazard and unsubstantiated by scientific evidence. It has been observed (WILLIS 1935) that the facial proportions are affected by fractured teeth, malocclusion, gross attrition, and gross irregularity of teeth. HARVEY (1948) demonstrated that the equality of measurements suggested by WILLIS (1935) occurred in only 27% of cases, whilst BOWMAN and CHICK (1962) found equality in only 9% of cases.

This evidence, together with the work of TALLGREN (1957) and NAIRN and CUTRESS (1967) who demonstrated changes in both vertical dimension of occlusion and rest vertical dimension with ageing and following the extraction of teeth, indicates that the method is unreliable.

The theory of parallelism was based on the belief that at the vertical dimension of occlusion with natural teeth, the occlusal plane of the maxillary teeth was parallel to the occlusal plane of the mandibular teeth. It does not follow, however, that after removal of the teeth the residual ridges are necessarily parallel. Most people lose teeth at isolated times and this together with variations in the amount of bone resorption may produce an alveolar ridge which is no longer parallel. It is also difficult to apply the word "parallel" to a pair of surfaces like the jaws which are essentially curved or rounded. This technique and that advocated by MCKEVITT (1957) can only be described as a rough method of estimation, whilst measurement of the rest vertical dimension, by virtue of the fact that it involves soft tissue measurement, is also inaccurate. (McMILLAN et al. 1970)

3.2.2 Functional Mandibular Movements

Complete dentures are designed not only to replace lost teeth and tissues, but also to restore the function of the stomatognathic system. Functional actions such as swallowing, mastication, speech and biting should be performed without discomfort or displacement of the dentures. It is an awareness of this that has led some clinicians to include tests of function when recording vertical dimension, and in some cases to use these tests to establish the vertical dimension of occlusion for each patient.

NISWONGER (1934) observed that in dentulous patients during a sequence of swallowing the mandible moved vertically upward from the "rest" jaw relationship, the mandibular teeth contacted the maxillary teeth, and the mandible returned to the "rest" position. Awareness of this has encouraged many authors (HARPER 1942, SHANAHAN 1955, 1956, MALSON 1960, VIERHELLER 1968) to use swallowing as a method of obtaining the vertical dimension of occlusion for patients. The technique will be fully discussed later in the text (Chapter 4).

The method of obtaining vertical dimension by the action of speech has been described by SILVERMAN (1953, 1956). According to the latter, approximately 44 phonetic sounds exist in the English language, and pronounciation of these requires various levels of jaw separation. The closest vertical level of the mandible to the maxilla occurs with one or more of the six sibilant sounds. Practical use is made of this fact by asking patients to say words like "Mississippi" or "sixty-six" (MORRISON 1959). If the vertical dimension is excessive the teeth or blocks will contact and the subjects will be unable to enunciate the words. If, conversely, the vertical dimension is insufficient then an excessive speaking space is seen. SILVERMAN suggested that when saying a single word some voluntary control over the mandible could be exerted. During rapid speech, however, he believed that such control was lost, and accordingly tested the success of the technique by asking the patient to read aloud rapidly from any convenient publication.

These methods aid the establishment of a vertical dimension by utilising the action of the mandible and its associated musculature during speech.

The biting power of a patient was considered by BOOS (1940) to be a possible method of determining vertical dimension. The level at which resistance was met when the contraction of the masticatory muscles provided a biting force, was determined by the contact of the complete dentures at their vertical dimension of occlusion. BOOS was of the opinion that a critical point existed in the distance from the origin of a muscle to its insertion, at which it could exert its greatest force of contraction. If this distance were shortened or lengthened then the muscle would lose some of its efficiency. In the construction of complete dentures the maximum biting force was found to occur at the rest vertical dimension in a horizontal position protrusive to the retruded contact position (BOOS 1956). If this point was recorded by biting, then the resultant vertical dimension could be reduced by 1.5 - 2.25 mm to give the correct vertical dimension of occlusion.

Comment

If the theory behind the physiology of swallowing is correct, then it appears to offer a simple method whereby a patient can establish his own vertical dimension of occlusion. Evaluation of this technique and its rationale will be fully discussed in Chapter 4.

The use of phonetic principles as an aid to the determination of the vertical dimension of occlusion is mentioned in many text-books on prosthetic dentistry. It appears to be a technique used to locate errors in a tentative vertical dimension of occlusion, rather than to provide a definite recording.

GEISSLER (1971), however, has cast doubt on the constancy of the closest speaking space and has noted variations of 1.5 mm in vertical mandibular movement in a single patient during the 'S' sound. Excessive emphasis therefore should not be placed on the sole use of speech when establishing a vertical dimension of occlusion, although it may be a useful aid.

Recording the vertical dimension of occlusion by biting power has been questioned by BOUCHER et al. (1959) who observed that the vertical dimension obtained by biting power was greater than that determined either clinically or electromyographically. KURTH (1959) also noted that serious errors could occur because differences between pressures at various vertical dimensions were so minimal that accurate measurement was difficult. O'ROURKE (1949) pointed out that many factors were uncontrollable, and that results could be unreliable. TUELLER (1969) however, demonstrated a similarity between a vertical dimension of occlusion established by biting power and those established by other methods. He did admit, however, that his recording apparatus had a distracting influence on the patients.

3.2.3 Facial Appearance

The appearance of the face with the record blocks in position may give a guide to the correct vertical dimension of occlusion (SMITH 1958, ANDERSON and STORER 1966). Excessive vertical dimension results in a strained appearance of the circumoral tissues, and may make lip contact difficult to achieve. Conversely a collapsed facial contour combined with forward posturing of the mandible, occurs when the vertical dimension of occlusion is insufficient (CHICK 1949).

Comment

Facial appearance is often a successful guide to vertical dimension (ANDERSON and STORER 1966, TURRELL 1968) but it is dependent on the buccal and labial contour of the record block and its periphery. It is very much a matter of opinion of the individual clinician, and is an artistic rather than scientific guide.

3.2.4 Comfort and Memory

LYTLE (1964) and TIMMER (1967) described similar techniques which permitted a patient to select a vertical dimension of occlusion according to comfort. It was believed that patients could recognise a correct vertical dimension of occlusion if they had previously been subjected to an incorrect one. The patient was given experience of both an insufficient and excessive vertical dimension of occlusion. Extreme values were unacceptable but by gradual vertical alterations the patient could distinguish a preferential vertical dimension of occlusion using his own neuromuscular perception.

MILLER (1966) considered that patients had the ability to locate their own vertical dimension of occlusion by memory. He encouraged patients to bite into an air filled cushion, and expected that this action would terminate at the previous vertical dimension of occlusion.

Comment

The problems of discomfort resulting from an incorrect vertical dimension of occlusion have already been discussed. This does not necessarily mean that when discomfort is removed then the vertical dimension of occlusion is correct. Furthermore, TIMMER has noted that patients may be comfortable over a range of vertical dimension and has stressed that three separate determinations are necessary, the final vertical dimension of occlusion being the average recording.

The reliability of a patient's memory of jaw position appears to be doubtful in the light of findings regarding changes in resting and occlusal face height to which reference has already been made. TIMMER (1967) has also demonstrated that patients were unable to remember either their natural vertical dimension of occlusion or that of any previous dentures.

3.3 Horizontal Jaw Relationships

If an adjustable articulator is used then the horizontal relationships which may be recorded are the retruded contact position together with lateral and protrusive mandibular positions. If the articulator has an average condylar movement the retruded contact position is the only relationship which need be recorded. These records, which are used to locate the casts in position on the articulator, may be made in various materials, the most common being wax or plaster of Paris.

Although the retruded contact position is reproducible, this is not necessarily so for eccentric mandibular positions. Indeed CRADDOCK (1949) considered the recordings of these eccentric positions so unreliable as to be practically worthless, and the idea of relying entirely on the so-called Christensen phenomen (CHRISTENSEN 1905) is no longer accepted as accurate.

Wax records had been condemned earlier as leading to great error (GYSI 1929) and it was suggested that plaster of Paris would be a more suitable recording medium. Nevertheless intra-oral recording techniques are widely taught, and more recent work (SKURNIK 1969, FRAZIER et al. 1971) indicates that both wax and plaster records are useful as a means of recording jaw relationships.

The most important horizontal jaw relationship is the retruded contact position as it can be repeated consistently, and is therefore a constant anatomical reference (BOUCHER 1963, RAMFJORD and ASH 1971), and the most reliable position used to relate the mandible to the maxilla (WIRTH 1971). The difference between the retruded contact position and the intercuspal position has been discussed (Chapter 2). SILVERMAN (1957) has pointed out that the disharmony between the two positions is not as great as some clinicians believe, and that the intercuspal position and the retruded contact position should in fact coincide - that is that they are one and the same position. This is achieved in the edentulous patient by recording the retruded contact position, mounting casts on the articulator in that position, and then setting the teeth to provide maximum intercuspation.

The retruded contact position can be established accurately (INGERVALL 1964) and it follows that techniques to record the position lay emphasis on the resultant accuracy. The methods of recording this position in edentulous patients may be described as either functional or non-functional. Regardless of the method used, however, it is essential that the bases of the record blocks are well fitting with optimum tissue coverage to aid retention and stability (WRIGHT 1939, KAPUR and YURKSTAS 1957).

3. 3. 1 Functional Recordings

Functional records of horizontal jaw relationships may be produced by mandibular movements associated with specific actions such as biting, chewing and swallowing.

It was demonstrated by KURTH (1942) that the closing jaw movement in mastication was a retrusive one. This, together with the observation of LAMMIE and OSBORNE (1954) led SILVERMAN (1957) to advocate that the retruded contact position could be obtained by allowing a patient to close with maximum power, which would allow the forces of the closing musculature to place the mandible in the most retruded position. Earlier work by BOOS (1940, 1943) had suggested that in the majority of people the mandible should exert maximum power at or close to the retruded contact position. Record blocks can then be sealed in this position with wax or plaster of Paris.

Chewing movements may be recorded by tracing devices which make use of the lateral mandibular movements which occur during chewing (BALKWILL 1866, GYSI 1910, STANSBERY 1929, MATTHEWS 1944). The resultant tracing is referred to as an arrowhead or Gothic arch tracing because of its similarlity in shape to these structures. When making such a record the occlusal rims should be adjusted to the position considered to be the correct vertical dimension of occlusion for the individual. A stylus is mounted on either block, and a table coated with carbon on the opposite block. As the patient moves his mandible into left and right lateral excursions a line tracing is produced on the carbon table for each excursion. The point of intersection (the apex point) of these tracings should coincide with the retruded position of both condyles. The blocks may be located at this position by drilling a small hole with which the stylus can engage. In order to minimise unequal pressures or displacement of the blocks during tracing a central bearing device may be included.

A variety of instruments have been devised to determine the retruded contact position in this manner (BOUCHER 1970), but each is based on the same fundamental principle.

During the process of swallowing in dentulous patients NISWONGER (1934) observed that the maxillary and mandibular teeth contacted in the retruded contact position. The application of swallowing action to determine the retruded contact position will be discussed in the following chapter.

Comment

Doubt has been cast on the method of recording the retruded contact position by the exertion of maximum biting power. BOOS(1956) found that although he was able to demonstrate 65% of patients who registered a maximum power point close to the apex of an arrowhead tracing, the remainder (35%) registered a maximum power point which showed lateral or protrusive deviations of up to 7 mm from the apex point. SILVERMAN (1957) showed similar discrepancies although of a lesser magnitude (3 mm), and also noted that some edentulous patients were able to exert their maximum biting power in various positions. These discrepancies indicate a considerable lack of the precision which is required when recording the retruded contact position, and the method would appear to be unreliable.

The success of chewing techniques is dependent upon the patient and his co-operation. If the patient is permitted to make uncontrolled movements of the mandible while the blocks are in position, inaccuracies might be expected due to possible displacement of the record blocks (SMITH 1941). The belief that the apex of the arrowhead tracing corresponds to the retruded contact position has also been questioned. In a study of 5 edentulous subjects PAYNE (1969) demonstrated that although the apex point was constantly reproducible, it did not indicate the most retruded contact position of the mandible. In each case the mandible could be moved distally 0.2 mm from the apex point which he considered more likely to represent the intercuspal position. Although considered ideal by many clinicians (MOYLAN, 1953) the reliability of this method must be questioned.

3.3.2 Non-functional Recordings

In a non-functional recording, record blocks are placed in the mouth, the mandible is retracted to the retruded contact position, and the blocks are united intra-orally to provide a record of the jaw relationship. Difficulty is sometimes experienced however in the retraction of the mandible to the retruded contact position. This has been suggested by BOUCHER (1970) as being due to a lack of synchronisation between the muscles of protrusion and retrusion, and the difficulty increases as a patient continually loses more teeth before eventually becoming edentulous. Accordingly, more than one technique is used to assist the patient to retrude the mandible. Protrusive and retrusive mandibular exercises may result in the retruded position being eventually attained by virtue of the fact that the muscles of mastication, particularly the lateral pterygoid muscle, become fatigued. If this is unsuccessful, then repeated tapping together of the occlusal rims may cause the centre of muscle pull to return the mandible to the retruded contact position. Further muscular assistance includes placing the tip of the tongue at the posterior border of the upper base before closing, or tilting the head backwards. The former tends to retrude the mandible by a simple pulling action of the genio-glossus muscle, and the latter produces tension on the submandibular muscles which tend to pull the mandible to a retruded position.

Whether or not the mandible is correctly retruded may be checked by palpation of the temporal muscles which do not function in a protrusive position. This is purely a clinical guide and will indicate a position which is <u>approximately</u> the retruded contact position.

Once the clinician is satisfied that the mandible can be retruded, the desired position is recorded intra-orally with record blocks. The rims are carved until an even interocclusal contact is obtained at the correct vertical dimension, after which they may be sealed together using wax or plaster of Paris. Conflicting opinion exists as to whether blocks should contact with minimal pressure (WRIGHT 1939, JARVIS 1963, BOUCHER 1970) or with a functional load such as might be recorded in a "closed mouth" impression technique (SCHLOSSER 1931, WATT 1952). Excess pressure may cause unequal tissue displacement and error resulting from the resilient effect of the compressed tissue (HANAU 1923). If softened wax is used when sealing the blocks, the force required to deform it may cause tipping (BOOS 1956), or pressure which will cause activity in the muscles of mastication (SHPUNTOFF and SHPUNTOFF 1956). Plaster will reduce such problems if used before initial setting takes place. Whether wax or plaster is used, the mandible and record blocks must be maintained in position by the clinician until the material has finally hardened.

Comment

The variety of methods suggested to obtain and record the retruded contact position by non-functional means merely serves to emphasise the difficulty and lack of certainty of obtaining an accurate recording by any one method. Establishment of the retruded contact position by the carving of occlusal rims may lead to error, as interceptive contacts are difficult to detect, and slipping between the occlusal planes may occur (KURTH 1959, JARVIS 1963). Softened wax rims can also be condemned due to the possibility of uneven softening, differential rates of cooling, and visco-elastic properties of wax.

SIMPSON (1939) has condemned non-functional methods as unscientific and subject to guesswork. In addition, the fact that the operator is, to a certain extent dependent upon the patient's understanding of what is required makes these methods unreliable.

CHAPTER 4

Swallowing and Jaw Relationships

SWALLOWING AND JAW RELATIONSHIPS

4.1 Introduction

Swallowing is a physiological action which is established in utero by the action of the foetus in drinking amniotic fluid (KEELE and NEIL 1971). In man it is performed intermittently throughout the twenty-four hours of the day and night, and the number of swallows per 24 hours has been quoted from 600 (FLANAGAN 1963) to 1,200 (KYDD and NEFF 1964). The rate is greatly decreased during sleep (FLANAGAN 1963). Although a complex action requiring co-ordination of activity of a number of reflex arcs (SCOTT and DIXON 1972), it requires no learning and can be performed by patients suffering from pathological conditions and developmental anomalies (SYROP 1953) provided that the pathway for passage of food and liquids is not blocked. Once swallowing commences, it is not readily suspended by any voluntary action (SCOTT and DIXON 1972) and of the various functions associated with mastication it is least easily disturbed (SILVERMAN 1961).

It is divided into three separate stages : oral pharyngeal, and oesophageal (JOFFE 1961, JENKINS 1966, POSSELT 1968). The present study is applied to the oral division. In order to appreciate the assocation between swallowing and jaw relationships, the mandibular positions in dentulous persons before and after swallowing must be considered. Immediately prior to swallowing the mandible is normally at the rest vertical dimension with the occlusal surfaces of the maxillary and mandibular teeth separated by the extent of the interocclusal clearance. As a patient swallows, contraction of the elevating muscles occurs, and the mandible moves towards the maxilla assuming a new temporary relationship to it. This relationship is thought to be at the occlusion of the maxillary and mandibular teeth (GILLIS 1941, RUSHMER and HENDRON 1951, POSSELT 1968).

For correct function it is preferable that dentures are constructed to conform to the oral physiological pattern of the patient, and this should include a jaw relationship which will permit swallowing without excess loading of supporting tissues or strain on the oral musculature. SHANAHAN (1955, 1956) has suggested that in the process of swallowing saliva, the mandible leaves its rest relationship and rises to the natural vertical dimension of occlusion and is also pulled backwards to its retruded contact position. He suggested that there exists the practical application of using swallowing as a means of determining the jaw relationship in edentulous patients. Furthermore, if the jaw relationships of a patient could be precisely determined during the act of swallowing, these would be the most acceptable jaw relationships for the construction of complete dentures.

4.2 Occlusal Tooth Contact

There is doubt as to whether or not occlusal tooth contact occurs during swallowing. The position of contact has also given rise to discussion and has been described variously as the retruded contact position, the intercuspal position, and a position somewhere between the retruded contact and intercuspal positions (GRAF and ZANDER 1963, RAMFJORD and ASH 1971). JANKELSON (1953) stated that "only during deglutition does tooth contact occur as a functional act". RUSHMER and HENDRON (1951) and WARD and OSTERHOLTZ (1963) stated that, in preparation of propulsion of food or fluids into the pharynx, the mandible in dentate patients is stabilised in an occluded position. PAMEIJER et al. (1968) considered that in "most instances" teeth contacted while swallowing, whilst ARDRAN and KEMP (1955) found that in "many instances" teeth were not brought into contact. Other studies (CLEALL 1965, MØLLER 1966, INGERVALL et al. 1971) have shown a high incidence of occlusal tooth contact during swallowing but have noted that it is not invariably present.

Earlier, RIX (1946) had described the oral physiology of the basic or refreshing swallow which was merely the swallowing of saliva in the mouth, but noted, however, that this could be modified when eating or drinking. He stated that during a basic swallow with a complete natural dentition, the mandibular teeth were brought into occlusal contact with the maxillary teeth. Some children however exhibited an "atypical" swallow, where the mandibular and maxillary teeth never contacted and extreme difficulty was experienced if an attempt is made by these children to achieve contact. In a group of 93 children he found that only 61 (65.6%) swallowed with their teeth in occlusion, the remainder exhibiting varying patterns of tooth contact, or no tooth contact at all. More recently RAMFJORD and ASH (1971) have stated that during swallowing the teeth are pressed together after the mandible has been stabilised in a posterior position. The contact is not always in the retruded contact position but may be somewhere between it and the intercuspal position. If cuspal interference occurs at the retruded contact position then a second swallow in the intercuspal position will often follow immediately. GRAF and ZANDER (1963) showed contact in both positions in 4 out of 5 subjects, but noted that the longest contacts were seen in the intercuspal position. Contact was found to occur more commonly in the intercuspal position than in retruded contact position by PAMEIJER et al. (1970). Contact during swallowing was not present in all cases, RAMFJORD and ASH (1971) in particular, stating that drinking of liquids is often done with the teeth apart, the jaws being stabilised by the tongue or lips.

4.2.1 Comment

Occlusal tooth contacts during swallowing

Due to the small number of patients studied by GRAF and ZANDER or PAMEIJER et al., it is difficult to draw definite conclusions. From the survey of RIX, however, it might be expected that if adult swallowing followed the same pattern as the swallowing of children, then natural occlusal contact during swallowing would occur in 65.5% of persons. The reliability of the figures in the survey are, however, open to question. Results are presented purely from clinical inspection which must be extremely difficult due to the possibility of the view of the teeth being interrupted by movements of the lips and tongue. The lack of any measuring devices or double determination techniques of assessment, also increases the possibility of observer error.

4.3 The Vertical Dimension of Occlusion

SHANAHAN (1955) stated that "the constant function of swallowing saliva is the basis for establishing the mandibular positions and occlusion". Swallowing is commonly used to establish the rest jaw relationship by the mandibular relaxation which follows a swallow (NISWONGER, 1934, TALLGREN 1957, FENN et al. 1961), but SHANAHAN was making use of this function to determine the mandibular position of occlusion (the vertical dimension of occlusion). This was based on the belief that in the dentulous patient, light occlusal contact occurred during swallowing and that this situation should be reproduced in complete dentures. The theory that the vertical dimension during swallowing should be equal to the vertical dimension of occlusion was therefore being assumed.

The method employed by SHANAHAN involved the determination of a tentative vertical dimension of occlusion with wax rims by any technique other than swallowing. Casts and rims were mounted to this registration on an articulator. The lower occlusal rim was reduced by 3 mm and a cone of soft wax placed on its occlusal surface in the midline. After placing the rims in the mouth, the patient was requested to swallow several times. By this means, the height of the cone of wax was reduced until it contacted the upper rim at the natural and physiological vertical dimension of occlusion.

The accuracy of the swallowing technique was investigated by ISMAIL and GEORGE (1968) using a similar technique. After recording the vertical dimension by swallowing, teeth were set on an articulator and tried in the mouth. Wax was dropped on to the lower premolars and the subject was asked to swallow his saliva "casually". If considerable tooth structure were exposed, it indicated that the vertical dimension was excessive. If a considerable amount of wax remained over the teeth, it indicated that the vertical dimension was insufficient. If a thin film of wax remained over the teeth it was accepted as correct. Using these rather haphazard methods they found that none of the dentures constructed required any alteration in the vertical dimension of occlusion, and they considered the technique to be reliable in establishing the vertical dimension of occlusion for the edentulous patient.

VIERHELLER (1968) also reported on swallowing as a functional method of establishing the vertical dimension of occlusion. If tooth contact occurred only during the act of swallowing then this functional position of the mandible which was obtained must be the vertical dimension of occlusion. The technique employed differed slightly from those already described. The mandibular occlusal plane was first determined as extending from the lower lip line to the centre of the retromolar pad. Notches were cut in the surface of the mandibular occlusal rim in the premolar and molar region. Cones of beeswax were softened and sealed on a maxillary record base without an occlusal rim. The maxillary base was inserted, water was injected into the mouth and the subject swallowed. This was repeated two or three times, after which the registration bases were removed from the mouth and the beeswax was hardened in cold water. The record bases were then replaced and the mouth was closed. If even contact was obtained and the beeswax projections on the upper base fitted accurately into the notches on the lower occlusal rim then it was believed that a functionally accurate vertical relationship had been achieved.

4.3.1 Comment

The work referred to is based on the belief that swallowing is accompanied by occlusal tooth contact, and that this situation should be reproduced in the construction of a prosthesis. Problems may arise however when utilising this action to achieve correct occlusal vertical dimension. MALSON (1960), pointed out some factors which will inhibit normal swallowing, such as loss of the upper dentition or premature contact of occlusal rims. SHANAHAN (1956) cast some doubt on his own hypothesis, by stating that variations in swallowing may occur according to the age of the subject, and around middle age the pattern of swallowing lacked "the sharpness of the reflexes in youth". The technique remained the same, but "considerable care must be exercised to select the appropriate swallowing level, and to be certain it has an accompanying interocclusal distance". He stated later "tests are made routinely for the presence of these spaces (interocclusal clearance) after the vertical dimension had been established". It would appear that SHANAHAN considered that his technique was neither completely reliable nor suitable for every patient. ISMAIL and GEORGE (1968) who supported SHANAHAN's hypothesis used phrases such as "a considerable thickness of wax", or "a considerable amount of tooth showing", but no guidance is given regarding the authors' understanding of the word "considerable". When the vertical dimension of occlusion was being registered, the subjects were asked to swallow "several times" and no allowance appeared to have been made for any resistance to closure offered by the wax. ISMAIL (1969) attempted to clarify some of these points. Subjects were requested to swallow a total of "between 6 and 10 times". These were empty swallows, i.e. nothing was present in the mouth except saliva. If insufficient saliva was present, however, the subject was given a little water to drink. The wax cones were 10 mm wide at the base and 10-15 mm in height, and were formed in "Utility wax" of the type used for boxing impressions, which was heated to 135°F (56°C) before use. One might expect some resistance to closure from this amount of wax, but it was claimed that it offered "minimal, if no, resistance". The lack of standardisation and precision in these investigations reflects adversely on the accuracy of the results. The main difference between VIERHELLER'S technique and other methods is that no tentative vertical relationship was established before determining a functional vertical dimension of occlusion. It was established by swallowing alone. No comment, however, was made on the thickness and consistency of the wax used and apparently it was considered that the functional position will be achieved in spite of possible resistance offered by the wax. Previously, in 1958, POSSELT had reported on a swallowing study of 12 subjects with complete or almost complete, natural dentitions. This work considered the effect of the relative thickness of wax when placed between the occlusal surfaces of the teeth. Two series of records were obtained, one using wax of 1 mm thickness, the other using wax 2-3 mm thick, in order to determine whether or not the greater thickness of wax offered more resistance to the establishment of occlusal contact whilst swallowing. The resultant vertical dimension for each thickness differed by only 0.1 mm which might suggest that the amount of wax used in establishing the vertical dimension of occlusion by swallowing is not critical. The force exerted during swallowing by dentulous patients, however, may differ from the force exerted by edentulous patients, and it is possible that POSSELT'S results are not applicable to edentulous subjects. Furthermore, if wax of similar thickness were used to determine the vertical dimension of occlusion by swallowing for edentulous subjects, a fairly accurate vertical dimension of occlusion would require to be established in the first instance thus leaving little margin for error.

4.4 Occlusal Force and Swallowing

A further technique to determine vertical dimension by swallowing was suggested by FINNEGAN (1967) who attempted to establish a relationship between the vertical dimension of occlusion and the force exerted by the jaws during swallowing. He suggested that if the magnitude of an interocclusal swallowing force could be changed by alterations in the vertical dimension of occlusion, then a pattern might be produced which would indicate optimum vertical dimension of occlusion for complete dentures. An intra-oral hydraulic system connected to a strain-gauge and wired to an amplifier and recorder was used, and swallowing was performed, i) on command; ii) involuntarily, and iii) on drinking water. He found a linear relationship existed between swallowing force and vertical dimension only at lower levels of jaw opening.

4.4.1 Comment

Although it was demonstrated that there existed a relationship between swallowing force and vertical dimension of occlusion over a limited range, no relationship was formed which would have permitted its clinical use in the determination of the vertical dimension of occlusion. The method of recording vertical dimension of occlusion by jaw forces during swallowing was considered impractical.

CHAPTER 5

Methods of Investigation

METHODS OF INVESTIGATION

5.1 Introduction

Various methods of investigation have been developed and used to record information from the mouth during functions such as swallowing. Methods used have included visual assessment, transmitting apparatus, radiography and electomyography.

5.2 Visual Assessment

Direct clinical observations on vertical mandibular movement and occlusal tooth contact during swallowing were made by NISWONGER (1934) and later by RIX (1946) in his study on occlusal tooth contact during swallowing in a group of children.

Other techniques were used by ISMAIL and GEORGE (1968), who determined the incidence of occlusal tooth contact during swallowing by placing soft wax on the occlusal surface of the teeth and inducing the subject to swallow. The amount of deformation of the wax was used as an assessment of contact.

5.3 Transmitting Apparatus

Transmitting apparatus has been used to study tooth contacts which occur during mastication (JANKELSON et al. 1953, YURKSTAS and EMERSON 1954, ANDERSON and PICTON 1957). Information was recorded by placing metal inserts in opposing teeth, and leading wires from the inserts to recording equipment. When the opposing metal surfaces contacted the electrical circuit was completed and a signal transmitted to the recording apparatus.

More sophisticated techniques using intra-oral radio telemetry have been reported by several workers (BREWER and HUDSON 1961, GILLINGS et al. 1963, GRAF and ZANDER 1963, ADAMS and ZANDER 1964, SCHARER and STALLARD 1965, NEILL 1967, GLICKMAN et al. 1968). In each of these studies, information from the mouth was transmitted directly to a radio receiver in the vicinity of the patient and so dispensed with wires emanating from the mouth. These studies were related to tooth contact alone, the transmitter being switched on by a metallic contact in an opposing tooth. Measurement of tooth contact together with a range of interocclusal clearance was obtained by THOMSON and MACDONALD (1969) employing miniature transducers whose output signal varied with their proximity to a diamagnetic material. A different approach used the principle of the Hall effect to monitor the interocclusal separation in the anterior region of the mouth during speech (KYDD et al. 1967). The Hall effect is the change in current distribution in a conductor or semi-conductor according to its proximity to a magnet. These instrumental techniques described involve fairly complex electronic circuitry or sophisticated detector apparatus.

5.4 Radiography

In routine dental radiography the area being radiographed is held stationary and is subjected to a limited time exposure of X-rays. An image of the structure is recorded on a film. This technique is suitable for most clinical or diagnostic purposes and is also used in serial or comparative studies of certain jaw positions (TALLGREN 1957, INGERVALL 1964). For the study of functional movements such as swallowing it is clearly preferable that the radiograph will record the complete range of continuous movement. This is done by making a continuous exposure which may be viewed directly (fluoroscopy), or recorded on film (cineradiography or cinefluorography). The latter method will allow repeated visual study of the various phases of movement and also permit detailed analysis of individual film frames.

Direct fluoroscopy with a bismuth swallow was first used by CANNON and MOSER (1898) to study the oesophageal stage in swallowing. Radiation levels in this technique were very high, but with improvements in apparatus, indirect cinefluorography or cineradiography can be performed with negligible risk to patient.

More recent studies on oesophageal and pharyngeal stages of swallowing using such techniques have been reported by RUSHMER and HENDRON (1951), and RAMSEY et al. (1955). Cineradiography was used by ARDRAN and KEMP (1955) to study movements of the tongue in swallowing, whilst COOPER (1956) used cinefluorography with an image intensifier as an aid to diagnosis and treatment planning for cleft palate patients. Similar techniques were used in investigations into tongue behaviour (TULLEY 1960, CLEALL 1965), development of the deciduous dentition (LEIGHTON 1960) function of the temporomandibular joint (BERRY and HOFFMAN 1959) mandibular movements during swallowing (INGERVALL et al. 1971) and masticatory ability (WATSON 1972).

5.5 Electromyography

PRUZANSKY (1952) in discussing the possible applications of electromyography in dentistry suggested its use in obtaining electromyographic patterns of muscles of facial expression and muscles of mastication. Earlier work by MOYERS (1956) had concentrated on electromyographic recordings of the rest position and movements of the mandible, whilst NEUMANN (1950) had studied electrical activity in the masticatory musculature in an effort to measure the force exerted when chewing. In 1956, SHPUNTOFF and SHPUNTOFF, in an investigation of patients with normal occlusion, found that a characteristic electromyogram was produced by normal adults with their teeth in the intercuspal position. (In the course of their study they also noted that the movement from the rest vertical dimension to the intercuspal position was usually accompanied by the swallowing of saliva). Electrical muscle activity in swallowing was investigated by MØLLER et al. (1971) who demonstrated that such activity was unaffected by the position of the patient's head. Studies of tooth contact during chewing (HANNAN et al. 1969) have demonstrated inhibition of activity in the masseter muscle immediately after contact. During swallowing, however, tooth contact has been shown to co-incide with increased activity in the temporal muscles (MØLLER, 1966).

5.6 Comment

Direct clinical observation of functional movements such as swallowing, is fraught with difficulties. The observer can view the teeth only when the lips are parted, which may occur only when the subject draws liquid into the mouth. It is very likely that any separation of the lips by the fingers of the observer during the sequence will interfere with normal function and may influence mandibular movements. Such a method of investigation is unsatisfactory (LEIGHTON 1960).

The use of soft waxes as a recording medium would also appear to be subject to considerable error. These materials by their very nature are susceptible to rapid distortion when placed in the mouth (at 37°C) even without the application of stress. Consequently such an approach does not provide reliable data.

Recording of electrical signals enjoys considerable popularity. Apparatus in which wires run from an intra-oral structure to an extra-oral recorder has been criticised on the grounds that such wires may affect normal function

(NEILL 1967, THOMSON and MACDONALD 1969). Intra-oral telemetry, which avoids the use of wires, can be used to demonstrate both contact and interocclusal clearance. It is limited, however, by the number and width of switches which can be incorporated into a contact area, and consequently is unable to produce signals for all possible positions of contact.

The major problems in the use of radiographic techniques are image sharpness (RAMSEY et al. 1955) and radiation dosage in prolonged viewing. BERRY and HOFFMAN (1959) have deduced that when using a cinefluorographic technique a patient exposed for one minute received no more radiation than when having a periapical film taken of a lower molar tooth. TULLEY (1960), however, observed that limitations of the apparatus allowed viewing for only a few seconds, whilst LEIGHTON (1960) quoted a safety range of 10 seconds filming for a 3 year old child. Image sharpness has improved since 1955, due to developments in equipment, and the advent of the electronic image intensifier has considerably reduced the radiation dosage. Radiography thus remains a useful method for a comprehensive investigation of functional movement.

Electromyography has been used to study the activity of the muscles of mastication during specific jaw functions and at specific jaw positions. There appears to have been little consideration of the possible relationship of electromyographic patterns either to tooth contact or to interocclusal clearance during swallowing.

SUMMARY AND CONCLUSIONS

The review of the literature has included both a description and discussion of methods used to record jaw relationships and methods used in the investigation of oral functions. It can be summarised in two parts :

1. Recording Jaw Relationships

i) A correct recording of both vertical and horizontal jaw relationships is of considerable importance in the design of complete dentures.

ii) Some methods of recording jaw relationships make use of specific jaw movements and may be described as functional methods. Other methods may be described as non-functional.

iii) Non-functional methods may be used either before or after extraction of the natural teeth. Neither recordings made before extraction or after extraction appear very reliable. Furthermore, recording of jaw relationships while the natural teeth are present is only of value if it is considered desirable to construct dentures to pre-extraction measurements.

iv) Functional methods such as biting action and chewing movements lack precision. The use of the principles of phonetics and also the patient's own neuromuscular perception may offer some success in the establishment of vertical jaw relationships, but such methods are by no means infallible.

v) Considerable attention has been given to the association between swallowing and jaw relationships. It seems possible that both vertical and horizontal relationships may be recorded by swallowing. There are, however, conflicting reports regarding both the occurrence of occlusal tooth contact and the position of occlusal tooth contact during swallowing.

2. <u>Investigation of Oral Functions</u>

i) Various functions of the mouth may be seen by clinical observation, but the recording of more accurate data has been attempted by many workers using transmitting apparatus, radiographic and electromyographic techniques.

ii) In spite of many advances in techniques of investigation there still remains doubt and uncertainty about deriving conclusive results.

iii) A number of the above techniques, or variations of them, have been incorporated in the present study.

SECTION 3

MATERIAL AND METHODS

CHAPTER 6

The Sample Investigated

THE SAMPLE INVESTIGATED

6.1 The Number of Subjects

The total study was performed in 70 adult subjects living in the West of Scotland who were patients, members of staff or undergraduate students at Glasgow Dental Hospital. All were volunteers. Each subject was asked to perform six swallowing sequences, making 420 sequences available for analysis. The first part of the investigation, in which a transmitting coil was used, involved a group of dentulous subjects. The second part of the investigation, in which fluorographic techniques were used involved the remaining subjects both dentulous and edentulous. The edentulous subjects were investigated in two groups, one without dentures, the other wearing dentures. The number of cases in each group participating in both parts of the study is shown in Table 3, 1.

6.2 Criteria for Selection

The following criteria were applied in the selection of subjects for the investigations :

6.2.1 Age

For all subjects the lower age limit was fixed at 18 years. According to the eruption times of teeth, with the exception of the third molar teeth, this was an age at which the dentition was considered fully developed. There was no restriction on the upper age limit. The number of subjects in various age groups is shown in Table 3, 2.

6.2.2 State of the Dentition

In the fluorographic investigation involving dentulous subjects it would seem reasonable to use subjects with as many of their natural teeth present as possible. This would allow the widest possible examination of tooth contact and the position at which contact occurred. Complete dentitions, even in the younger age groups, are seldom found in the West of Scotland (STEPHEN 1970, STEPHEN and SUTHERLAND 1971), and therefore many subjects had isolated missing teeth. Subjects were included for investigation only if they had sufficient natural teeth in occlusion to establish a vertical dimension of occlusion in the intercuspal position. This allowed reference to an established anatomical position. The minimum number acceptable was two posterior teeth on each side, which were able to occlude with opposing teeth. Bridges and partial dentures were not acceptable substitutes. Grossly carious dentitions involving loss of tooth structure were also excluded. Of the 30 subjects selected for investigation, 27 of them more than fulfilled the above criteria.

For the part of the investigation using transmitting coils, it was necessary to select subjects with a dentition which, besides complying with the above criteria, had opposing edentulous saddles into which coils could be positioned opposite each other.

6.2.3 Type of Occlusion

Loss of isolated teeth, rotation and malposition of individual teeth and crowding all contribute to the presence of malocclusion. In the present study this situation was accepted provided that the subject could achieve tooth contact in the intercuspal position. Gross malocclusions, however, either pre- or post-normal (ANGLE 1899) were excluded.

6.2.4 Edentulous Subjects

Edentulous subjects were included in the study provided that they had been edentulous for at least 12 months. Subjects with skeletal or developmental anomalies (e.g. cleft palate) were excluded. Subjects wearing complete dentures were included if they had been wearing their dentures without discomfort for a period of not less than 2 months and not more than 12 months. This period of time permitted subjects to become accustomed to their dentures but limited the possibility of reduction of the vertical dimension of occlusion due to wear of the teeth. In an attempt to achieve some degree of standardisation of the dentures, all such subjects had their dentures constructed either by the author or in clinics under the supervision of the author. In all cases, jaw relationships for these subjects were recorded by techniques other than swallowing.

6.3 Comment

The group of dentulous subjects was divided fairly evenly between males and females, whilst the group of edentulous subjects showed a preponderance of females. In view of the nature of the investigation this is not likely to have any decisive effect on findings.

If a subject agreed to volunteer for the investigation, he or she was examined and questioned, and if the criteria of selection were fulfilled, was included in the investigation. This method of selection was continued until the desired number in each group had been obtained.

CHAPTER 7

The Transmitting Coil Study

THE TRANSMITTING COIL STUDY

7.1 Description of Apparatus

The instrument used in the preliminary study was designed to measure occlusal tooth separation by means of electrical field variations (LAIRD et al. 1971). It makes use of the varying coupling between the primary and secondary coils of an air cored transformer as the coils are separated. A primary air cored coil of a few turns is driven from an oscillator (a.c. voltage source), and a secondary or search coil with many turns, and mounted on the same axis as the primary coil, feeds an amplifier. The amplified signal is rectified.

Each coil is hand wound with 40 swg (0.12 mm diameter) enamelled copper wire around a core of 6.5 mm diameter. The coils have limited maximum dimensions as they are designed to be placed in opposing edentulous saddles which can be as small as the space left by an extracted tooth. The wires from the coils are led from the mouth, the primary coil being linked to the oscillator and the secondary coil being linked to the amplifier. The amplitude of the induced voltage depends on the physical relationship of the two coils (i.e. their vertical separation). Any variation in the coil separation produces a corresponding change in the output signal from the circuit.

A block diagram of the apparatus is shown in Fig. 3, 1. Both the oscillator and the amplifier are constructed using μA703 amplifiers (Fairchild) which are designed for use with transformer coupled circuits, tuned circuits or both.

The ratio of the number of secondary to primary turns should be large to obtain a high induced voltage, but the oscillator should not be loaded excessively. The coils are therefore wound to a core of diameter 6.5 mm with 200 turns on the secondary coil and 15 turns on the primary coil (Fig. 3, 2). This ratio, together with the fact that the primary coil has limited maximum dimensions as it must fit into a tooth space, limits the primary coil inductance to about 8μH. For a good voltage transformation with little loading of the oscillator the primary impedance should be high. The oscillator is therefore tuned to 3.35 MH_z which ensures reasonable primary coil impedance, but is not so high as to be affected by the stray capacitance of long lead wires.

The amplifier is fed from the multi-turn search coil and the amplified signal from the output transformer is rectified and fed to a 500Ω potentiometer via a resistor. It is thus short-circuit proof. The potentiometer allows adjustment of the sensitivity of the apparatus and also provides damping for a UV recorder galvanometer. The output signal is also sufficient to drive most pen recorders. Continuous graphic presentation of the output enables the coil separation to be readily determined at any given time. In order to meet variations in space available in the dental arches of subjects, the ratio of the number of secondary to primary turns in the coils together with the diameter of the core, is adjustable. Such adjustments result in alterations in signal strength however, and individual calibration is necessary. The power supply, nominally 12 volts at 20mA is decoupled for high frequencies by a capacitor, and is provided by standard Léclanche batteries.

Recordings were made using a potentiometric pen recorder[1] suitable for small d.c. voltage inputs (Fig. 3,3). No warming-up time is required and the recorder has a chart width of 200 mm with a response time of 1 sec for a full scale deflection. The zero position is adjustable over the whole writing width of 200 mm. The chart drive speed selected for recordings was the maximum available (600 mm/min) in order to obtain clear graphical detail.

7.2 Procedure

Alginate[2] impressions were obtained of the mouth of each subject and poured in dental stone. The casts were mounted in the intercuspal position on an articulator.[3] Acrylic bases[4] were laid down on each cast with the addition of 0.7 mm stainless steel wrought wire retainers on suitable teeth. Two coils were selected and sealed opposite to each

---

1 R.E. 511 Standard Servoscribe, Smiths Industries Ltd., Wembley, Middlesex.

2 Super Kromopan : F.H. Wright Dental Manufacturing Co. Ltd., Dundee, Scotland.

3 Gibling Bros. Patent 31363/49 : J. Fielding and Co. Ltd., Sydney, Australia

4 Orthocryl : Dentaurum, West Germany.

other in wax rims. The coils were linked to the voltage source and recording system, and the bases were inserted in the mouth (Fig. 3,4). The swallowing sequences were performed with the subject seated in an upright position with the head unsupported, as suggested by MØLLER et al. (1971.). Before commencing the experiment each subject was given some practice in locating his or her intercuspal position. Water was then provided and the subject was asked to sip and swallow a small amount. Several swallowing sequences were recorded graphically. At the termination of each swallowing sequence, the subject was asked to close his or her teeth in the intercuspal position with the coils in place. The pen deflection at this position was an indication of occlusal tooth contact in the intercuspal position, and established a base line from which measurements could be made. After recording the swallowing sequences for each patient the instrument was calibrated by inserting spacers of 1, 2, 3, 4, and 5 mm between the coils in the mouth.

7.3 Measurement of Recordings

In each swallowing sequence, measurements were made of the occlusal tooth separation during clinical swallowing, and the occlusal tooth separation at the termination of the swallowing sequence. Measurement was also made of the duration of the occlusal tooth separation prior to swallowing. As the relationship between the coil separation and the output signal is non-linear (Fig. 3,5) the results were plotted on millimetre graph paper and a calibration curve was constructed for each patient (Fig. 3,6). By measuring the distance of the tracing from the base line at any point, and applying this measurement to the curve, the amount of occlusal tooth separation was determined.

7.4 Comment

The technique described was unsuitable for use in subjects with complete natural dentitions, as the presence of opposing edentulous areas were required for location of the wax record blocks which carry the coils. Accordingly this study on occlusal tooth contact was performed only on partially edentulous patients.

It is possible that a technique where wires pass from the mouth may result in displacement of the wax record block and so induce gross errors in the recordings. This, however, would be dependent upon the weight of the wire, and whether or not any tension was being exerted upon it. In the present study, lightweight wires of only 0.12 mm in diameter were used and were free from any direct tension. It has been suggested that when wires pass between the lips they may initiate abnormal reflex mechanisms due to their contact with the labial mucosa (NEILL 1967). It has been noted, however, (Chapter 4) that swallowing can be performed in patients suffering from pathological conditions and developmental anomalies (SYROP 1953) and is the least easily disturbed of all the functions associated with mastication (SILVERMAN 1961). Once the reflex swallowing act is initiated it is not readily suspended by any voluntary action (SCOTT and DIXON 1972). It is therefore unlikely that there will be any appreciable interference from the lightweight wires attached to the record blocks.

CHAPTER 8

The Fluorographic Study

THE FLUOROGRAPHIC STUDY

8.1 Description of Apparatus

In fluorographic techniques, when a subject is placed between a source of X-rays and a fluorescent screen, an image will be produced on the screen and may be recorded by photographic techniques. The fluorographic apparatus[1] used in the present study employs an electronic image intensifier which increases considerably the brightness of the fluorescent screen, resulting in a reduction in radiation dosage and permitting the recording of events on motion film. In the present study, the X-rays produced are converted into visible light and the image is photographed by a television camera which is built into the apparatus. The television picture uses a 625 line system and viewing may be carried out as the investigation is performed, or if it is desired to view at a later date a sequence may be recorded directly on to a videotape.[2] By using a second television camera and incorporating a mixing unit, a split screen form may be obtained allowing synchronised radiographic and visual images to be viewed simultaneously. A diagram illustrating the units and connections is shown in Fig. 3,7.

---

1 Siemens (Medical Division), Erlangen, West Germany

2 Model IVC 801A : International Video Corporation, California

The image intensifier unit is mobile with the X-ray tube and the image intensifier plus television camera mounted on opposite ends of a C arm (Fig. 3,8). This ensures that they are always in alignment. The movable C arm can be positioned to record any head view of the patient, but for the present investigation a horizontal beam was used to give a lateral view of the jaws. The target film distance was 84 cm. A general view of the apparatus is shown in Fig. 3, 9.

8.2 Preparation of Subjects

Subjects were divided into three groups, dentulous, edentulous (without dentures) and edentulous wearing dentures. The criteria of selection were as described in Chapter 6. Subjects were advised regarding the form of the investigation, and all were volunteers.

Dentulous Subjects

Although measurements may be made from anatomical references on the facial skeleton, additional references for dentulous subjects were provided by lead pellets attached to the teeth (NEVAKARI 1956). These pellets were approximately 2 mm in diameter, and were attached buccally in the interproximal region between the right premolar teeth, and labially in the interproximal region between the central incisor teeth in both mandible and maxilla, using soft wax.[3]

---

3 "Dentina" ribbon wax : Brownings' Dental Supply Co. Ltd., Hull.

Care was taken to ensure that there was no interference with the occlusion. Dentulous subjects were also instructed in tooth closure in the intercuspal position and were given some practice in its location. The intercuspal position could then be recorded on the radiographic sequence and used as a reference for measurements.

Edentulous Subjects

As all measurements from edentulous subjects were made from anatomical references on the facial skeleton, no preparation of these subjects was required.

Edentulous Subjects wearing Dentures

As it was desired to investigate such subjects wearing dentures at a vertical dimension of occlusion to which they had become accustomed, and also at a reduced vertical dimension of occlusion, it was necessary to duplicate their present dentures. Duplicates were prepared by pouring fluid acrylic resin[4] into a mould of hydrocolloid duplicating material, which had been prepared from their present denture. The mould, plus resin, was then placed in a pressure vessel. Polymerisation of the resin was achieved at room temperature under a pressure of 25 lbs/in^2 for 35 minutes (RALPH and PAUL 1972). Two duplicate sets of dentures were constructed for each subject.

Both sets of duplicate dentures were then mounted in

---

4 Pour/Cure : Coe Laboratories Inc., Chicago.

the intercuspal position on an articulator.[5] On one set the occlusal surfaces and incisal edges were reduced until a space of 3 mm was present between the occlusal surfaces as measured by a spacing shim. In both upper and lower dentures lead pellets were placed interproximally between the premolar and central incisor teeth for reference purposes. Thus each subject had prepared dentures at both accustomed and reduced vertical dimensions of occlusion.

8.3 Procedure

Each subject was seated, and the head so positioned that the median plane of the head was at right angles to the Central X-ray beam (Fig. 3,10). This allowed a lateral jaw recording. As repetition of recordings was not required for comparative measurements, and as it is preferable to have the head position in natural balance for lateral projections of functional movements (BJÖRK 1954, CLEALL 1965), no cephalostat was used. Lateral movement of the head was controlled by placing the lateral surface of the face against the flat surface of the housing of the image intensifying apparatus (Fig. 3,10). Before commencing each recording a trial exposure was performed to assess the position of the head and clarity of the image. As the image density was influenced by the morphological features of the subject, the exposure factors were modified to obtain the best image.

---

5 Gibling Bros. Patent 31363/49 : J. Fielding & Co. Ltd., Sydney, Australia.

The most common exposure factors were 75 kV and 1.8 mA.

All subjects were informed that they would be provided with water and would be asked to sip a small amount and swallow it. They were not advised of the precise purpose of the investigation. Swallowing was by command, and six sequences were recorded for each subject. Dentulous subjects and edentulous subjects wearing dentures were told to bring their teeth together in the intercuspal position before commencing the swallowing sequences. This provided a reference for measurements. Edentulous subjects were asked to "relax" before commencing the sequences.

Each sequence was viewed directly on the television monitor and simultaneously recorded on videotape for later analysis.

8.4 Methods of Analysis

The recordings on the videotape were subjected both to visual analysis and measurement analysis.

8.4.1 Visual Analysis

This was restricted to the assessment of the presence or absence of occlusal tooth contact during swallowing sequences from dentulous subjects. Such contact was assumed to be present on radiographic superimposition of the cusps of opposing premolar and molar teeth. Each sequence was viewed several times.

8.4.2 Measurement Analysis

Direct measurement from the videotape was impossible, and therefore each sequence was filmed from the television monitor on 35 mm fast panchromatic film using a camera[6] with a film speed of 3 frames per second. A frame analysis was performed and in order to obtain more detailed measurements, prints were made from relevant frames using Kodak Ektamatic Paper Grade 2, designed for use with an automatic processing machine.[7] The majority of measurements were relative to measurements at a reference position, but where absolute values were required these were calculated by reference to correction factors determined for a dentulous skull positioned with the premolar teeth at known distances from the intensifying screen (Chapter 10).

Reference lines from which measurements could be made were based on those suggested by BJÖRK and PALLING (1955). For reasons of accuracy and clarity however some modifications were considered desirable in the present study. The reference lines used are shown in Fig. 3,11 and are designated as follows :

NL - The nasal line which passes through the junction of the compact bone of the anterior part of the hard palate and the floor of the nose (point X) and the pterygomaxillare (pm).

---

6 Nikon F., Nippon Kogaku, Tokyo, Japan

7 Kodak Auto-Processor Model Q 14 : Kodak Ltd., London.

The latter point represents the posterior contour of the maxilla where it intersects the contour of the hard palate.

ML - The mandibular line which is at a tangent to the lower border of the mandible.

AB - The line joining the uppermost border of the lead pellets attached to the maxillary teeth.

CD - The line joining the lowermost border of the lead pellets attached to the mandibular teeth.

The points from which these lines were constructed were obtained by piercing the film negative with a pin before printing. This resulted in the appearance on the print of a well defined black spot surrounded by a white halo. The amount of error resulting from the puncture of a film in this manner has been estimated at 0.05 mm (NEVAKARI 1956). The points were then joined by lines 0.1 mm thick.

From these reference lines measurements were made as follows :-

Dentulous subjects

(i) from the upper lead pellets perpendicularly to the line CD,

(ii) from the anterior lower lead pellet to the point where a perpendicular from the posterior upper lead pellet intersected the line CD.

Edentulous subjects

(i) from point X perpendicularly to the mandibular line.

(ii) from point X to the point where a line perpendicular to the nasal line, and passing through point X, intersected the mandibular line.

Edentulous subjects wearing dentures

(i) from the upper lead pellets perpendicularly to the nasal line

(ii) from the lower lead pellets perpendicularly to the mandibular line

(iii) from the upper lead pellets perpendicularly to the line CD

(iv) from the anterior lower lead pellet to the point where the perpendicular from the posterior upper lead pellet intersected the line CD.

All measurements were made using the blades of a caliper gauge with a vernier scale calibrated to 0.1 mm (Fig. 3,12).

8.5 Comment

The technique described is suitable for use with both dentulous and edentulous subjects. The video recording permits the investigator an appreciation of the complete range of movement, whilst a frame analysis of the filmed recording permits measurements to be made at any desired stage in the sequence. As the precise nature of the study was related to the examination of the level of jaw separation immediately prior to swallowing, and as this separation has been quoted as being maintained for approximately 1 second (BREWER 1963) and an average of 0.8 seconds (LAIRD 1972), a film transport speed of 3 frames per second was considered adequate.

It has been suggested (NEVAKARI 1956) that in a study such as this it is advantageous to film both coronal and sagittal planes. Such exposures however, must necessarily be made simultaneously to provide absolute comparison. This was not possible with the equipment available. It was also considered that superimposition of anatomical structures in a frontal view would create problems in diagnosis with subsequent increase in error and merited a separate study. Accordingly investigations have been restricted to exposures in a sagittal plane as suggested by BJÖRK (1954). Satisfactory images from this apparatus were obtained with radiation levels of 5-15 milliroentgens/second to the skin surface nearest the X-ray tube. This meant that viewing for approximately 20 seconds resulted in a radiation dose similar to that required for a dental periapical film (MASON and DAVISON, 1972). The total filming for each subject, including trial exposures, did not exceed 45 seconds, and the radiation dose was therefore well within safety limits (SMITH and HEIGHWAY 1969).

For dentulous subjects and edentulous subjects wearing dentures, the references from which measurements were made permitted calculation of the degree of occlusal tooth contact during swallowing by comparison with similar measurements taken in the intercuspal position. For edentulous subjects, jaw separation during swallowing could be measured and compared with the extent of jaw separation in the "relaxed" position prior to the commencement of the investigation. In addition, for edentulous subjects wearing dentures the distances from the lead pellets to the respective nasal and mandibular lines when compared with those at the intercuspal position gave an indication of vertical displacement of the dentures during the swallowing sequence.

Both visual and measurement analysis of the recordings were subjected to a double determination assessment, the result of which is reported in Chapter 12. Production of suitable negatives and prints for a frame analysis proved to be a complicated exercise, and the problems encountered and the methods developed are discussed in Appendix B.

CHAPTER 9

Statistical Analysis

STATISTICAL ANALYSIS

9.1 Introduction

Although differences and similarities between results may appear obvious, for complete interpretation of them it is necessary to perform a statistical analysis. In the present study such an analysis has been used to compare results with those of other workers and in some cases with theoretical predictions. It can be made clear therefore whether any relationship between results has occurred merely by chance, or whether it is real and significant, and thus can be expected to occur again under similar experimental conditions.

9.2 Symbols

The following symbols have been used in the statistical analysis.

n	The number of observations in a sample.
X	The variable
$\bar{X}$	The arithmetic mean or average of observations.
Σ	Indicates summation of data
S	The standard deviation of a sample
t	A normally distributed deviate expressed in units of standard deviation. Used in calculations involving measurement data.
χ^2	Chi-squared. Used in calculations involving enumeration data.
p	Probability

9.3 Statistical Methods

The statistical methods used in this study were standard ones contained in most textbooks on the subject. Particular reference has been made to BISHOP (1966), HILL (1967) and MORONEY (1968). The data available for analysis were both enumeration data and measurement data. Each of these required different methods of analysis.

9.3.1 Enumeration Data

The statistical method used in the analysis of enumeration data was the χ^2 (Chi squared) test. Using this test data could be compared with results of other workers, or subdivided (e.g. according to age or sex) and further comparisons made. The results of such an analysis give an indication of the significance of difference or similarity between groups of data compared.

When comparing two sets of enumeration data, the following formula may be used :

$$\chi^2 = \frac{(ad - bc)^2\,(a+b+c+d)}{(a+b)\,(c+d)\,(a+c)\,(b+d)}$$

where a, b, c, and d are the numbers falling into each group. How this formula is used is given in the following example :

	No. of subjects		TOTAL
	Tooth Contact	No Tooth Contact	
Group I	a	c	a + c
Group II	b	d	b + d
Total	a + b	c + d	a+b+c+d

If the numbers involved are relatively small as in the present study, Yates' correction is applied to the formula as suggested by HILL (1967). The exact formula used in the study was therefore :-

$$\chi^2 = \frac{\left[ad-bc-\frac{1}{2}(a+b+c+d)\right]^2 (a+b+c+d)}{(a+b)(c+d)(a+c)(b+d)}$$

From the value of χ^2, a probability value (p) could be obtained by reference to the table of χ^2 (FISHER and YATES 1963). From the p value the level of significance was determined as follows :

If $p \leqslant .05$ the results were termed as probably significant.

If $p \leqslant .01$ the results were termed as significant

If $p \leqslant .001$ the results were termed as highly significant.

9.3.2 Measurement Data

The analysis of measurement data was performed to determine mean values, standard deviations and the significance of difference between means in different groups.

The standard deviation was determined from the following formula :

$$S = \sqrt{\frac{\Sigma(x - \bar{x})^2}{n - 1}}$$

where the sum of the squares of the deviations from the mean is divided by n - 1 and not n. As the standard deviation is an estimate for the variability of observations in the population, division by n - 1 instead of n results in a better estimate (HILL 1967).

Comparison of the means of different groups was performed by using the distribution of t from the following formula :

$$t = \frac{\text{deviation of the difference of the means, from zero}}{\text{standard deviation of the difference of means}}$$

$$= \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} \quad \frac{s_2^2}{n_2}}}$$

From the values of t a value of p can be calculated to demonstrate the significance of the results.

9.4 Calculations

All statistical calculations were done on a desk top computer[1] which was programmed to give means, standard deviations, t values and values of p calculated from t.

---

1 9100A Calculator : Hewlett Packard Ltd. , Slough, Bucks.

SECTION 4

CONSIDERATION OF ERRORS

INTRODUCTION

In all investigations standardisation of techniques and equipment is designed to eliminate or minimise error. Some errors however, are unavoidable such as those known to be present in recording instruments. For commercial reasons these are stated in operating instructions and are usually small. Other potential errors are present in materials used, techniques employed, and methods of analysis. Whilst some of these may be eliminated or reduced by using recommended manipulative techniques, others require investigation in order to determine the possible effect on results.

CHAPTER 10

Errors in Instruments

ERRORS IN INSTRUMENTS

10.1 Intra-oral Transmitting Apparatus

A circuit diagram of the transmitting apparatus is shown in Fig. 4,1. The output of the oscillator is affected by the primary and secondary coils. The primary coil has an inductance of about 8 μH which offers an impedance of about 110 Ω at 3 MHz., which causes the output voltage of the oscillator to drop. The input impedance of the amplifier is so large, however, (about 7 kΩ) and the coupling so loose, that the oscillator output drops only about 5% when the coils are brought into contact. The loading effects remain constant for each combination of circuit and transducer coils.

For each complete system, drift of peak-to-peak output current (for the oscillator) and the amplification factor of the amplifier are affected by the supply voltage and the temperature at which the instrument is used.

The supply voltage of 12 volts was provided by two PP1 batteries connected in series. These have a life of 200 hours down to 9 volts and the drift of voltage with temperature is negligible (0.00048 volts/^{o}C). With a supply voltage of 9 volts the oscillator current and voltage output is 60% of that obtained with a 12 volt supply. A decrease in the amplification factor also occurs and the total output of the system is down by about 60%. Therefore using a supply voltage of two PP1 batteries in series would result in a system output drift of only - 0.3% per hour.

At temperatures between $0^{o}C$ and $20^{o}C$ the decrease in amplification factor is compensated for by an increase in oscillator output. Between $20^{o}C$ and $50^{o}C$ the amplification factor decreases by 2% while the oscillator output remains constant. The system is therefore stable within 2% between $0^{o}C$ and $50^{o}C$. The complete system is not absolute, and is designed for calibration after each recording using spacing shims of known dimensions.

10.2 The Potentiometric Recorder

According to the literature provided by the manufacturer the accuracy of the recorder is $\pm$ 0.5% of the full scale value. The maximum jaw separation which was recorded was 5 mm, thus resulting in a possible error of $\pm$ 0.02 mm. The normal full scale deflection was achieved in 1 second (pen response speed of 200 mm/second) and under the worst conditions was achieved in 1.5 seconds (pen response speed of 133 mm/second).

10.3 The Fluorographic Apparatus

Where absolute values were required from the measurement analysis, it was necessary to determine the degree of reduction or enlargement of the radiographic image. The photographic techniques used (Appendix B) ensured a standard reduction of image size. A correction factor could therefore be determined which would be applicable to any measurement value.

The correction factor was calculated in the following manner. A dentulous human skull was positioned for a true lateral radiograph at a known distance from the housing of the image intensifying apparatus (Fig. 4,2). Lead pellets were attached to the maxilla and mandible interproximally between the premolar teeth and interproximally between the central incisors. The distance between the pellets in each situation was determined using a caliper gauge with a vernier scale. A radiographic exposure was made and from the length measurements between the lead pellets on the resultant image and the measured lengths on the skull, a correction factor was calculated.

In the investigation of human subjects, however, the mandible and maxilla were separated from the housing of the image intensifier by the soft tissues of the face. According to the thickness of these tissues, this results in a variable object-film distance which will affect the size of the resultant image. For each object - film distance therefore a separate correction factor appeared necessary.

The variation in correction factors for different object - film distances was determined by making radiographic exposures of the dentulous skull positioned at 40, 50 and 60 mm, respectively from the housing of the intensifying apparatus. Correction factors were calculated as previously described and are presented in Table 4,1.

Lateral tilting of the head during exposure may result in either foreshortening or elongation of the radiographic image. The effect of such tilting on the correction factors was determined by making exposures of the skull tilted at 10° and 30° from the horizontal towards the film. Correction factors were calculated as described and are presented in Table 4,2.

10.4 Comment

In the clinical investigation the transmitting coil system was in use intermittently for a total period of less than two hours. The maximum drift in output was therefore -0.6%. The possible effect of this drift on the results was reduced further by calibrating the instrument with spacing shims after each recording (which lasted approximately 10 minutes). The possible error due to changes of temperature was extremely small as the system was used within a very limited temperature range (mouth temperature, approximately 37°C). Considering the circumstances of use, it is unlikely that the transmitting coil system makes any appreciable contribution to errors in results. The maximum error present in the potentiometric recorder is so small ($\pm$ 0.5%) that it also is unlikely to have any appreciable effect on the results.

The correction factors used in the fluorography study varied according to the distance of the skull from the screen, and the angle of the skull to the screen from the horizontal. As the skull-screen distance increased the correction factor decreased. Conversely as the angle of the skull from the horizontal increased, so also did the correction factor. The correction factors for the premolar and incisor regions at each position of the skull will vary slightly as a result of the difference in object-film distances for each region.

The maximum difference in correction factors was 0.032 being the difference in the incisor region between a skull-screen distance of 40 mm and 60 mm respectively. As the correction factors will be used to convert small readings of interocclusal clearance, a difference of 0.032 when applied to an interocclusal clearance of 5 mm would result in the error of only 0.16 mm. Such an error should not be clinically detectable. The distance of the skull from the screen therefore, provided it is not excessive should not have any appreciable effect on results. Lateral tilting of the skull was controlled to some extent during the investigation by placing the side of the face against the housing of the image intensifier. It is unlikely that such tilting will exceed 10° and will therefore have little effect on results.

CHAPTER 11

Errors in Materials

ERRORS IN MATERIALS

11.1 Introduction

In the present study some of the dental materials used introduce errors which are essentially related to their dimensional accuracy and stability. Some of these errors are inherent in the materials themselves, whilst others arise from techniques of manipulation. In the present study the materials used included alginate impression material,[1] dental stone[2] and fluid acrylic resin.[3] Some consideration has been given to both the inherent errors and errors due to manipulative techniques. The general description of the properties of the materials has been derived from SKINNER and PHILLIPS (1967), PEYTON (1968) and ANDERSON (1972).

11.2 Alginate Impression Material

The dimensional stability of most present day alginates is good, the dimension of a cast poured from an alginate impression having an error not greater than 0.15% (WILSON and SMITH 1963a). Inaccuracies, however, may occur when taking the impression, removing it from the mouth, storing it, or pouring a cast into it.

The alginate used in the present study has been reported as being dimensionally stable to within 0.02% (WILSON and SMITH 1963a). This degree of accuracy is obtained only by the correct manipulative techniques. Accordingly the instructions of the manufacturer with regard to mixing were

---

1 Super Kromopan : F.H. Wright Dental Mfg. Co. Ltd., Dundee, Scotland.

2 Kaffir D : British Gypsum Ltd.

3 Pour/Cure : Coe Laboratories Inc., Chicago.

followed throughout. The development of strains in the material, which may occur due to uneven bulk and differential rates of gelation was minimised by using impression trays which were specially constructed for the individual subject (OSBORNE and LAMMIE 1954). Adhesion to the tray was achieved by both proprietary tray adhesive[4] and perforations, to resist tensile and shearing forces respectively between the material and the tray on removal from the mouth (WILSON and SMITH 1963b). On completion of gelation, the impression was removed swiftly in order that the strain induced would be counteracted by the elastic recoil, and so avoiding tearing and permanent deformation of the material.

After removal from the mouth, casts were poured immediately in order to avoid the contraction and dimensional change of the material due to loss of water to the atmosphere (DONNISON and DOCKING 1960). The occlusal part was poured first and the base added later to minimise distortion.

11.3 Dental Stone

Dental stone is prepared by dehydrating gypsum in a closed container to form the α-hemihydrate. The setting expansion (in the region of 0.1 - 0.2%) is usually independent of the powder water ratio in mixing. At room temperature and humidity, the dimensional change after setting is approximately 0.02%, and is negligible (SWEENEY and TAYLOR 1950,

---

4 Hold : Hill Bros. (Hull) Ltd., Hull

MAHLER 1955).

11.4 Fluid Acrylic Resins

Fluid acrylic resins have been used as both denture base materials and in the duplication of dentures as described by SHEPARD (1968), WAGNER (1970), and RALPH and PAUL (1972). They have been found more accurate than conventional heat cured resins (ANTHONY and PEYTON 1962, SHEPARD 1968). Furthermore, the mould used in polymerisation is a reversible hydrocolloid which reduces the inaccuracy caused by the setting expansion of gypsum mould used with heat cured resins (GRANT 1962).

In the present study the error present in a duplicate denture was investigated in the following manner. A master upper denture and its duplicate were placed with the occlusal surface uppermost, in plaster of Paris mixed with an anti-expansion solution. The dentures were sectioned vertically at the distal border of the canine teeth and at the distal border of the first molar teeth.

Each section in its plaster base was placed against a straight edge under a travelling microscope (Fig. 4,3). Measurements were made of the interbuccal distance, the sulcus depth and palatal thickness as indicated in Fig. 4,4. An average was taken from readings in both directions of travel. The values for each section for both master and duplicate dentures are shown in Table 4,3.

11.5 Comment

The contribution to error from alginate and dental stone is minor and unlikely to have any noticeable effect on results. Dimensional differences exist between master and duplicate dentures but these are also small and in most cases would not be detectable clinically. However, loss of vertical dimension of occlusion in dentures processed in fluid acrylic resin has been reported (SHEPARD 1968). In the present study the vertical dimension of occlusion was verified by fitting the duplicate dentures on casts mounted at the vertical dimension of occlusion of the master denture. If a discrepancy was present the process of duplication was repeated.

In general therefore it would appear that if the correct manipulative techniques are followed the errors due to materials are unlikely to have appreciable effects on the results.

CHAPTER 12

Errors in Analysis

ERRORS IN ANALYSIS

12.1 Introduction

In any investigation, potential sources of error may arise in the analysis of the data obtained. The present study employed both visual and measurement techniques of analysis, and investigations have been performed to determine the error present in the visual assessment, the accuracy of measurements and the reliability of reproduction of reference points and lines from which measurements are made.

12.2 Visual Analysis

The visual analysis was applicable only to the part of the fluorographic study which realised enumerative data related to the presence or absence of occlusal tooth contact in dentulous subjects during each swallowing sequence. Such an analysis is subject to intra-observer error where variations may occur in separate assessments of the same parameter by a single investigator, or inter-observer error where variations may occur in the assessments of different investigators. Accordingly, intra-observer error was determined by comparison of data obtained on separate occasions from 60 swallowing sequences, and inter-observer error was determined by comparison of data obtained from the same sequences by an independent observer (F. B. C.). The results are presented in Table 4,4.

12.3 Accuracy of Measurements

Measurement data were investigated from both the transmitting coil study and the fluorographic study. In the former it had been necessary to construct calibration curves (Chapter 7) to determine jaw separation of subjects, as relationship between recorder pen deflection and true jaw separation was non-linear. In order to investigate the error present in measurements obtained from such curves, one was constructed by the author, and a separate one from the same recording by an independent investigator (M.H.) using millimetre graph paper. Readings were taken at 10 mm intervals of trace deflection from 0 to 100 mm. From these were derived the corresponding values for true jaw separation (Table 4,5). Differences were present in only three readings, the greatest being 0.15 mm.

The fluorographic study involved the minute adjustments and readings associated with a caliper gauge calibrated to 0.1 mm, and accordingly was investigated with regard to both intra- and inter-observer error. Prior to the commencement of these investigations, readings from the caliper gauge at various positions were made by the author and an independent investigator (M.S.S.). The results of these readings are shown in Table 4,6, and indicate that there is little error between investigators in reading the gauge. The maximum error recorded (0.1 mm) is extremely small and equal to the accuracy of the gauge itself. Length measurements were then made by each investigator from point X perpendicularly to the mandibular line (Chapter 8), on one print from each of the 20 edentulous subjects. The results are shown in Table 4,7. Following these readings, measurements were repeated by the author and compared to his original observations (Table 4,8). The error in such a method was computed using the formula :

$$S = \sqrt{\frac{(\Sigma d^2)}{2n}}$$

(where d is the difference between readings and n the number of readings) as suggested by NEVAKARI (1956) and LUNT (1966). This showed an intra-observer error of 0.06 mm and an inter-observer error of 0.1 mm.

12.4 Reliability of References

The frame analysis of a swallowing sequence for any one subject required measurements from relevant photographic frames from the sequence. Reproduction in successive frames of reference points and lines from which measurements are made constitutes a possible source of error (RICHARDSON 1966). The magnitude of the error and its effect on results were determined in the following manner. A dentulous subject was selected and 30 photographic exposures were made of a lateral jaw radiograph with the teeth at the intercuspal position. Reference points and lines as described in Chapter 8 were located on prints prepared from these negatives. Thus the full range of measurements used in the fluorographic study could be obtained.

On each print, six length measurements were made as shown in Figure 4,5. The values of these measurements for each of the 30 frames, together with the calculated means and standard deviations are shown in Table 4,9. It is illustrated in Fig. 4,6 how the standard deviation increases as the value of the mean rises. The effect that the increase in the standard deviation will have on results may be seen if normal distribution curves are constructed from the graph for mean values of 10, 20, 30 and 40 mm (Fig. 4,7). The tall narrow curve constructed for the 10 mm mean indicates a tight grouping of readings around the mean - the range of dispersion is limited. As the mean increases, however, the curves lose height and gain width indicating a greater possible dispersion of readings. Therefore in the present study, the smaller the mean, the greater the accuracy of the results. This is in agreement with KVAM and KROGSTAD (1971) who noted that the variability of measurements from X-ray films was related to the size of the reading.

12.5 Comment

In a visual analysis the scope for error is great and may be due either to the inability of the investigator to analyse correctly a rapidly moving sequence, or to a preconception of the results which prevents an impartial opinion being made. Although the differences between intra- and inter-observer analysis are small and not statistically significant (for intra-observer difference $p > .1$ and for inter-observer difference $p > .8$) such a method is clearly unsuitable for a detailed analysis. Its main value is in allowing a rapid initial assessment which can act as guidance in more sophisticated methods of analysis.

The intra-observer error of 0.06 mm in measurement is extremely small being less than the 0.1 mm minimum division on the measuring instrument. The inter-observer error is equal to the accuracy of the measuring instrument. Contribution to error by techniques of measurement is therefore minimal and should have no appreciable effect on results.

Errors arise, however, in the reproduction of reference points and lines. Each measurement must be considered from a probabilistic point of view. By reference to the graph of standard deviation against the mean (Fig. 4, 6) an estimation may be made of a range of possible readings around any mean. Assuming a normal distribution 95% of readings of a single parameter will lie within ± 2 standard deviations of the mean. In the measurement analysis therefore any single measurement which lies within ± 2 standard deviations of the value of the reference measurement cannot be considered to represent a true difference from the reference measurement.

In order to estimate the level at which true differences between measurements are present, normal distribution curves were constructed for means of 10 and 11 mm, 25 and 26 mm and 40 and 41 mm (Fig. 4, 8a, 8b and 8c). From the resultant curves it can be seen that at the 10 mm level a difference in measurement of 1 mm noticeably represents a true difference in all cases. At a level of 25 mm it represents a true difference in approximately 95% of cases, while at 40 mm a true difference is present in approximately 90% of cases. The area of overlap between the bell-shaped curves and its ratio to the total area under one such curve allows one to make these estimates.

In summary therefore, throughout this range of measurement, 0-40 mm, a difference in reading of 1 mm represents a real difference. For measurements in the lower part of this scale, reading differences of even less than 1 mm may be relied upon to represent true differences.

CHAPTER 13

Random Errors

RANDOM ERRORS

13.1 Introduction

Random errors are those which may occur in an irregular pattern. Although they may be anticipated, they cannot always be controlled. They may, however, be minimised by standardisation and care in techniques. Such errors may be divided into operator-induced error, subject-induced error, and apparatus-related error.

13.2 Operator-induced Error

The simplest form of operator-induced error occurs when the subject becomes influenced, by directions and instructions, to provide a subjective rather than an objective result. In order to minimise this error subjects were not informed of the precise nature of the investigation, and were only instructed to sip some water and swallow it.

In the fluorographic study, the position of the head of the subject also suggested a potential source of error. Although lateral head movement was controlled by positioning the lateral surface of the face against the housing of the image intensifier, the distance of the teeth from the screen was variable dependent upon the thickness of the soft tissues of the face. It has been shown (Chapter 10) that the correction factor varies with the object - film distance.

Measurement on a subject immediately prior to exposure was considered to cause interference with the position of the head, necessitate re-positioning and so introduce further error. In order to determine the variability in distances of teeth from the screen, a group of 20 dentulous subjects, 10 male and 10 female were positioned for lateral jaw radiographs. The distances from the buccal cusp of the upper first premolar and from the mesio-incisal point of the upper central incisor to the housing of the image intensifier were measured. The average of three measurements was taken for each subject. For the purposes of analysis the subjects were divided into three groups : (i) the total sample (ii) males (iii) females. The individual measurements, means, and standard deviations are presented in Table 4, 10a, 10b and 10c. The means of the premolar and incisor distances from the second and third groups were compared with the means of the first group using a 't' test. The differences between the means were not significant ($p > .1$ for males, $p > .2$ for females).

13.3 Subject - Induced Error

Participation in experimental work may impose a mental strain on certain persons. This is particularly so if they are uninformed and confronted suddenly with a mass of complex apparatus. The fact of being under observation is also a contributory factor. The performance of a subject under strain may be unnatural and lead to unreliable results. Unfortunately it is virtually impossible to determine the effect of such strain on an individual subject, but an attempt can be made to control and minimise it. In the present study this was done by limiting the amount of apparatus visible, by attempting to put the subject at ease, and by making recordings of several swallowing sequences to allow the subject to become accustomed to the procedure of investigation.

Discomfort or pain during experimentation may initiate undesirable reflex actions, particularly with reference to the preliminary study where the subject had record blocks placed in the mouth, and to the section of the fluorographic study devoted to subjects with complete dentures. Considerable care was taken in the construction of these appliances in order to eliminate potential traumatic areas, and subjects were questioned regarding comfort prior to the commencement of the recording.

The volume of water which constituted a "sip" was an uncontrolled variable throughout the whole study. It would have been preferable to provide each subject with a specific volume of water for each sip, but as this would have involved switching off the machine and changing drinking vessels between sips, it was considered impractical. It was also considered that such a manoeuvre could result in a change in the head position of the subject and possibly introduce more error than it avoided. However, in order to have some guidance to the total amount of water swallowed during six sequences, measurements were made from 12 subjects. The volume swallowed by each one together with the mean volume swallowed is shown in Table 4,11. From the large spread of values it is evident that a "sip" has a meaning peculiar to each individual.

13.4 Apparatus - Related Error

The term apparatus-related error is used to denote the error in results which may be attributed directly to the use of apparatus. It does not include the consideration of stated errors in commercial equipment or the strain imposed on a subject when he is confronted with such equipment.

In the present study, this source of error is related to the presence of foreign bodies in the mouth in the form of record blocks and wires (transmitting coil study) or lead pellets attached to the teeth, and duplicate dentures (fluorographic study). These may all have an effect on normal function.

Record blocks and transmitting coils may interfere with function by virtue of their bulk. The precise effect on the swallowing sequence is extremely difficult to determine as any assessment using a transmitting technique would still involve placing apparatus in the mouth. Fluorographic techniques on partially edentulous subjects avoid the use of record blocks and wires. Comparison of results therefore from each study can provide an estimate of potential error by determining the significance of association or similarity in results using a χ^2 test.

The lead pellets which are attached to the teeth in the interproximal region are small (approximately 2 mm in diameter) and clear of the occlusion. They are therefore unlikely to interfere with swallowing function. Part of the investigation in the study was specifically directed to jaw relationships during swallowing while wearing complete dentures. Such dentures were not considered as contributing to error provided the subjects had become accustomed to them, and there was no displacement of the dentures during the swallowing sequence. The incidence of displacement of the dentures is reported in Chapter 18.

13.5 Comment

Random errors in the study have been controlled as far as possible as described above. Nevertheless they cannot be entirely eliminated and may have an indeterminate effect on results. The greatest range of difference in distances from the jaws to the image intensifier was 18 mm. It has been demonstrated (Chapter 10) that a difference in correction factor over a range of 30 mm is extremely small and unlikely to have any appreciable effect on results. The correction factors used for all subjects therefore were those calculated in Chapter 10 for a 40 mm object - film distance in the premolar region.

The amount of water swallowed at each sip remained a variable throughout the study. It was considered, however, that this variable was less likely to contribute to error than the problems associated with the provision of definite volumes of water for swallowing.

SECTION 5

PRESENTATION OF RESULTS

CHAPTER 14

The Transmitting Coil Study

THE TRANSMITTING COIL STUDY

14.1 Introduction

In the transmitting coil study interest was centred on the presence or absence of occlusal tooth contact during swallowing. Ten subjects participated in the study, 5 male and 5 female. Their ages ranged from 18 to 60 years with a mean age of 37.2 years.

14.2 The Swallowing Sequence

The vertical mandibular movements during the swallowing sequences were recorded graphically (Fig. 5, 1). Some variability within and between subjects was evident, but a similar overall pattern emerged. Sequences commenced either from a position of occlusal tooth contact or from a position where some interocclusal clearance was present. The interocclusal clearance increased as water was drawn into the mouth, and was indicated normally by a single peak on the trace. Occasionally, however, twin peaks separated by a shallow trough were evident. A rapid decrease in interocclusal separation immediately prior to clinical evidence of swallowing then followed. In many cases a zero measurement was reached which indicated tooth contact in the intercuspal position, but in some sequences, extension of the trace below the established base line occurred. Such an anomaly could possibly be explained by the occurrence of lateral or antero-posterior mandibular movements causing a change in coil relationships, which might result in an intensified signal because of a more favourable field. The tooth contact or level of separation was maintained for a short period (Table 5, 1) as the subject swallowed the water, the mean length of time being 0.8 seconds.

The vertical jaw position following a swallowing sequence was variable. Some sequences terminated in occlusal tooth contact whilst others demonstrated some degree of interocclusal clearance. Most sequences featured some oscillation in the degree of interocclusal clearance until a stable mandibular position was reached.

14.3 Occlusal Tooth Contact

The estimation of means of individual measurements of separation is of no great value over such a small range. Accordingly, results have been expressed as enumeration data, either as contact or as lack of contact, during several swallowing sequences for each subject (Table 5, 2). As the relationship between the interocclusal clearance and signal intensity was non-linear a calibration curve was plotted for each subject (Chapter 7). Although definite occlusal tooth contact could be ascertained, measurements of 0.2 mm separation or less could not be determined accurately. An interocclusal clearance of 0.2 mm however, is so small that it is of minor clinical importance, and may be considered as equivalent to occlusal tooth contact (NEILL 1964). Tooth contact was evident therefore in 45 from the 60 swallowing sequences (75%). Five subjects demonstrated contact consistently throghout the recordings, whilst in 1 subject contact was consistently absent. In the remaining 4 subjects there were variations in the number of sequences exhibiting contact. Due to the limited number of subjects investigated however, it is unrealistic to present these latter figures as percentages.

14.4 Position of Contact

The problem of determining the position of contact was emphasised by the extension of the trace below the established base line. It was considered that this extension probably indicated occlusal tooth contact in a position other than the intercuspal position. On this assumption it was found that occlusal contact in a position other than the intercuspal position occurred 24 times in 45 swallowing sequences. The position of contact, however, could not be determined.

14.5 Final Mandibular Position

The position adopted at the completion of the sequence was extremely variable (Table 5,3). Occlusal contact at the end of a swallowing sequence was demonstrated in 48% of all the swallows in the study, and two subjects exhibited occlusal contact at the end of every swallowing sequence.

14.6 Comment

The part of the study using the transmitting coil involved only dentulous subjects (with opposing edentulous saddles present in the mouth). The results can therefore be compared with results from the fluorographic study on dentulous subjects. In view of the association between the two groups of subjects and in order to avoid unnecessary repetition the discussion of the present results has been included with the discussion of the results from dentulous subjects in the fluorographic study (Chapter 16).

CHAPTER 15

The Fluorographic Study : Swallowing Sequences and Analysis

THE FLUOROGRAPHIC STUDY : SWALLOWING SEQUENCES AND ANALYSIS

15.1 Introduction

The investigations in the fluorographic study were performed on 60 subjects who were either dentulous, edentulous, or edentulous wearing dentures. In each of 59 subjects, 6 swallowing sequences were recorded and in 1 subject 5 sequences were recorded. A total of 359 sequences was therefore available for analysis. Typical sequences from each group of subjects are shown in Fig. 5, 2a and 2b.

15.2 The Swallowing Sequence

Swallowing sequences for individual subjects followed a general pattern, although minor variations were sometimes evident both within and between subjects. Following the initial opening of the mouth in order to sip the water provided, the mandible was observed to move vertically upwards, assuming a relationship to the maxilla which was normally maintained until the water was swallowed. In dentulous subjects this relationship appeared often but not invariably, to be the position of occlusal tooth contact. Commencement of true swallowing was evidenced by the backwards and upward movement of the soft palate to contact the posterior pharyngeal wall, together with forward and upward movement of the hyoid bone towards the lower border of the mandible. This latter movement was more definite in dentulous subjects and edentulous subjects wearing dentures, than it was in edentulous subjects. The termination of the swallowing sequence was evidenced by the return of the hyoid bone and soft palate to their pre-swallow position. In some cases this was accompanied by a vertically downward movement of the mandible.

The most common variation in a single sequence was the occurrence of multiple movements of the soft palate and the hyoid bone, indicating the occurrence of several swallows. The first swallow in these cases rarely included vertical elevation of the mandible, which tended to remain at the initial mouth-open position. Subsequent swallows however, tended to follow the previous general description, being accompanied by mandibular elevation and evidence of occlusal tooth contact in some dentulous subjects and edentulous subjects wearing dentures. Complex movements of the tongue may also occur during swallowing. No observations were made on such movements, however, as in fluorographic study the soft tissues of the tongue were not clearly defined.

15.2.1 Comment

Upward movement of the mandible prior to swallowing is effected by the elevating muscles of mastication. In dentulous subjects it has been suggested that this position indicates contact of the maxillary and mandibular teeth (GILLIS 1941, RUSHMER and HENDRON 1951, POSSELT 1968, SCOTT and DIXON 1972) and that swallowing is difficult, if not impossible, if such contact does not occur (BELL et al. 1972). From the general description of the swallowing sequence it is clear that neither of these statements is necessarily true in every case.

The backward and upward movement of the soft palate and its contact with the posterior pharyngeal wall, seals the nasopharynx from the oropharynx and prevents escape of the water via the nose. Upward and forward movement of the hyoid bone is effected by contraction of the suprahyoid group of muscles, as the water is propelled from the oral cavity into the oropharynx. After completion of swallowing the soft palate and hyoid bone return to their pre-swallow position.

The reason for the occurrence of a tooth apart swallow in the dentulous subjects is not clear. There may, however, be some association with the situation in which liquid may be poured directly into the pharynx and swallowed while the mouth remains open. In the present study a related situation may have resulted from a subject taking an excessively large sip of water.

In all swallowing sequences viewed, the movements of the soft palate and hyoid bone were consistently present. From the general description therefore, the precise moment of swallowing can be determined on the screen by the combined movements of these structures.

15.3 The Analysis

The interest in the present study is centred on the presence or absence of occlusal tooth contact during swallowing in dentulous subjects, the relationship of mandible to maxilla during swallowing in edentulous subjects, and the presence or absence of occlusal tooth contact during swallowing in edentulous subjects wearing complete dentures, together with the final mandibular position in all cases. Information on these questions was obtained by both visual and measurement analyses.

15.3.1 Visual Analysis

As the exact position of the edentulous mandible in space is difficult to determine visually, and the complete dentures were constructed in radiolucent acrylic resin and consequently were not clearly visible radiographically, the visual analysis is applicable only to dentulous subjects, being restricted to the assessment of presence or absence of occlusal tooth contact preceding and during each swallowing sequence.

15.3.2 Measurement Analysis

The measurement analysis was performed on prints from photographic frames of swallowing sequences as described in Chapter 8. As the presence of active swallowing was determined by the movement of the hyoid bone, the frames selected for analysis were those in which the hyoid bone was elevated from its pre-swallow position. This ensured that measurements of the mandibular position were made during the active part of the swallowing sequence.

Additional frames at the beginning and end of the investigation for each subject were also included in the measurement analysis. The frame at the beginning was included for purpose of reference, and was a record of the subject with the jaws at the pre-swallow position. In dentulous subjects and edentulous subjects wearing dentures, the jaws and teeth were in the intercuspal position, whilst in edentulous subjects the mandible was in a "relaxed" position. The frame at the end of the sequence gave an indication of the position of the mandible after completion of swallowing and was included in order to assess whether or not "rest jaw relationship" occurred after swallowing.

In the analysis of results, all measurements recorded were compared to a reference measurement. The variability of the value for the reference measurement was calculated to $\pm$ 2 standard deviations as described in Chapter 12. The measurements recorded, when compared to the reference measurement fell into one of three categories.

The first category included measurement values within an estimated $\pm$ 2 standard deviations of the range of variability of the reference measurement. Such values were indistinguishable from the reference measurement at 95% level of probability.

The second category included measurement values which differed from the reference measurement by 1 mm or more. As explained in Chapter 12, within the range of measurements recorded in the study this was an indication of a true difference between measurements.

The third category included measurements which lay outwith the range of variability of the reference measurement but the difference between the two measurements was less than 1 mm. In such cases the range of variability of these measurements to $\pm$ 2 standard deviations was estimated. If the calculated ranges of variability of the recorded and reference measurements overlapped by 1 standard deviation or more the difference between the two values was not considered a true difference. This situation, however, occurred very rarely, but when present indicated some bias of the results towards agreement with the reference measurement.

CHAPTER 16

The Fluorographic Study :

Dentulous Subjects

THE FLUOROGRAPHIC STUDY :

DENTULOUS SUBJECTS

16.1 Introduction

Analysis of swallowing sequences from dentulous subjects was directed to :-

i) the presence or absence of occlusal tooth contact immediately prior to or during a swallow

ii) the position of occlusal tooth contact if and when it occurred

iii) the vertical jaw position at the termination of the swallowing sequences.

Sequences were subjected both to visual and measurement analysis. The former, however, was restricted to the assessment of the presence or absence of occlusal tooth contact, as such an analysis can only be used to provide enumerative data where measurements are not required.

16.2 Visual Analysis

The visual analysis involved 30 dentulous subjects, 18 male and 12 female. Their ages ranged from 19 years to 46 years with a mean age of 24.7 years. Six swallowing sequences were performed by each of 29 subjects, whilst 1 subject performed 5 sequences. A total of 179 sequences was thus available for viewing.

Before commencing a swallowing sequence subjects were observed with their teeth in contact at the intercuspal position. Assessment of contact during a sequence was made relative to the intercuspal position, and contact was assumed to have occurred with radiographic superimposition of the cusps of the upper and lower posterior teeth. The results of the visual analysis are presented in Table 5, 4 and indicate that occlusal tooth contact occurred in 57.5% of swallows in the present series. Comparison of results for males and females did not show any significant difference ($p > .8$).

The validity of the visual analysis, however, is dependent upon the ability of the observer to assess accurately events in a rapidly moving sequence. Although it has been demonstrated (Chapter 12) that differences between separate investigators, and successive observations of the same investigator were not statistically significant, this does not yield any information regarding the precision of the investigation. In addition, the visual analysis is biased towards occlusal tooth contact, as contact was assumed to be present on superimposition of opposing cusps. It is therefore essentially a preliminary analysis which although yielding information is open to a considerable degree of error.

16.3 Measurement Analysis

For the purposes of measurement analysis it was necessary to eliminate 2 subjects due to lack of clarity in the radiographic image and consequent difficulty in the accurate location of references form which measurements could be made. Of the 28 subjects remaining for analysis 16 were male and 12 were female, their ages ranging from 19 to 46 years with a mean age of 25 years. A total of 167 sequences were available for analysis.

Occlusal Tooth Contact

The estimation of occlusal tooth contact was made from measurements from the upper lead pellets in both the incisor and premolar region perpendicularly to the line CD (Fig. 3,11). Presence of contact was determined by comparison of measurements obtained during the swallowing sequence with a reference measurement obtained with the teeth in the intercuspal position.

The recorded measurements for both the incisor and premolar regions are presented in Table 5, 5a and 5b, and the incidence of occlusal tooth contact throughout the sequences is shown in Table 5, 6.

Position of Contact

The position of occlusal tooth contact is not necessarily the intercuspal position, although this was the position of reference in the present study. Contact of teeth may occur laterally, medially, anteriorly or posteriorly to the intercuspal position. As the present investigations were restricted to jaw relationships in the sagittal plane, only positions of contact anterior or posterior to the intercuspal position can be considered. Accordingly the position of tooth contact during swallowing was compared to the position of tooth contact at the intercuspal position, in order to determine any possible difference in the antero-posterior relationship of the jaws and teeth. The measurement used for comparison was the distance from the anterior lower lead pellet to the point at which a perpendicular from the posterior upper lead pellet intersected the line CD (Fig. 3,11). Differences were converted to true values using the correction factor (Chapter 10), and are presented in Table 5,7.

Final Mandibular Position

The position adopted by the mandible after swallowing is widely held to be the rest jaw relationship at which some degree of interocclusal clearance is present (THOMPSON 1946, FENN et al. 1961). In the present study the amount of interocclusal clearance present at the termination of swallowing was determined by comparing the vertical distance between the jaws at the final mandibular position, with that at the intercuspal position as described above. Measurements were made from 27 subjects and the values for the interocclusal clearance are presented in Table 5,8.

16.4 Discussion

Occlusal Tooth Contact

The fluorographic investigation has confirmed findings by previous investigators (RIX 1946, CLEALL 1965, MØLLER 1966, INGERVALL et al. 1971) that the act of swallowing may be performed with or without occlusal tooth contact. In the subjects studied tooth contact during swallowing was present in 20 of 28 subjects (71.4%) although not invariably present in every sequence. Contact, however, was present on only 82 of 167 sequences (49.1%). This large discrepancy is explained by the fact that in many subjects contact was present in some sequences but not in others. In only 7 subjects was tooth contact present in all swallowing sequences and in 8 subjects it was absent in all sequences. The remainder (13 subjects) demonstrated a variability in tooth contact, being present in some sequences but not in others.

The percentage of subjects who demonstrated tooth contact at some stage during the swallowing sequence (71.4%) agrees well with that reported by RIX (69.6%) and is higher than that reported by CLEALL (60%) and MØLLER (65%). The methods of investigation of these workers were respectively visual, radiographic and electromyographic assessments. The frequencies of tooth contact reported were with reference to the swallowing of saliva. The subjects involved in the investigations were young children (RIX), adolescents (CLEALL) and adults (MØLLER). The results of these investigators for the incidence of tooth contact during swallowing, together with similar results from the present study are presented in Table 5,9.

Comparison of the present results with those of previous investigators was made using a χ^2 test. The greatest difference recorded (11%) was between results in the present study and those of CLEALL. This difference, however, was not statistically significant ($p > .2$). The differences between present study and the results of RIX and of MØLLER are even less significant ($p > .8$ and $p > .5$).

The close correlation between the present results and those of other workers strongly suggest that occlusal tooth contact is to be expected in the majority of subjects during a swallowing sequence. In the present study the results have been determined from a greater number of swallowing sequences for each patient than in the other studies. It is clear that tooth contact during swallowing is not necessarily present in every sequence and that variability occurs in sequences from the same individual.

The lower incidence of tooth contact (49.1%) throughout the total number of swallowing sequences was noted as being associated with the irregularity of tooth contact in the majority of subjects. In a radiographic study, however, INGERVALL et al. (1971) reported tooth contact occurring in 78% of swallows in a series of 63 sequences. Two different media for swallowing were selected, water and barium of varying viscosities. In addition, swallowing was performed both before and after anaesthetising the capsules of the temporomandibular joints. With the introduction of such variables it is perhaps unrealistic to state that tooth contact occurs in 73% of sequences. It is noted, however, that when swallowing water (with both anaesthetised and non-anaesthetised joint capsules) that the incidence of tooth contact is reduced to 67% in a series of 21 sequences. This figure appears considerably higher than that found in the present study. If compared to the present study using a χ^2 test, however, the difference is not statistically significant ($p > .1$).

The percentage incidence of tooth contact throughout the total number of swallowing sequences in the transmitting coil study (75%) was considerably greater than that recorded in the fluorographic study. Comparison of the results indicated that this difference was probably significant ($p < .05$). This difference might possibly be explained by vertical displacement during swallowing, of the record blocks which carried the coils, which might result in contact of the coils before contact of the natural teeth. Alternatively it is possible that the presence of blocks in the mouth may have interfered with natural function, resulting in a higher incidence of tooth contact.

Position of Contact

It has been noted (Chapter 4) that the position of occlusal tooth contact during swallowing may vary. It has been stated to be at the retruded contact position (KYDD and SANDER 1961), somewhere between the retruded contact position and the intercuspal position (RAMFJORD and ASH 1971), at either the intercuspal position or the retruded contact position (GRAF and ZANDER 1963), or most commonly in the intercuspal position (PAMEIJER et al. 1970).

In the majority of sequences in the present study (65) contact occurred with the teeth in the intercuspal position. This is in agreement with the findings of MØLLER (1966), PAMEIJER et al. (1970) and INGERVALL et al. (1971).

Of the sequences in which contact occurred in a position other than the intercuspal position, 16 contacts were posterior to it and one was anterior to it. The variation in contact position was restricted to swallowing sequences from 6 of the subjects. In sequences in which contact occurred posterior to the intercuspal position the greatest discrepancy recorded was 1.2 mm and the least 0.7 mm, the average being 1 mm. Whether or not this position was the retruded contact position of the jaws could not be determined, as no reference measurement was available for this position. POSSELT (1968) however, has indicated that the horizontal distance between the retruded contact position and the intercuspal position seldom exceeds 1 mm. In the present study therefore it would appear that the posterior position of tooth contact may closely approach the retruded contact position.

Tooth contact anterior to the intercuspal position occurred in only 1 sequence out of 82. Accordingly, no significance can be attached to such a result. It should be noted, however, that tooth contact anterior to the intercuspal position during swallowing has been reported by PAMEIJER et al. (1970).

The difference between the incidence of contact in a position other than the intercuspal position in the transmitting coil study (24 sequences from 45) and that recorded in the fluorographic study was highly significant ($p < .001$). This might be explained by displacement of the record blocks or by contact in a lateral position. Such displacements could cause variations in coil relationships resulting in changes in signal intensity.

Final Mandibular Position

In the present study, occlusal contact was noted at the termination of swallowing sequences of 16 subjects (59.2%)

from the 27 subjects available for analysis. This percentage is higher than that recorded in the transmitting coil study (46.4%) but the difference between the results is not significant ($p > .1$). The remaining 11 subjects demonstrated varying degrees of interocclusal separation. Although the existence of interocclusal clearance is not evidence of rest jaw relationship, it is accepted that when the mandible is at rest jaw relationship some interocclusal clearance is present (OSBORNE 1949, BERRY 1960, MACK 1964). Occlusal tooth contact occurred in the majority of subjects at the termination of swallowing sequences in the present study which indicated that the action of swallowing was unreliable to determine the rest jaw relationship.

16.5 Conclusions and Comment

It appears that although the majority of subjects showed evidence of tooth contact, this contact is not invariably present. The percentage of contacts occurring in a number of swallowing sequences therefore gives no indication of the percentage of subjects who might demonstrate contact. The irregularity of incidence of contact emphasises the importance of observing several sequences from a single subject. Similarly if the technique is being used clinically then a patient should be encouraged to perform several sequences.

From comparison of the fluorographic study with the investigations of other workers there appears little difference either in the incidence of tooth contact between children and adults during swallowing, or between swallowing of water and swallowing of saliva. Although the incidence of tooth contact in the transmitting coil study appears high it is possible, for the reasons already stated, that it was biased towards contact. Excessive emphasis should not therefore be placed on the results from the transmitting coil study.

The position of contact is most commonly the intercuspal position. In sequences where contact was outwith the intercuspal position it occurred most often in a retrusive position and tended to be demonstrated over several sequences by comparatively few subjects. This position although retrusive to the intercuspal position was not necessarily the retruded contact position. The observations in the present study were restricted to the sagittal plane and it is possible that deviation from contact at the intercuspal position may also occur in the coronal plane. This might partially account for the higher incidence of contact outwith the intercuspal position recorded in the transmitting coil study as change of coil relationships in both sagittal and coronal planes could be recorded.

The relationship of the jaws at the termination of swallowing sequences was variable, but occlusal tooth contact was present in over 50% of cases. As rest jaw relationship is associated with some degree of interocclusal clearance the action of swallowing cannot be regarded as useful in establishing the rest jaw relationship.

CHAPTER 17

The Fluorographic Study :

Edentulous Subjects

THE FLUOROGRAPHIC STUDY :

EDENTULOUS SUBJECTS

17.1 Introduction

The analysis of swallowing sequences from edentulous subjects involved measurements of the vertical position of the mandible relative to the maxilla, and was directed as follows :-

i) to establish whether or not a constant and reproducible vertical jaw relationship existed in the edentulous subject during swallowing. This jaw relationship will be referred to in the text as the swallowing level.

ii) to examine the relationship between the swallowing level and the "relaxed" position of the mandible prior to commencement of the swallowing sequences.

iii) to compare the vertical relationship of the mandible to the maxilla in the "relaxed" position prior to commencement of the swallowing sequences, with that recorded after completion of the sequences, the final jaw separation.

Swallowing sequences for edentulous subjects were subjected only to a measurement analysis.

17.2 Measurement Analysis

The data for analysis was obtained from swallowing sequences for 20 subjects, 7 male and 13 female. Their ages ranged from 39 years to 75 years with a mean age of 59 years. The range of dispersion around the mean was fairly large (standard deviation = 11.93). Each subject performed 6 swallowing sequences, making 120 sequences available for analysis.

All estimations of the vertical jaw separation between the mandible and maxilla were made from point X perpendicular to the mandibular line and from point X to where a line perpendicular to the nasal line and passing through point X intersected the mandibular line (Fig. 3,11). The former measurement gave an indication of jaw separation in the region where the premolar/molar teeth had been, and the latter in the region where the incisor teeth had been.

<u>The Swallowing Level</u>

The recorded measurements of vertical jaw separation during each swallowing sequence from each subject, together with their mean values are presented in Table 5, 10a and 10b The mean value for the swallowing threshold was used as a reference to which the other values in the sequence were compared, as described in Chapter 15. A reproducible swallowing level was only considered present if at least 3 of the readings for jaw separation fell within the range of variability of the mean. The mean reading, its range of variability and the number of readings within and without that range are presented in Table 5, 11a and 11b for both premolar/molar and incisor regions. The results indicate that a reproducible swallowing level was present in 18 subjects and absent in 1 subject as evidenced by measurements in both the premolar and incisor regions. One further subject was classed as doubtful as a reproducible level appeared to exist in the incisor region for 3 sequences, but did not appear to exist in the premolar/molar region.

The relationship between the swallowing level and the "relaxed" position of the mandible was determined by comparing the mean value for the vertical jaw separation throughout the swallowing sequences for each subject with the corresponding value for the "relaxed" position of the mandible at the commencement of sequences. This has been presented as a scatter diagram for both incisor and premolar regions (Fig. 5, 3a and 3b), the value for the "relaxed" position being plotted against the value for the mean swallowing level for each subject. If the value for the swallowing level falls within $\pm$ 2 standard deviations of the value for the "relaxed" position calculated as described in Chapter 12, then it is indistinguishable from the relaxed position and will fall within the double lines on the diagram. In only a few cases (2 in the incisor region and 4 in the premolar region) do the mean swallowing level and the "relaxed" position correspond. The majority of points are outwith the range of the "relaxed" position and indicate that the vertical jaw separation during swallowing is less than that at the "relaxed" position in 12 subjects and greater in 4 subjects.

17.2.2 Final Mandibular Position

Comparison between the vertical jaw separation at the "relaxed" position prior to commencement of sequences, and that after completion of sequences is also presented in the form of scatter diagrams (Fig. 5, 4a and 4b) as described above. From these diagrams it is clear that approximately 50% of subjects show a vertical jaw separation at the completion of swallowing which is indistinguishable from the vertical jaw separation at the "relaxed" position. Of the remainder, in 40% of subjects the vertical jaw separation was less than that at the "relaxed" position and in 10% of subjects it was greater.

17.3 Discussion

Little is reported in the literature regarding vertical jaw separation in edentulous subjects during swallowing. The present results, however, appear to indicate that a reproducible swallowing level is present in the majority of subjects over a limited period of time. If a null hypothesis of reproducible swallowing level is assumed and the present results compared to it using a χ^2 test the difference is not statistically significant ($p > .2$) and the hypothesis of a reproducible swallowing level cannot be rejected.

The "relaxed" position to which the swallowing level has been compared is a clinical situation which is thought to correspond to the rest jaw relationship. It cannot be stated with any certainty, however, whether or not the mandible and its associated musculature are at a true rest relationship. A true determination of this requires recordings of the electrical activity of the muscles controlling the mandibular position. Nevertheless, the "relaxed" jaw relationship in the present study corresponds to the rest jaw relationship obtained by the clinician. The percentage of edentulous subjects (60%) demonstrating a vertical jaw separation during swallowing of less than that at the "relaxed" position may be compared to the dentulous subjects who demonstrated occlusal tooth contact during swallowing (occlusal tooth contact must also occur at a vertical jaw separation which is less than that at the relaxed or rest position). The difference between results from the two groups of subjects when subjected to a χ^2 test is not significant ($p > .5$).

On comparing the vertical jaw separation at the end of the swallowing sequence, it would appear to indicate, as in the previous sections of this study (Chapters 14 and 16) that a high percentage of subjects (50%) do not demonstrate a rest jaw relationship following a swallowing sequence, and is further evidence of the unreliability of using swallowing as a method for determining the rest jaw relationship.

17.4 Conclusions and Comment

Although the swallowing level in edentulous subjects has indicated some degree of constancy and reproducibility it does not imply that each subject will demonstrate permanently a constant and reproducible swallowing level. Investigation into such a hypothesis would require a longitudinal study extending over many years. Rather does it indicate that such reproducibility is present over a limited range of time.

There appears to be some correlation between dentulous and edentulous subjects when comparing the swallowing level relative to the "relaxed" position. It is, however, impossible to determine whether there is any correlation between the swallowing level of a subject when edentulous and the swallowing level demonstrated before extraction of the natural teeth. Such information could only be obtained by serial and longitudinal studies of subjects before and after extraction of their natural teeth.

Further evidence has been produced of the unreliability of using the function of swallowing to establish the rest jaw relationship.

CHAPTER 18

The Fluorographic Study :

Edentulous Subjects with Dentures

THE FLUOROGRAPHIC STUDY : EDENTULOUS SUBJECTS WITH DENTURES

18.1 Introduction

Investigation of swallowing sequences from edentulous patients wearing complete dentures was limited to a measurement analysis. This analysis was directed to :

i) the presence or absence of occlusal tooth contact of complete dentures immediately prior to or during a swallowing sequence

ii) the effect on occlusal tooth contact during swallowing resulting from reduction of the vertical dimension of occlusion of the dentures.

iii) the position of occlusal tooth contact if and when it occurred

iv) the vertical jaw position at the termination of the swallowing sequences.

This section of the investigation was performed on 10 subjects, 3 male and 7 female. Their ages ranged from 44 to 78 years with a mean age of 59.9 years. All the subjects had been wearing their dentures without discomfort and had been in possession of them for not less than 2 months and not more than 12 months. A denture adhesive[1] was used in all cases to lessen the possibility

---

1 Stera-fix : Reckitt and Sons Ltd., Hull and London

of displacement of the dentures during swallowing (SHEPPARD and SHEPPARD 1968). Each subject performed 3 swallowing sequences with their dentures at a vertical dimension of occlusion to which they had become accustomed (the original vertical dimension) and 3 sequences with the vertical dimension of occlusion reduced by approximately 3 mm (the reduced vertical dimension). Thus 30 sequences at each vertical dimension were available for analysis.

18.2 Occlusal Tooth Contact

The estimation of occlusal tooth contact was made by comparison of vertical measurements obtained during the swallowing sequence with reference measurements obtained with the dentures in occlusion at the intercuspal position. Measurements were made from the upper lead pellets in both the incisor and premolar region perpendicularly to the line CD (Fig. 3,11). The recorded values for both the incisor and premolar regions at the original vertical dimension and the reduced vertical dimension are presented in Table 5, 12a and 12b, and Table 5, 13a and 13b. The incidence of occlusal tooth contact in all subjects at each vertical dimension is shown in Table 5, 14. From this table it is clear that tooth contact during swallowing was demonstrated by 8 subjects at the original vertical dimension, but only by 3 subjects at the reduced vertical dimension. In the 30 swallowing sequences recorded at the original vertical dimension contact occurred in 19 of them (63%). When the vertical dimension was reduced contact was only recorded in 7 of 30 sequences (23%). The above results were compared using a χ^2 test. The difference between the number of subjects demonstrating occlusal tooth contact at each vertical dimension was not significant ($p > .05$). The difference between the total number of contacts recorded at each vertical dimension was, however, found to be significant ($p < .01$).

18.3 Position of Contact

The position of tooth contact in the sagittal plane was determined with reference to the intercuspal position. Readings were taken from the anterior lower lead pellet to the point at which a perpendicular from the posterior upper lead pellet intersected the line CD (Fig. 3, 11). The differences (if present) between the readings at the position of contact during swallowing and at the intercuspal position were converted to true values using the correction factor (Chapter 10). The variations in the antero-posterior position of contact during swallowing, both at the original and the reduced vertical dimension, are presented in Table 5, 15. The vast majority of contacts (23 of 26) occurred at the intercuspal position. Of the 3 contacts not at the intercuspal position, all were posterior to it.

18.4 Final Mandibular Position

Measurements of the vertical jaw position after swallowing were compared to similar measurements at the intercuspal position. Any difference between them indicated the amount of interocclusal clearance present after swallowing. The true values recorded for the interocclusal clearance are shown in Table 5, 16. From the results presented, interocclusal clearance appears to be present more often at the termination of swallowing sequences with complete dentures in which the vertical dimension of occlusion had been reduced.

18.5 Discussion

Occlusal Tooth Contact

The incidence of occlusal tooth contact recorded in swallowing sequences with dentures at the original vertical dimension (63%) is greater than that recorded for dentulous subjects (49%). As the vertical dimension of occlusion of the dentures was, within clinical and technical limitations, believed to be correct for each subject, it might have been expected that the incidence of occlusal tooth contact in each group would be similar. The difference, however, was not found to be significant ($p > .2$).

It has been suggested (O'LEARY et al. 1967) that contact of the natural teeth during swallowing makes a significant contribution to the maintenance of tooth position. If this is also true for complete dentures then any awareness by the subject of movement of his dentures might be followed by tooth contact to maintain them in position. Such an action could possibly explain the apparent greater incidence of tooth contact in subjects wearing dentures.

Noticeable movement of complete dentures during oral function has been reported by ARDRAN et al. (1957), KAIRES (1957), and SMITH et al. (1963). It was noted, however, that if the subject had a favourable denture bearing area with firm alveolar ridges, then movement of a denture was extremely small, being less than 1 mm (WOELFEL et al. 1962). Although a denture adhesive was used in the present study this does not guarantee that the dentures will remain in position. It is clear that any vertical displacement of the dentures during swallowing may result in an artificially high recording of the incidence of occlusal tooth contact. The amount of displacement during each sequence was therefore determined by recording the distance from the lead pellets in both upper and lower dentures, to the nasal and mandibular lines respectively (Fig. 3, 11), and comparing them to similar measurements recorded at the intercuspal position (Table 5, 17a and 17b). Little displacement of the upper denture was evident, occurring in only 1 of 60 swallowing sequences. There was a greater incidence of displacement of the lower denture, which was, however, mainly restricted to 1 subject. Of the instances of displacement which were recorded none had the effect of increasing the incidence of occlusal tooth contact as in the sequences in which displacement occurred occlusal tooth contact was not evident.

The results in the present study can also be compared with results from a study of SHEPPARD and SHEPPARD

(1971) who demonstrated occlusal tooth contact in 52.5% of swallowing sequences from subjects with complete dentures. The difference between these results and the present study is not significant ($p > .5$) but these workers did consider the incidence of contact to be extremely low. They were of the opinion that this was due to the fact that in many of the dentures examined the vertical dimension of occlusion was insufficient. Furthermore, it was thought that some subjects may have consciously avoided tooth contact because of pain or discomfort in the denture bearing area. These comments, however, are not applicable to the present study, as the original vertical dimension of occlusion of the dentures was considered to be sufficient and clinically correct, and each subject had reported his or her dentures as being comfortable.

In the present investigation, however, reduction of the vertical dimension of occlusion of the dentures was accompanied by a significant decrease in the incidence of occlusal tooth contact during swallowing. This would appear to support the opinion expressed by SHEPPARD and SHEPPARD (1971), and may be explained by reference to Chapter 17 where it was demonstrated that the majority of edentulous subjects demonstrated a reproducible vertical jaw separation during swallowing (the swallowing level). It would appear that this situation may be applicable also to the majority of subjects wearing complete dentures, in which the swallowing level permitted occlusal tooth contact of the dentures at the original vertical dimension, but did not permit contact when the vertical dimension was reduced.

Position of Contact

Contact of complete dentures during swallowing was most commonly at the intercuspal position, which would appear to be in agreement with the findings from the fluorographic investigation involving dentulous subjects. It has been explained, however, (Chapter 2) that complete dentures are normally constructed so that maximum intercuspation of the teeth occurs at the retruded contact position, and so in complete dentures the intercuspal position and the retruded contact position co-incide. The position of contact exhibited by the subjects with complete dentures would therefore correspond to the retruded contact position in the dentulous subject, and not the intercuspal position. In the three instances in which occlusal contact appeared in a position posterior to the intercuspal/retruded contact position, this may possibly be due to some antero-posterior movement of the dentures which was not detected.

When subjected to a χ^2 test, the difference in the position of contact between dentulous subjects and edentulous subjects with dentures was found to be highly significant ($p < .001$).

Final Mandibular Position

The dentures used in this part of the investigation were constructed in such a manner that, at the original vertical dimension, some interocclusal clearance was present at the rest jaw relationship. With the reduction in the vertical dimension of occlusion this clearance should be increased by some 3 mm.

The incidence of tooth contact recorded at the end of swallowing sequences with dentures at the original vertical dimension, would indicate that establishment of the rest jaw relationship by swallowing is unreliable. This also appeared true for dentures at the reduced vertical dimension, as although the incidence of tooth contact was less, the interocclusal clearance recorded in most cases did not correspond to the expected 3 mm difference from the original vertical dimension.

18.6 Conclusions and Comment

It is of value to make comparisons between the results recorded for edentulous subjects with dentures and those recorded for dentulous subjects because it is the function (and appearance) of the dentulous state which the clinician wishes to restore. With dentures at the original vertical dimension it is apparent, as with dentulous subjects, that the majority of subjects exhibit occlusal tooth contact when swallowing. Contact during swallowing in any individual is present in some sequences but not in others, which emphasises the importance of viewing several sequences.

Reduction in vertical dimension of occlusion is accompanied by a decrease in the incidence of occlusal tooth contact when swallowing. A fall in the incidence of tooth contact in dentures, where contact had been demonstrated previously, may therefore be an indication that the vertical dimension of occlusion of the dentures has become insufficient.

The position of tooth contact, which has been considered to occur at the retruded contact position, differs significantly from the position of contact commonly recorded for dentulous subjects (the intercuspal position). It is difficult however to determine whether or not this position is influenced by the cuspal pattern of the teeth which may guide both natural and artificial dentitions to a position of maximum intercuspation. It is also possible that some antero-posterior movement of the dentures occurred which was not detected. Nevertheless the trend of the results suggests that in the edentulous subject contact of dentures during swallowing is more likely to correspond to the retruded contact position rather than the intercuspal position.

The variability of the vertical jaw position after swallowing has been demonstrated yet again, and emphasises the unreliability of establishing the rest jaw relationship by swallowing.

CHAPTER 19

Interpretation of Findings

INTERPRETATION OF FINDINGS

19.1 Introduction

The results presented in the various parts of the investigation have indicated some of the jaw relationships which may occur during swallowing under differing clinical circumstances. Observations have also been made on the frequency and consistency with which these relationships occur. Interpretation of these findings is with reference to the practice of prosthetic dentistry, and in particular to the recording and evaluation of jaw relationships in the design of complete dentures.

The investigations have yielded information regarding the relationship of swallowing to :

i) the vertical dimension of occlusion

ii) the horizontal jaw relationship in the sagittal plane

iii) the rest jaw relationship.

19.2 The Vertical Dimension of Occlusion

The findings from the part of the study involving dentulous subjects indicated that, in the majority of subjects the natural function of swallowing appears to be associated with occlusal tooth contact. As complete dentures are constructed to restore natural function as far as possible, this would suggest that the vertical dimension of occlusion which is recorded should also permit occlusal tooth contact when swallowing. In the present study such contact was encountered in subjects with complete dentures which had been constructed to a vertical dimension of occlusion which was believed to be correct. This cannot be taken as evidence, however, that the vertical dimension of occlusion can be recorded by swallowing action. Nor is occlusal tooth contact during swallowing evidence that the vertical dimension of occlusion of complete dentures is necessarily correct, as such contact would also occur at an excessive vertical dimension. It would suggest, however, that if tooth contact during swallowing is continually absent, then the vertical dimension of occlusion of the dentures may be insufficient. This is supported by the findings from subjects wearing complete dentures, in which a reduction of the vertical dimension of occlusion was associated with a significant decrease in the incidence of tooth contact when swallowing.

In edentulous subjects, it was demonstrated that the vertical jaw separation during swallowing was, in the majority of cases at a reproducible level. The separation recorded was normally less than or equal to the separation at the "relaxed" position which was recognised as a clinically determined rest jaw relationship. When the vertical jaw separation during swallowing (the swallowing level) was less than that at the "relaxed" position, there appeared to be some correlation between it and the occlusal tooth contact in dentulous subjects. From this observation it follows that the recording of the swallowing level in the majority of edentulous subjects may be useful in establishing a natural vertical dimension of occlusion for complete dentures.

As reduction of vertical dimension of occlusion in complete dentures was associated with a decrease in the incidence of tooth contact when swallowing, this knowledge may be of use in making a continuous assessment of the vertical dimension of occlusion. If complete dentures when constructed initially, demonstrate occlusal tooth contact when swallowing, then subsequent lack of contact may be an early indication of a reduction in their vertical dimension of occlusion.

19.3 Horizontal Jaw Relationship

Observations on the horizontal jaw relationship during swallowing were limited to the position of occlusal tooth contact in the sagittal plane in both dentulous subjects and edentulous subjects wearing dentures. In each group the majority of contacts occurred at a position of maximum intercuspation of the teeth. In the dentulous subject this was the intercuspal position, but in the edentulous subject was a retruded contact position as discussed in Chapter 18. Although the position of tooth contact may be influenced by cuspal morphology, which may guide the teeth to the position of maximum intercuspation during swallowing, it is clear that the mandible is able to assume a retruded position (with reference to the intercuspal position). Although the retruded position was demonstrated in some dentulous subjects it was more commonly present in subjects whose natural teeth had been extracted and who were wearing complete dentures.

From these observations it appears possible that in edentulous subjects the horizontal jaw relationship during swallowing is a retruded one. The function of swallowing therefore may offer a method of establishing the retruded contact position when recording jaw relationships for patients requiring complete dentures.

19.4 The Rest Jaw Relationship

The rest jaw relationship is normally accompanied by some degree of interocclusal clearance both in the dentulous subject and the edentulous subject wearing dentures constructed to the correct vertical dimension of occlusion. In prosthetic dentistry it may be used as a reference position, from which some clinicians assess the suitability of a vertical dimension of occlusion of complete dentures by observing the amount of interocclusal clearance present. The observations in the present study are negative rather than positive, based as they are on the assumption that rest jaw relationship cannot be present without an associated interocclusal clearance. As approximately 50% of subjects in the above categories did not demonstrate interocclusal clearance at the final mandibular position after swallowing, it would appear that the action of swallowing is not a suitable method for establishing rest jaw relationship. Furthermore, there is no evidence that a true rest jaw relationship was established in the subjects who did demonstrate interocclusal clearance after swallowing. Such evidence can only be obtained by recording electrical muscle activity and equipment for such recordings was not available in this study.

The above observations were further emphasised by results from the edentulous subjects studied, which showed that the vertical jaw separation at the end of the swallowing sequences was less than that at the "relaxed" position, which was considered as a clinically established rest jaw relationship.

19.5 Conclusions and Comment

When the results of this study are applied to the practice of prosthetic dentistry it becomes apparent that the action of swallowing may be useful in the determination of jaw relationships when constructing complete dentures. Its application to partial dentures is of lesser importance as jaw relationships are often determined by the position and intercuspation of the remaining natural teeth. In the vertical plane swallowing may be used both to record and evaluate the vertical dimension of occlusion of complete dentures, whilst in the horizontal plane it may possibly be used to record the retruded contact position. There is, however, no evidence from the present study that the action of swallowing may be useful in establishing the rest jaw relationship.

These findings appear applicable to the majority of patients. This does not mean, however, that the utilisation of swallowing action is the only method of achieving correct jaw relationships. A rational basis for its use has been established however, and it presents as a logical technique which by utilising natural movements of the jaws, may permit the construction of complete dentures with a greater degree of functional success.

CONCLUSIONS AND SUGGESTIONS

Conclusions

From the results and discussions regarding jaw relationships in the sample of subjects selected for this study, the following conclusions may be drawn :

i) The majority of dentulous subjects demonstrated occlusal tooth contact during swallowing. The position of contact was most commonly at the intercuspal position although in some cases it was at a position retrusive to the intercuspal position.

ii) Occlusal tooth contact during swallowing occurred in the majority of subjects wearing complete dentures constructed to a vertical dimension of occlusion which was believed to be correct. An insufficient vertical dimension of occlusion of the dentures was associated with a decrease in the incidence of occlusal tooth contact when swallowing.

The position of occlusal tooth contact at the correct vertical dimension of occlusion occurred with the teeth of the dentures in maximum intercuspation. From the recording of the horizontal jaw relationships made when constructing the dentures, that position was believed to correspond to the retruded contact position recorded in dentulous subjects.

iii) The majority of edentulous subjects demonstrated a constant and reproducible vertical jaw separation during swallowing, which was termed the swallowing level. In most cases the swallowing level was less than, or equal to the vertical jaw separation at the relaxed position of the jaws.

iv) The final mandibular position after swallowing, in each group of subjects, did not correspond to the rest jaw relationship.

v) The action of swallowing appeared to be a useful method in recording and evaluating the vertical dimension of occlusion in the design and construction of complete dentures. In addition, it may be of some use in determining the horizontal jaw relationship at the retruded contact position. The use of swallowing to establish the rest jaw relationship was not supported by the results of this study.

Suggestions for further work

The findings in the present study may be used as a basis for further work. It is suggested that the following investigations might be performed in order to provide more data on the subject of swallowing and jaw relationships :

i) A study of the effect that the various forms of malocclusion might have on the incidence and position of tooth contact during swallowing in dentulous subjects.

ii) Investigations in the coronal rather than the sagittal plane of jaw relationships during swallowing. This would permit observations to be made simultaneously on each side of the mouth, and would provide information on lateral deviation of the jaws during swallowing.

iii) A longitudinal study extending over several years to investigate the constancy of the swallowing level in edentulous subjects.

iv) A longitudinal study to investigate the relationship between the vertical jaw separation during swallowing recorded before extraction of the natural teeth, and that recorded after extraction of the teeth.

v) The techniques developed in the present study might also be extended to include investigations of movements of the temporomandibular joint during function, both in health and disease.

SECTION 6

APPENDICES

APPENDIX A

Some Properties of Waxes

SOME PROPERTIES OF WAXES

A. 1 Introduction

The application of swallowing in the registration of jaw relationships requires a recording of the relationship of the mandible to the maxilla at the swallowing level. A common material reported useful for this purpose is wax (SHANAHAN 1955, 1956, MALSON 1960, WARD and OSTERHOLTZ 1963, VIERHELLER 1968, and ISMAIL and GEORGE 1968). Cylinders or cones of wax are softened either by flaming, or by immersion in warm water at approximately 45°C. The softened wax is placed on the occlusal rim of a lower record block which has been trimmed short of a tentative vertical dimension of occlusion. Upper and lower record blocks are then inserted in the mouth and the patient is instructed to swallow. As themandible rises to the swallowing level, the wax cylinder is deformed by the rim of the opposing record block and so records jaw relationships at the swallowing level.

The effectiveness of any wax used in such a technique is related to the ease with which it may be deformed. This in turn is related to the strength properties of the wax when subjected to compression. Clearly, for intra-oral use, deformation must occur under such forces as might be generated by muscular action. Although properties of the modelling waxes, natural waxes, and wax mixtures have been reported (SMITH et al. 1965, CRAIG et al. 1965, 1967, OHASHI and PAFFENBERGER 1966, 1969), little consideration has been given to the properties of waxes when used as a recording medium. Accordingly the following investigations were undertaken to determine the relationship between the ease of deformation, the type of wax, the specimen size, and the temperature of use.

A. 2 Materials and Methods

The waxes used in the investigation and their sources of supply are listed in Table 6, 1. Boxing, dentina,korecta wax no. 4 and trubyte wax were all considered clinically suitable for the purpose of recording jaw relationships by swallowing. Beeswax was included because of its reported use as a recording medium (VIERHELLER 1968). Modelling wax, which is normally used in the construction of record blocks and trial dentures and which therefore might be expected to show some resistance to deformation, was included for purposes of comparison.

Preparation of Specimens

The most acceptable form of sample for use in compression tests is a cylinder (PEYTON 1968). Cylindrical specimens of each wax, 10 mm (length) x 5 mm (diameter) and 5 mm (length) x 5 mm (diameter) were therefore prepared in machined stainless steel moulds (Fig. 6, 1). These specimen sizes were considered representative of opposite ends of a range of sizes which might be used clinically.

Each wax was heated in a container in a water bath to a temperature slightly above its melting point, and poured into the mould which was at room temperature. Previously the mould had been coated with a lubricant spray[1] to facilitate the removal of the set wax. The specimens were allowed to cool slowly to room temperature before being removed from the mould. This permitted the wax molecules to assume normal intermolecular distances, so minimising internal stresses in the specimens which might lead to inaccuracies due to subsequent stress relief (PEYTON 1968).

Investigations

Specimens were tested at room temperature (approximately 24°C) and mouth temperature (37°C) using an Instron Universal Testing Machine.[2] The 10 mm specimens were strained by 70% and the 5 mm specimens by 40%. These values represented the approximate change in length of such specimens if used to record jaw relationships by swallowing. The rate of strain was 200 mm/min. which, from the graphical recordings obtained in the transmitting coil study, appeared consistent with the rate of approximation of the jaws during swallowing. Specimens tested at 37°C were first raised to that temperature by immersion in a thermostatically controlled water tank for 15 minutes. Subsequent tests were performed with the compression plates of the testing machine immersed in a water bath maintained at 37°C (Fig. 6, 2).

Ten specimens of each wax (both 5 mm and 10 mm) were tested at each temperature.

---

1 Tissue-Tek Hold Release Spray : Lab-Tek, Westmont, Illinois

2 Model TTCM : Instron Ltd., High Wycombe

A. 3 Results

The behaviour of the waxes under compression has been represented by a stress-strain diagram (Fig. 6, 3a and 3b, and Fig. 6, 4a and 4b) constructed from the mean values of data obtained in the study. Each diagram shows a general pattern. As the specimen is strained there is an increase in stress which is directly proportional to the strain produced as indicated by the straight line. At a certain point, however, the proportionality ends and beyond this proportional limit (with the exception of korecta wax no. 4 at 37°C) there is a sharp decrease in stress, followed in the 10 mm specimens by a gradual increase until the specimen is strained by the desired amount.

The mean values for the proportional limits of the wax specimens are presented in Table 6, 2. Variations occur between the individual waxes. For each specimen size and each temperature the greatest values were recorded for modelling wax and beeswax, the least for dentina and boxing waxes, with trubyte having an intermediate value. Korecta wax no. 4 although recording one of the greatest values at room temperature, had the lowest value at 37°C.

The values recorded at 37°C, for each specimen size of each wax, were lower than those recorded at room temperature. When subjected to a 't' test the differences were found to be highly significant ($p < .001$).

In general, values recorded for 10 mm specimens were greater than those recorded for 5 mm specimens at the same temperature, the differences being highly significant ($p < .001$). Two exceptions were the values for 5 mm and 10 mm specimens of modelling wax and korecta wax no. 4 at 37°C, which showed no significant difference ($p > .05$ and $p > .1$ respectively).

Stress-strain Modulus

The slope of the stress-strain curve below the proportional limit has been expressed as a modulus. The mean values for the moduli are presented in Table 6, 3.

The greatest values for each specimen size at each temperature were recorded by modelling wax and beeswax. Dentina and boxing waxes had the lowest values, whilst trubyte wax had an intermediate value. Korecta wax no. 4, although recording high modulus values at room temperature, recorded the lowest values at 37°C. An increase in testing temperature from room temperature to 37°C was accompanied by a decrease in the value of the modulus for each specimen of each wax. This decrease was highly significant ($p < .001$).

In general at each temperature greater values were recorded for the 10 mm specimens than for the 5 mm specimens, with one exception (korecta wax no. 4 at 37°C). The differences in values between specimens were highly significant ($p < .001$) with the exception of korecta wax no. 4 at 37°C in which there was no significant difference ($p > .5$).

Terminal Stress

The mean stresses required to produce the desired strain in both 5 mm and 10 mm specimens of each wax at each temperature are shown in Table 6, 4.

The greatest mean values for each specimen size at each temperature were recorded for modelling wax and beeswax, the lowest for boxing and dentina waxes with trubyte wax having an intermediate value. Korecta wax no. 4 although having a high value at room temperature recorded the lowest value at mouth temperature.

The values recorded for each specimen size at 37°C were lower than those recorded at room temperature the difference between values being highly significant ($p < .001$).

Values recorded for 10 mm specimens were generally greater than those recorded for 5 mm specimens at the same temperature, the difference being highly significant ($p < .001$). Two exceptions were the values recorded for trubyte wax and modelling wax which did not demonstrate any significant difference between 5 mm and 10 mm specimens at 37°C ($p > .9$ and $p > .8$ respectively).

Discussion

It has been demonstrated (FINNEGAN 1967) that the force exerted by the jaws during swallowing ranges from 0.6 kg to 1.45 kg. During mastication, ATKINSON and SHEPHERD (1967) recorded a maximum force of 13 kg for a patient with a complete upper denture opposing natural lower teeth and a maximum force of 7 kg for a patient with complete upper and lower dentures. BOOS (1940) had suggested that an average force in mastication was 4.5 kg but this was rejected as being too high by BOUCHER et al. (1959).

It appears, however, that the force exerted during swallowing is less than that exerted during mastication. When recording jaw relationships by swallowing therefore it is important that the wax should be easily deformable. On no account should the patient feel that he has to "bite" the wax.

Stress-strain Modulus

For some materials this is described as the modulus of elasticity. This term, however, is only applicable to elastic materials, which if stressed below their proportional limit, will return to their original dimensions on removal of the stress. Wax, however, is a visco-elastic material combining the properties of elasticity and plasticity at all levels of stress. When stressed it not only undergoes elastic strain but also demonstrates creep (HALL 1968) which is the increase of strain with time observed in a specimen under constant stress. On removal of the stress there is instantaneous recovery of elastic strain, but the plastic strain is permanent.

The greater the value of the modulus, the greater the stress required to achieve any strain up to the proportional limit. The stress-strain modulus varies with temperature however, and as in the case with polymers, drops considerably with a rise in temperature (GILLAM 1969). In all the waxes in the present investigation, the moduli were found to have a lower value at 37^{o}C than at room temperature.

Although the stress-strain modulus varies with temperature, because it is a property of the material it should not vary according to specimen size. In the present investigation, however, differences were apparent between values of moduli for 5 mm and 10 mm specimens at both room and mouth temperatures. A possible explanation of this may rest in the problems encountered in compressive testing of the waxes. In such tests the specimens are squeezed between two flat surfaces. When compressive forces are applied, the phenomenon of Poisson's effect tends to make the specimen expand laterally and assume a barrel shape. At the anvil/specimen interface frictional forces arise and restrict lateral movement of the specimen in this area. The overall contribution from this effect decreases as the length of the test specimen is increased.

Although more accurate values for the stress-strain moduli might have been obtained by using larger wax specimens, the test pieces chosen were representative of a size which might be used in the mouth.

The results show that by raising the temperature of a wax the stress-strain modulus is reduced. It then becomes more suitable for intra-oral use because the stress required to produce a strain below the proportional limit is reduced. The variation in the value for a modulus as a result of specimen size suggests also that for ease of deformation, the smallest specimen compatible with the technique should be used. However, the variation due to specimen size also emphasises the potential inaccuracy which exists in the use of small pieces of wax.

<u>Terminal Stress</u>

In the 5 mm specimens, the mean values for the terminal stress were less than the mean values for the proportional limit (with the exception of korecta wax no. 4 which nevertheless recorded the lowest mean terminal stress value). In these specimens therefore the terminal stress value is of less importance, as if sufficient force is generated to stress the specimen beyond its proportional limit then this stress if maintained will be sufficient to produce the desired strain. This situation is also applicable to the 10 mm specimens at 37^{o}C. In 10 mm specimens at room temperature the terminal stress is higher than the proportional limit in modelling, beeswax, dentina and trubyte waxes, but slightly lower in boxing wax and korecta wax no. 4. The reduction in stress beyond the proportional limit is most likely related to a combination of the plastic properties of the wax together with some fracture of the specimen under compression.

The values for the terminal stress in this investigation are with reference to 40% strain for 5 mm specimens and 70% strain for 10 mm specimens. From the stress-strain diagrams it is clear that in clinical use, the terminal stress of a specimen will vary being dependent upon the amount of strain or deformation to which a specimen is subjected.

Conclusions/

Conclusions

From the results of the investigations the following conclusions may be drawn :

i) The most suitable wax for recording jaw relationship by swallowing, with regard to its ease of deformation, appears to be korecta wax no. 4. Both 5 mm and 10 mm specimens of this wax at 37°C may be strained to the desired amount in this investigation within the range of force generated by the jaws in swallowing (FINNEGAN 1967).

ii) The use of wax at room temperature is contraindicated due to the amount of stress required to produce a desired strain. A rise in temperature of a wax however increases the ease of deformation.

iii) Apart from korecta wax no. 4, in which there is little difference between the properties of 5 mm and 10 mm specimens at 37°C, a smaller specimen appears to be more easily deformed than a larger specimen.

At present, however, no alternative method exists for recording jaw relationships during functions such as swallowing. It is suggested, therefore, that for ease of deformation the wax should be prepared as a small specimen and heated to 37°C before use.

APPENDIX B

Photographic Techniques

PHOTOGRAPHIC TECHNIQUES

B.1 Introduction

In Chapter 8 it was noted that direct measurement from the videotape or television screen was impossible and it was necessary to film each sequence from the television monitor in order to perform an individual frame analysis. This appendix considers some of the technical problems encountered and the method developed in the investigation in order to obtain film recordings from the television screen.

B.2 The Television Screen Image

The image on a television screen is formed by a scanning beam which traverses the screen rapidly in a pattern of horizontal lines. As it crosses the screen it is modulated by the incoming signal to the television receiver and so an image is formed. The image is the sum of two sets of alternating lines. In the television monitor used in the fluorographic study each beam scanned the image area in $^1/_{50}$ second, and a complete image was therefore produced in $^1/_{25}$ second. The television signal was also directly recorded on videotape. This is magnetic tape on which no visible image is present, signals being recorded in the form of magnetic variations. The advantages of recording on videotape are related to the high quality of the image recorded, and the fact that no processing of film is required. Although such a technique is useful for visual analysis and repetitive viewing, it is not suitable for an analysis of individual frames which requires the recording of data on photographic film. Photographic recordings from the television screen may be made on motion film or by still screen photography.

B. 3 <u>Motion Film Recording</u>

Motion film recordings are achieved by displaying the television image on the screen and photographing it using a motion picture camera. Difficulties occur in such techniques however related to the fact that the pull down time of film frames through the camera, must coincide with the time interval between successive television pictures. This time interval is extremely short being approximately 0.0015 seconds (LEGGAT 1965), but by using 16 mm film, a satisfactory rate of pull down of film frames can be achieved. Difficulties arise however when using 35 mm film due to the increased dimensions of the film.

B. 4 <u>Screen Photography</u>

It is relatively simple to take well defined still photographs from a television screen image (Fig. 6,5). In the system under consideration $^1/_{25}$ of a second is required to produce a complete image. It follows therefore that an exposure time of less than $^1/_{25}$ second will only record part of that image and exposure times greater than $^1/_{25}$ second may record a blurred image due to registration on the film negative of more than one modulated scanning beam.

B. 5 <u>The Fluorographic Study</u>

In an attempt to obtain material for frame analysis, swallowing sequences were recorded initially on motion film using a 16 mm motion picture camera.[1] The film speed, which was synchronised with the mains current was $12\frac{1}{2}$ frames per second, with an effective exposure time of $^{1}/_{25}$ second. A slow film[2] was used to reduce grain size and give good detail. Trial exposures were performed at apertures f/1.8, f/2.8 and f/4. Recordings at each aperture were processed commercially to various densities. The results in all cases were poor (Fig. 6, 6), due to the small size of image, graininess of the film, and the problem of subsequent enlargement for frame analysis. Anatomical references for use as measuring points could not be defined clearly and such a technique was unsuitable for obtaining accurate measurements.

For purposes of measurement analysis therefore the image produced by static screen photography is superior. The fluorographic study however required exposures to be made in rapid succession and this could not be achieved using a camera with a manual film transport system. Accordingly it was decided to use a motorised system which could be set to transport the film at a rate of three frames per second. Technical testing at this setting had shown

---

1 Bolex Paillard : Marconi Instruments Ltd., St. Albans

2 Pan F : Ilford Ltd., Ilford.

an average speed of 2.5 frames per second (CRAWLEY 1965). Exposures were made with such a system connected to a Nikon F camera[3] using a 55 mm Micro-Nikkor lens at an aperture of f/3.5.

It has been explained previously that the exposure time required for screen photography is $^1/_{25}$ second. Such time exposure was not available on the shutter speed dial of the camera, but satisfactory images on the negatives were obtained with an exposure time of $^1/_{30}$ second. Due to the intensity of the light from the television screen a fast panchromatic film[4] was used. After exposure all films were processed using an ultra-fine grain developer[5] which reduced the grain size, gave good tone separation and increased the emulsion speed of the film. A dilution technique was used in development according to the manufacturer's instructions, being used once and then discarded. This technique was advantageous as it gave consistency of results together with an increased image sharpness. Films were fixed in a standard fixing solution, washed, and dried.

All exposures were made with the camera mounted on a tripod at a fixed distance from the television screen (Fig. 6,7). Following processing relevant frames were printed on Kodak Ektamatic Paper Grade 2, designed for use with an automatic processing machine.[6] Prints from each frame

---

3 Nikon F. : Nippon Kogaku, Tokyo, Japan

4 Tri-X : Kodak Ltd., London

5 Promicrol : May and Baker Ltd., Dagenham

6 Kodak Auto-Processor Model Q14 : Kodak Ltd., London

were made to a standard enlargement. An example of the quality of print obtained using these techniques is shown in Fig. 6, 8.

As the prints produced were used in the measurement analysis, considerable care was taken in the standardisation of techniques particularly with regard to camera position, film processing, and enlargement and processing of prints.

BIBLIOGRAPHY

ADAMS, S.H. and ZANDER, H.A. (1964) Functional tooth contacts in lateral and in centric occlusion. J. Amer. dent. Ass. 69 : 465

ANDERSON, D.J. and PICTON, D.C.A. (1957) Tooth contact during chewing J. dent. Res. 36 : 21

ANDERSON, J.N. and STORER, R. (1966) Immediate Replacement Dentures Oxford : Blackwell Scientific Publications

ANDERSON, J.N. (1972) Applied Dental Materials 4th ed. Oxford and Edinburgh : Blackwell Scientific Publications.

ANGLE, E.H. (1899) Classification of malocclusion. Dent. Cosmos. 41 : 248

ANTHONY, D.H. and PEYTON, F.A. (1962) Dimensional accuracy of various denture - base materials. J. prosth. Dent. 12 : 67

ARDRAN, G.A. and KEMP, F.H. (1955) Radiographic study of movements of the tongue in swallowing Dent. Practit. 5 : 252

ARDRAN, G.A., KEMP, F.H., and MUNZ, F.R. (1957) Observations on the behaviour of full lower dentures. An X-ray cinematographic study with special reference to the perspex tray impression method. Dent. Practit. dent. Rec. 7 : 180

ATKINSON, H.F. and SHEPHERD, R.W. (1967) Masticatory movements and the resulting force. Arch. oral Biol. 12 : 195

ATWOOD, D.A. (1966) A critique of research of the rest position of the mandible. J. prosth. Dent. 16 : 848

ATWOOD, D. A. (1968) A critique of research of the posterior limit of the mandibular position. J. prosth. Dent. 20 : 21

BALKWILL, E., (1866) The best form and arrangement of artificial teeth for mastication Trans. odont. Soc. G. B., 5 : 133

BELL, G. H., DAVIDSON, J. N. and EMSLIE-SMITH, D. (1972) Textbook of Physiology and Biochemistry 8th ed. Edinburgh and London : Churchill Livingstone.

BERRY, D. C. (1960) The constancy of the rest position of the mandible Dent. Practit. dent. Rec. 10 : 129

BERRY, H. M. Jr., and HOFMANN, F. A. (1959) Cineradiographic observations of temporomandibular joint function. J. prosth. Dent. 9 : 21

BISHOP, O. N. (1966) Statistics for Biology 1st ed. London : Longmans, Green & Co. Ltd.

BJÖRK, A. (1954) Cephalometric x-ray investigations in dentistry. Int. dent. J. 4 : 718

BJÖRK, A., and PALLING, M (1955) Adolescent age changes in sagittal jaw relation, alveolar prognathy, and incisal inclination. Acta odont. scand. 12 : 201

BOOS, R. H. (1940) Intermaxillary relation established by biting power J. Amer. dent. Ass. 27 : 1192

BOOS, R. H. (1943) Centric and functional bite relations J. Amer. dent. Ass. 30 : 262

BOOS, R.H. (1956) Physiologic denture technique. J. prosth. Dent. 6 : 726

BOUCHER, C.O. (1963) Maxillomandibular relations. Dent. Practit. dent. Rec. 13 : 427

BOUCHER, C.O. (1970) Editor, Swenson's Complete Dentures, 6th ed. , St. Louis : C.V. Mosby Co.

BOUCHER, L.J. (1961) Limiting factors in posterior movements of mandibular condyles J. prosth. Dent. 11 : 23

BOUCHER, L.J. (1962) Anatomy of the temporomandibular joint as it pertains to centric relation. J. prosth. Dent. 12 : 464

BOUCHER, L.J. ZWEMER, T.J. and PFLUGHOEFT, F. (1959) Can biting force be used as a criterion for registering vertical dimension? J. prosth. Dent. 9 : 594

BOYLE, H.H. (1947) Importance of the vertical dimension in complete dentures Brit. dent. J. 83 : 159

BREWER, A.A., and HUDSON, D.C. (1961) Application of miniaturised electronic devices to the study of tooth contact in complete dentures. J. prosth. Dent. 11 : 62

BREWER, A.A. (1963) Prosthodontic research at the school of aero-space medicine J. prosth. Dent 13 : 49

BRILL, N., LAMMIE, G.A., OSBORNE, J., and PERRY, H.T. (1959) Mandibular positions and mandibular movements. Brit. dent. J. 106 : 391

BRITISH STANDARDS INSTITUTION (1969) Glossary of terms relating to dentistry BS 4492 : 1969. London : British Standards Institution.

CANNON, W.B., and MOSER, A. (1898) The movements of food in the esophagus Amer. J. Physiol. 1 : 435

CHICK, A.O. (1949) The forward movement of the mandible during bite closure and its relation to excessive alveolar resorption in edentulous cases. Brit. dent. J. 87 : 243

CHRISTENSEN, C. (1905) The problem of the bite Dent. Cosmos 47 : 1184

CLEALL, J.F. (1965) Deglutition : a study of form and function. Amer. J. Orthodont. 51 : 566

COOPER, H.K. (1956) Cinefluorography with image intensification as an aid in treatment planning for some deft lip and/or cleft palate cases. Amer. J. Orthodont. 42 : 815

CRADDOCK, F.W. (1949) The accuracy and practical value of records of condyle path inclination J. Amer. dent. Ass. 38 : 697

CRADDOCK, F.W. (1956) Prosthetic Dentistry. A Clinical Outline. 3rd ed. London : Henry Kimpton

CRAIG, R.G., EICK, J.D., and PEYTON, F.A. (1965) Properties of natural waxes used in dentistry J. dent. Res. 44 : 1308

CRAIG, R.G., EICK, J.D., and PEYTON, F.A. (1967) Strength properties of waxes at various temperatures and their practical application. J. dent. Res. 46 : 300

CRAWLEY, G. (1965) The Nikon System London : Henry Greenwood & Co. Ltd.

DONNISON, J.A. and DOCKING, A.R. (1960) Alginate impression materials Aust. dent. J. 5 : 280

DOUGLAS, J.R., and MARITATO, F.R. (1967) A roentgenographic method to determine the vertical dimension of occlusion for complete dentures. J. prosth. Dent. 17 : 450

DOWNS, B.H. (1963) Discussion of "Prosthodontic research in progress at the school of Aerospace Medicine". J. prosth. Dent. 13 : 70

FENN, H.R.B., LIDDELOW, K.P. and GIMSON, A.P. (1961) Clinical Dental Prosthetics 2nd ed. London : Staples Press

FINNEGAN, F.J. (1967) Determination of maxillo-mandibular force generated during deglutition. J. prosth. Dent. 17 : 134

FISH, S.F. (1961) The functional anatomy of the rest position of the mandible Dent. Practit. dent. Rec. 11 : 178

FISH, S.F. (1964) The respiratory associations of the rest position of the mandible. Brit. dent. J. 116 : 149

FISHER, Sir R.A. and YATES, F. (1963)	Statistical tables for biological agricultural and medical research Edinburgh and London : Oliver and Boyd.
FLANAGAN, J.B. Jr. (1963)	The 24-hour pattern of swallowing in man Int. Ass. dent. Res. Abs. No. 165 March 1963.
FRAZIER, Q.Z., WESLEY, R.C., LUTES, M.R., HENDERSON, D., RAYSON, J.H., ELLINGER, C.W., RAHN, R.O., and HALEY, J.V. (1971)	The relative repeatability of plaster interocclusal eccentric records for articulator adjustment in construction of complete dentures. J. prosth. Dent. 26 : 456
GEISSLER, P.R. (1971)	A preliminary report on studies of mandibular movements in speech Dent. Practit. dent. Rec. 21 : 429
GILLAM, E. (1969)	Materials under stress London : Newnes-Butterworths.
GILLINGS, B.R.D., KOHL, J.T. and ZANDER, H.A. (1963)	Contact patterns using miniature radio transmitters J. dent. Res. 42 : 177
GILLIS, R.R. (1941)	Establishing vertical dimension in full denture construction. J. Amer. dent. Ass. 28 : 430
GLICKMAN, I, PAMEIJER, J.H.N. and ROEBER, F.W. (1968)	Intra-oral occlusal telemetry. Part I J. prosth. Dent. 19 : 60
GRAF, H., and ZANDER, H.A. (1963)	Tooth contacts in mastication J. prosth. Dent. 13 : 1055

GRANT, A. A. (1962) Effect of investment procedure on tooth movement.
J. prosth. Dent. 12 : 1053

GYSI, A. (1910) The problem of articulation
Dent. Cosmos 62 : 1

GYSI, A. (1929) Practical application of research results in denture construction
J. Amer. dent. Ass. 16 : 199

HALL, I.H. (1968) Deformation of Solids
Northern Ireland : The Universities Press Ltd.

HANAU, R.L. (1923) The relation between mechanical and anatomical articulation
J. Amer. dent. Ass. 10 : 776

HANNAN, A. G., MATTHEWS, B., and YEMM, R. (1969) Changes in the activity of the masseter muscle following tooth contact in man
Arch. oral Biol. 14 : 1401

HARPER, R.N. (1942) Vertical dimension in complete denture prosthesis.
J. Amer. dent. Ass. 29 : 762

HARVEY, W. (1948) Investigation and survey of malocclusion and ear symptoms, with particular reference to otitic barotrauma.
Brit. dent. J. 85 : 219

HEINTZ, W. D., and PETERS, G.W. (1959) Esthetic occlusion rims providing for jaw relations
J. prosth. Dent. 9 : 587

HICKEY, J. C., WILLIAMS, B.H. WOELFEL, J.B. (1961) Stability of mandibular rest position
J. prosth. Dent. 11 : 566

HILL, Sir A.B. (1967) Principles of Medical Statistics 8th ed. London : The Lancet Ltd.

HINDMAN, H., and BURR, G.S. (1949) The Instron tensile tester Trans. Amer. Soc. Mech. Eng. 71 : 789

INGERVALL, B. (1964) Retruded contact position of mandible. A comparison between children and adults Odont. Revy. 15 : 130

INGERVALL, B., BRATT, C.M., CARLSSON, G.E., HELKIMO, M., and LANTZ, B. (1971) Position and movements of mandible and hyoid bone during swallowing. A cineradiographic study of swallowing with and without anaesthesia of the temporomandibular joints. Acta. odont scand 29 : 549

INGERVALL, B., BRATT, C.M. CARLSSON, G.E., HELKIMO, M., and LANTZ, B., (1972) Duration of swallowing with and without anaesthesia of the temporomandibular joints Scand. J. dent. Res. 80 : 189

ISMAIL, Y.H., and GEORGE, W.A. (1968) The consistency of the swallowing technique in determining occlusal vertical relation in edentulous patients J. prosth. Dent. 19 : 230

ISMAIL, Y.H., (1969) Personal Communication

JANKELSON, B., HOFFMAN, G.M., and HENDRON, J.A. (1953) The physiology of the stomatognathic system J. Amer. dent. Ass. 46 : 375

JARVIS, E.C. (1963) A method of recording centric relation J. prosth. Dent. 13 : 617

JENKINS, G.N. (1966) The Physiology of the Mouth. 3rd ed. Oxford : Blackwell Scientific Publications.

JOFFE, B.M. (1961) Normal deglutition. J. dent. Ass. S. Afr. 16 : 11

KAIRES, A.K. (1 957) A study of occlusal contacts in artificial dentures. J. prosth. Dent. 7 : 553

KANTOROWICZ, A. (1932) Klinische Zahnheilkunde Berlin : Verlag Hermann Meusser

KAPUR, K.K. and YURKSTAS, A.A. (1957) An evaluation of centric relation records obtained by various techniques. J. prosth. Dent. 7 : 770

KEELE, C.A., and NEIL, E. (1971) Samson Wright's Applied Physiology. 12th ed. London : Oxford University Press.

KOVATS, J.J. (1967) Overclosure of the jaws : a clinical syndrome. J. prosth. Dent. 18 : 311

KURTH, L.E. (1942) Mandibular movements in mastication J. Amer. dent. Ass. 29 : 1769

KURTH, L.E. (1959) Methods of obtaining vertical dimension and centric relation. A practical evaluation of various methods J. Amer. dent. Ass. 59 : 669

KVAM, E., and KROGSTAD, O., (1971) Geometric errors in measurements on X-ray films Acta odont. scand. 29 : 185

KYDD, W.L., and SANDER, A. (1961) A study of posterior mandibular movements from intercuspal occlusal position
J. dent. Res. 40 : 419

KYDD, W.L., and NEFF, C.W. (1964) Frequency of deglutition of tongue thrusters compared to a sample population of normal swallows.
J. dent. Res. 43 : 363

KYDD, W.L., HARROLD, W., and SMITH, D.E. (1967) A technique for continuously monitoring the interocclusal distance
J. prosth. Dent. 18 : 308

LAIRD, W.R.E., MANSON, G., DAVIES, E.H., and von FRAUNHOFER, J.A. (1971) Measurement of occlusal tooth separation by means of electrical field variations.
Bio-med. Engng. 6 : 504

LAIRD, W.R.E. (1972) Intermaxillary relationships during deglutition
Paper presented to Annual Meeting of British Society for the Study of Prosthetic Dentistry, April 1972

LAMMIE, G.A., and OSBORNE, J. (1954) The bilateral free end saddle lower denture
J. prosth. Dent. 4 : 460

LAMMIE, G.A. (1956) Full Dentures
Oxford : Blackwell Scientific Publications

LANDA, J.S. (1954) Practical Full Denture Prosthesis 2nd ed.
London : Henry Kimpton

LAST, R.J. (1955) The muscles of the head and neck. A review
Int. dent. J. 5 : 338

LEGGATT, D.P. (1965) Television recording. In the Focal Encyclopaedia of Photography 2 : 1523 London and New York : Focal Press.

LEIGHTON, B.C. (1960) Early development of the deciduous dentition. Trans. B.S.S.O. Dent. Practit. dent. Rec. 10 : 100

LUNT, D.A. (1966) An odontometric study of mediaeval Danes Ph.D. Thesis : University of Glasgow

LYTLE, R.B. (1964) Vertical relation of occlusion by the patient's own neuromuscular perception. J. prosth. Dent. 14 : 12

McGEE, G.F. (1947) Use of facial measurements in determining vertical dimension. J. Amer. dent. Ass. 35 : 342

McKEVITT, F.H. (1957) Finding lost prosthodontic dimensions J. prosth. Dent. 7 : 738

McMILLAN, D.R., and IMBER, S. (1968) The accuracy of facial measurements using the Willis bite gauge. Dent. Practit. dent. Rec. 18 : 213

McMILLAN, D.R. BARBENEL, J.C., and QUINN, D. (1970) Measurement of occlusal face height by dividers. Dent. Practit. dent. Rec. 20 : 177

MACK, A. (1964) Complete dentures (IV) Brit. dent. J. 116 : 518

MAHLER, D.B. (1955) Plaster of Paris and stone materials. Int. dent. J. 5 : 241

MALSON, T.S. (1960) Recording the vertical dimension of occlusion
J. prosth. Dent. 10 : 258

MASON, W.N., and DAVISON, M. (1972) X-ray studies of movement
Glas. dent. J. 3, 2 : 12

MATTHEWS, E. (1944) A new approach to full denture construction.
Brit. dent. J. 76 : 261

MERKELEY, H.J. (1953) A complete standardised pre-extraction record.
J. prosth. Dent. 3 : 657

MILLER, D.I., (1966) Cushion-air denture technic
J. Amer. dent. Ass. 72 : 677

MØLLER, E. (1966) The chewing apparatus. An electromyographic study of the action of the muscles of mastication and its correlation to facial morphology
Acta. physiol. scand. 69 : Suppl. 280

MØLLER, E., LUND, P., and NISHIYAMA, T. (1971) Swallowing in upright, inclined, and supine positions : action of the temporal, lateral pterygoid and digastric muscles.
Scand. J. dent. Res. 79 : 483

MORONEY, M.J. (1968) Facts from Figures 3rd ed.
Middlesex : Penguin Books Ltd.

MORRISON, M.L. (1959) Phonetics as a method of determining vertical dimension and centric relation.
J. Amer. dent. Ass. 59 : 690

MOYERS, R.E. (1956) Some physiologic considerations of centric and other jaw relations
J. prosth. Dent. 6 : 183

MOYLAN, F.J. (1953) The temporo-mandibular-maxillary relationship.
J. prosth. Dent. 3 : 184

NAGLE, R.J. and SEARS, V.H. (1962) Denture Prosthetics 2nd ed.
St. Louis : C.V. Mosby Co.

NAIRN, R.I., and CUTRESS, T.W. (1967) Changes in mandibular position following removal of the remaining teeth and insertion of immediate complete dentures
Brit. dent. J. 122 : 303

NEILL, D.J. (1964) A study of the contact between artificial dentures using incorporated radio transmitters.
Int. dent. J. 14 : 255

NEILL, D.J. (1967) Telemetering equipment used in the study of tooth contacts.
Bio-med. Engng. 2 : 248

NEUMANN, H.H. (1950) Electrical action currents during mastication. Measurement of the effort exerted in chewing various foods.
J. dent. Res. 29 : 463

NEVAKARI, K. (1956) An analysis of the mandibular movement from rest to occlusal position.
Acta odont. scand. 14 : Suppl. 19

NISWONGER, M.E. (1934) The rest position of the mandible and the centric relation.
J. Amer. dent. Ass. 21 : 1572

NYLÉN, B.O. (1961) Cleft palate and speech.
Acta. radiol. (Stockh.) Supplement 203

OHASHI, M., and PAFFENBERGER, G.C. (1966)	Melting, flow and thermal characteristics of some dental and commercial waxes. J. Amer. dent. Ass. 72 : 1141
OHASHI, M., and PAFFENBERGER, G.C. (1969)	Some flow characteristics at 37°C of ternary wax mixtures that may have possible dental uses. J. Nihon. Sch. Dent. 11 : 109
O'LEARY, T.J., RUDD, K.D., NABERS, C.L., and STUMPF, A.J. (1967)	The effect of mastication and deglutition on tooth mobility. Periodontics 5 : 26
OLSEN, E.S. (1951)	A radiographic study of variations in the physiological rest position of the mandible in seventy edentulous individuals J. dent. Res. 30 : 517
O'ROURKE, J.T. (1949)	Significance of tests for biting strength J. Amer. dent. Ass. 38 : 627
OSBORNE, J. (1949)	Recording centric occlusion for edentulous cases. Dent. Rec. 69 : 6
OSBORNE, J., and LAMMIE, G.A. (1954)	The manipulation of alginate impression materials. Brit. dent. J. 96 : 51
PAMEIJER, J.H.N., GLICKMAN, I., and ROEBER, F.W. (1968)	Intraoral occlusal telemetry. Part II. Registration of tooth contacts in chewing and swallowing. J. prosth. Dent. 19 : 151
PAMEIJER, J.H. BRION, M., GLICKMAN, I., and ROEBER, F.W. (1970)	Intra-oral occlusal telemetry. Part IV. Tooth contact during swallowing J. prosth. Dent. 24 : 396

PAYNE, A.G.L. (1969) Gothic arch tracing in the edentulous. Some properties of the apex point. Brit. dent. J. 126 : 220

PEYTON, F.A. (1968) Restorative Dental Materials. 3rd ed. St. Louis : C.V. Mosby Co.

POSSELT, U. (1958) Occlusal relationship in deglutition and mastication Trans. Eur. orthod. Soc. 34 : 301

POSSELT, U. (1968) Physiology of occlusion and Rehabilitation. 2nd ed. Oxford and Edinburgh : Blackwell Scientific Publications.

PRUZANSKY, S. (1952) The application of electromyography to dental research J. Amer. dent. Ass. 44 : 49

RALPH, J.P., and PAUL, R.B. (1972) Some uses of fluid acrylic resins in prosthodontics. Glas. dent. J. 3,1 : 28

RAMFJORD, S.P. and ASH, M. (1971) Occlusion, 2nd ed. Philadelphia, London, Toronto : W.B. Saunders Co.

RAMSAY, G.H., WATSON, J.S., GRAMIAK, R., and WEINBERG, S.A. (1955) Cinefluorographic analysis of the mechanism of swallowing. Radiology 64 : 498

RICHARDSON, A. (1966) An investigation into the reproducibility of some points, planes and lines used in cephalometric analysis. Amer. J. Orthodont, 52 : 637

RIX, R.E. (1946) Deglutition and the teeth. Dent. Rec. 66 : 105

RUSHMER, R.F. and HENDRON, J.A. (1951) The act of deglutition : a cinefluorographic study.
J. appl. Physiol. 3 : 622

SCHARER, P., and STALLARD, R.E. (1965) The use of multiple radio transmitters in studies of tooth contact patterns.
J. Amer. Soc. Periodent. 3 : 5

SCHLOSSER, R.O. (1931) Advantages of closed mouth muscle action for certain steps of impression taking.
J. Amer. dent. Ass. 18 : 100

SCOTT, J.H., and DIXON, A.D. (1972) Anatomy for Students of Dentistry
3rd ed.
Edinburgh and London : Churchill Livingstone.

SHANAHAN, T.E.J. (1955) Physiologic jaw relations and occlusion of complete dentures.
J. prosth. Dent. 5 : 319

SHANAHAN, T.E.J. (1956) Physiologic vertical dimension and centric relation.
J. prosth. Dent. 6 : 741

SHEPARD, W.L. (1968) Denture bases processed from a fluid resin.
J. prosth. Dent. 19 : 561

SHEPPARD, I.M., and SHEPPARD, S.M. (1968) Denture occlusion
J. prosth. Dent. 20 : 307

SHEPPARD, I.M. and SHEPPARD, S.M. (1971) Denture occlusion
J. prosth. Dent. 26 : 468

SHPUNTOFF, H., and SHPUNTOFF, W. (1956) A study of physiologic rest position and centric position by electromyography
J. prosth. Dent. 6 : 621

SILVERMAN, M.M. (1950) Successful full dentures through accurate centric occlusion.
Dent. Dig. : 56 : 494

SILVERMAN, M.M. (1953) Speaking method in measuring vertical dimension
J. prosth. Dent. 3 : 193

SILVERMAN, M.M. (1956) Determination of vertical dimension by phonetics
J. prosth. Dent. 6 : 465

SILVERMAN, M.M. (1957) Centric occlusion and jaw relations and fallacies of current concepts.
J. prosth. Dent. 7 : 750

SILVERMAN, S.I. (1961) Oral Physiology
St. Louis : C.V. Mosby Co.

SIMPSON, H. (1939) Registration of centric relation in complete denture prosthesis.
J. Amer. dent. Ass. 26 : 1682

SKINNER, E.W. and PHILLIPS, R.W. (1967) The Science of Dental Materials 6th ed.
Philadelphia and London : W.B. Saunders Co.

SKURNIK, H. (1969) Functional interarch relationships recorded in wax.
J. prosth. Dent. 21 : 283

SMITH, D.C. EARNSHAW, R., and McCRORIE, J.W. (1965) Some properties of modelling and baseplate waxes.
Brit. dent. J. 118 : 437

SMITH, D.E., KYDD, W.L., WYKHUIS, W.A., and PHILLIPS, LA. (1963) The mobility of artificial dentures during comminution.
J. prosth. Dent. 13 : 839

SMITH, D.E. (1971) The reliability of pre-extraction records for complete dentures. J. prosth. Dent. 25 : 592

SMITH, E.S. (1941) Methods of securing centric relation and other positional records in complete denture prosthesis. J. Amer. dent. Ass. 28 : 37

SMITH, E.S. (1958) Vertical dimension and centric jaw relation in complete denture construction. J. prosth. Dent. 8 : 31

SMITH, N.J.D., and HEIGHWAY, W.P. (1969) Patient dose in dental cinefluorography Oral Surg. 27 : 349

STANSBERY, C.J. (1929) Functional position check bite technic J. Amer. dent. Ass. 16 : 421

STEPHEN, K.W. (1970) The Ford D300 mobile dental research unit preliminary studies. Glas. dent. J. 1 : 14

STEPHEN, K.W. and SUTHERLAND, D.A. (1971) A dental health study of 14-year old schoolchildren in Paisley. Brit. dent. J. 130 : 19

SWEENEY, W.T. and TAYLOR, D.F. (1950) Dimensional changes in dental stone and plaster. J. dent. Res. 29 : 749

SWERDLOW, H. (1965) Vertical dimension literature review. J. prosth. Dent. 15 : 241

SYROP, H.M. (1953) Motion picture studies of the mechanism of mastication and swallowing. J. Amer. dent. Ass. 46 : 495

TALLGREN, A. (1957) Changes in adult face height due to ageing, wear and loss of teeth and prosthetic treatment. Acta odont. scand 15 : Suppl. 24

THOMPSON, J.R., and BRODIE, A.G. (1942) Factors in the position of the mandible J. Amer. dent. Ass. 29 : 925

THOMPSON, J.R. (1946) The rest position of the mandible and its significance to dental science. J. Amer. dent. Ass. 33 : 151

THOMSON, J.C. (1967) Factors affecting support of full dentures. M.D.S. Thesis : University of Glasgow

THOMSON, J.C. and MACDONALD, N.S. (1969) Monitoring mandibular posture J. Biomech. 2 : 319

TIMMER, L.H. (1967) The vertical dimension. A reproducible method for the determination of the vertical dimension of occlusion. Netherlands dent. J. 74 : Suppl. 4, 55

TUELLER, V.M. (1969) The relationship between the vertical dimension of occlusion and forces generated by closing muscles of mastication. J. prosth. Dent. 22 : 284

TULLEY, W.J. (1960) Cineradiographic studies of tongue behaviour. Trans. B.S.S.O. Dent. Practit. dent. Rec. 10 : 135

TURNER, L.C. (1969) The profile tracer : method for obtaining accurate pre-extraction records. J. prosth. Dent. 21 : 364

TURRELL, A.J.W. (1955) The pre-extraction recording of the vertical dimension by an intra-oral method. Dent. Practit. 6 : 68

TURRELL, A.J.W. (1968) Vertical dimension as it relates to angular cheilosis. J. prosth. Dent. 19 : 119

TURRELL, A.J.W. (1972) Clinical assessment of vertical dimension. J. prosth. Dent. 28 : 238

WAGNER, A.G. (1970) Making duplicate dentures for use as final impression trays. J. prosth. Dent. 24 : 111

WARD, B.L., and OSTERHOLTZ, R.H. (1963) Establishing the vertical relation of occlusion. J. prosth. Dent. 13 : 432

WATSON, R.M. (1972) Masticatory ability - cineradiographic observations. J. Dentistry 1 : 54

WATT, D.M. (1952) The bite-tray technique. Int. dent. J. 3 : 74

WILLIS, F.M. (1930) Esthetics of full denture construction J. Amer. dent. Ass. 17 : 636

WILLIS, F.M. (1935) Features of the face involved in full denture prosthetics. Dent. Cosmos 77 : 851.

WILSON, H. J. and SMITH, D. C. (1963a) — Alginate impression materials. Brit. dent. J. 114 : 20

WILSON, H. J., and SMITH, D. C. (1963b) — The bonding of alginate impression materials to impression trays. Brit. dent. J. 115 : 291

WIRTH, C. G. (1971) — Interocclusal centric relation records for articulator mounted casts. Dent. Clin. N. Amer. 15 : 627

WRIGHT, W. H. (1939) — Use of intra-oral jaw relation wax records in complete denture prosthesis J. Amer. dent. Ass. 26 : 542

VIERHELLER, P. G. (1968) — A functional method for establishing vertical and tentative centric maxillomandibular relations. J. prosth. Dent. 19 : 587

YOUNG, H. A. (1949) — Diagnosis of problems in complete denture prosthesis J. Amer. dent. Ass. 39 : 185

YURKSTAS, A. A., and EMERSON, W. H. (1954) — A study of tooth contact during mastication with artificial dentures. J. prosth. Dent. 4 : 168

All the references listed have been examined personally with the exception of KANTOROWICZ (1932) which is quoted from TIMMER (1967).

OBSERVATIONS ON SOME JAW RELATIONSHIPS DURING SWALLOWING AS RELATED TO PROSTHETIC DENTISTRY

by

William Ronald Edwards Laird

B.D.S. (U.Glas.), H.D.D.R.C.P.S. (Glas.),

F.D.S.R.C.P.S. (Glas.).

THESIS

Submitted for the degree of Master of Dental Surgery
in the University of Glasgow Faculty of Medicine.

VOLUME II

ILLUSTRATIONS AND TABLES

May 1973.

SECTION 1

Figure 1, 1a

The vertical dimension of occlusion. At this vertical dimension, the maxillary and mandibular posterior teeth are in contact.

Figure 1, 1b

The rest vertical dimension. At this vertical dimension, the maxillary and mandibular posterior teeth are separated by the extent of the interocclusal clearance.

Figure 1, 2a

A B

Profile view of a subject at the correct vertical dimension of occlusion (A) and at an excessive vertical dimension of occlusion (B). At the excessive vertical dimension there is an increase in the chin to nose distance with elimination of the labio-mental groove.

Figure 1, 2b

A B

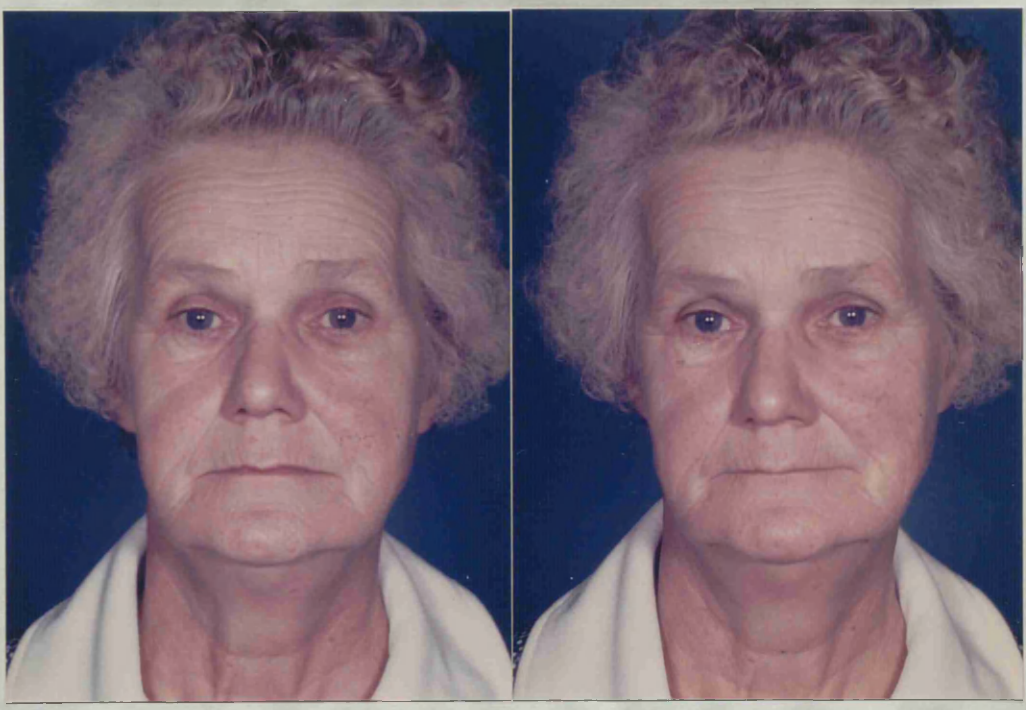
Facial view of a subject at the correct vertical dimension of occlusion (A) and an excessive vertical dimension of occlusion (B). At the excessive vertical dimension, there is an increase in vertical height of the lower part of the face, and loss of definition of the nasolabial grooves. The face assumes a strained appearance.

Figure 1, 3a

A B

Profile view of a subject at the correct vertical dimension of occlusion (A) and at an insufficient vertical dimension of occlusion (B). At the insufficient vertical dimension there is a tendency to a decreased chin to nose distance with deepening of the labio-mental groove and some forward posturing of the mandible.

Figure 1, 3b

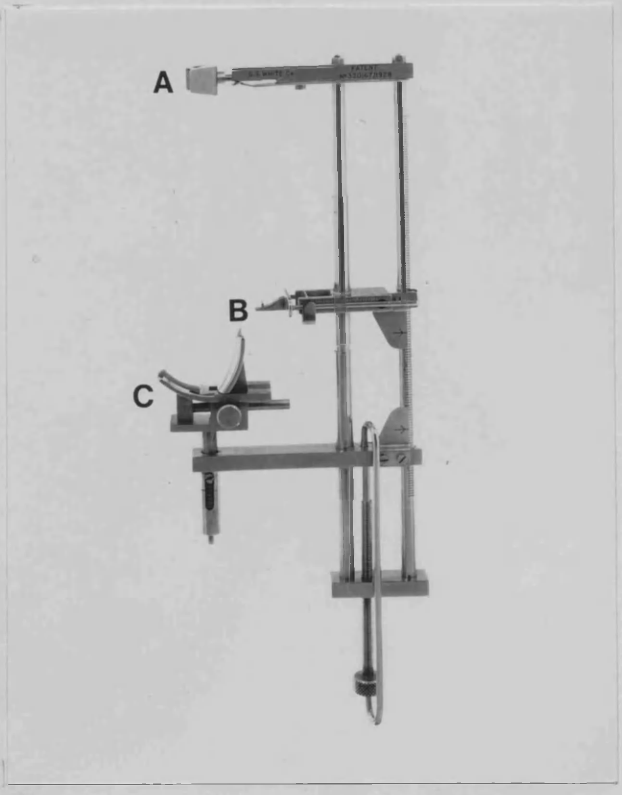


A B

Facial view of a subject at the correct vertical dimension of occlusion (A), and at an insufficient vertical dimension of occlusion (B). At the insufficient vertical dimension there is loss of vertical height in the lower part of the face and the vermilion borders of the lips are no longer visible.

SECTION 2

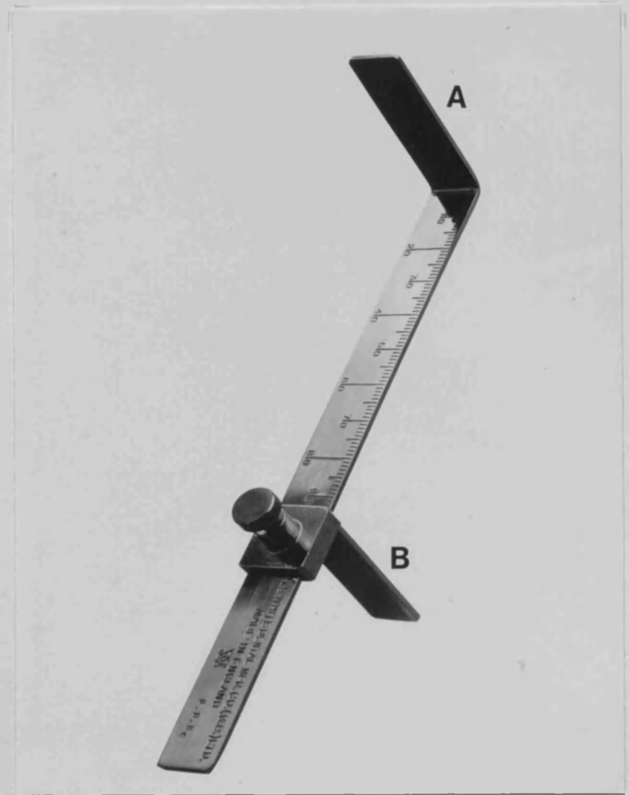
Figure 2, 1



The Dakometer

The carrier with impression compound (A) is placed against the bridge of the nose and the adjustable chinpiece (C) against the chin. The position of the upper cential incisors is recorded by the attachment (B).

Figure 2, 2



The Willis Gauge

The fixed arm (A) is placed at the base of the nose and the movable arm (B) is brought into contact with the skin overlying the chin.

SECTION 3

TABLE 3, 1.

Subjects	Dentulous	Edentulous		TOTAL
		without dentures	with dentures	
First Part (transmitting coil)	10	0	0	10
Second Part (fluorographic)	30	20	10	60

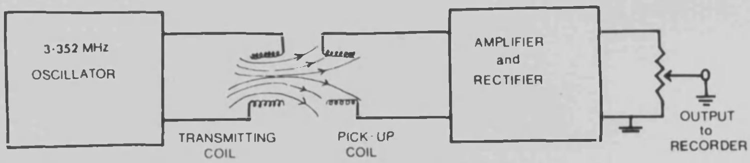
The number of subjects in each group in each part of the investigation.

TABLE 3,2

Age Groups	Dentulous	Edentulous		TOTAL
		without dentures	with dentures	
20 and under	9	0	0	9
21-30	15	0	0	15
31-40	3	1	0	4
41-50	3	5	2	10
51-60	0	2	3	5
Over 60	0	12	5	17

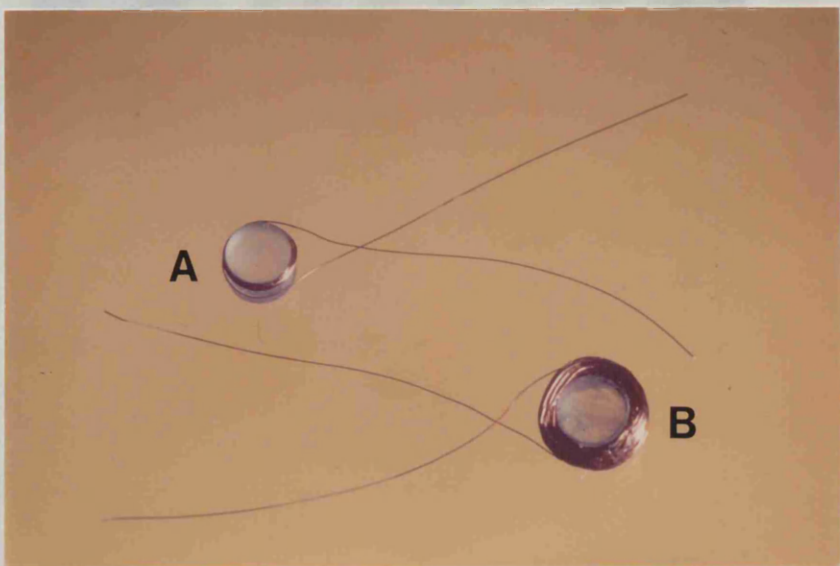
The number of subjects in both parts of the investigation grouped according to age.

Figure 3, 1.



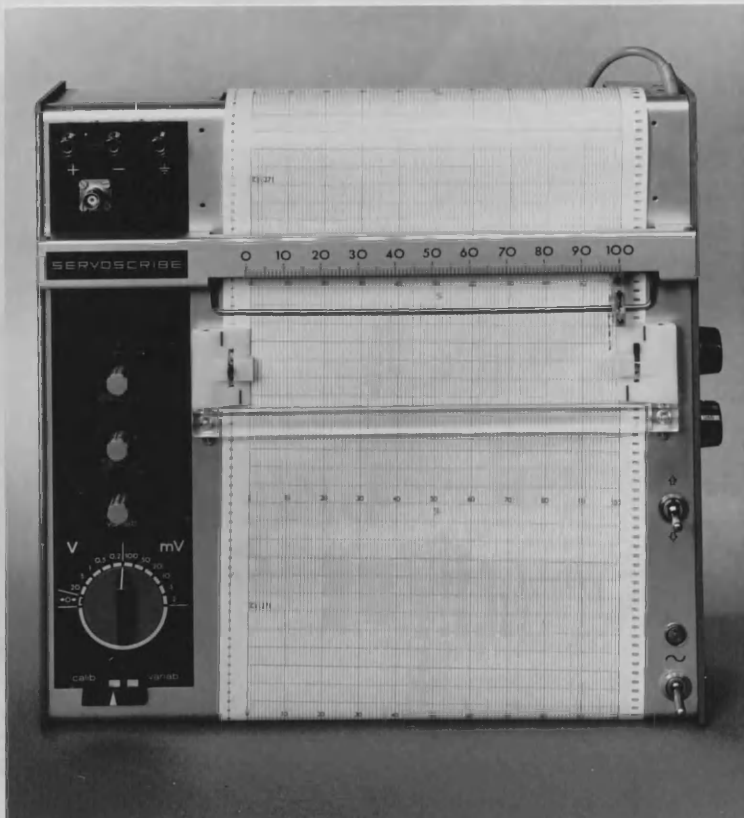
A block diagram of the transmitting and receiving apparatus showing the relationships of the coils.

Figure 3, 2.



A primary copper coil of 15 turns (A) and a secondary copper coil of 200 turns (B) round a core of diameter 6.5 mm (x 1.5).

Figure 3, 3



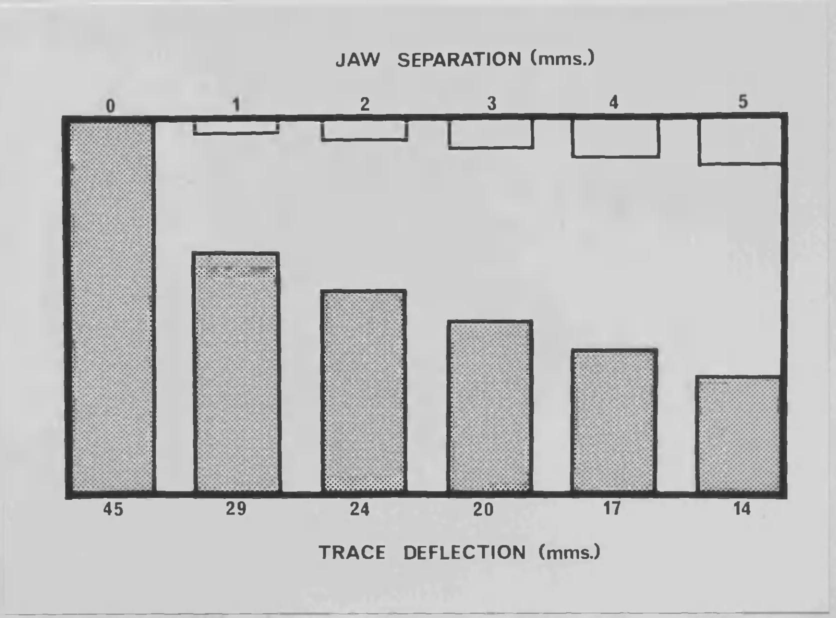
The Potentiometric Recorder

(RE 511 Standard Servoscribe)

Figure 3, 4

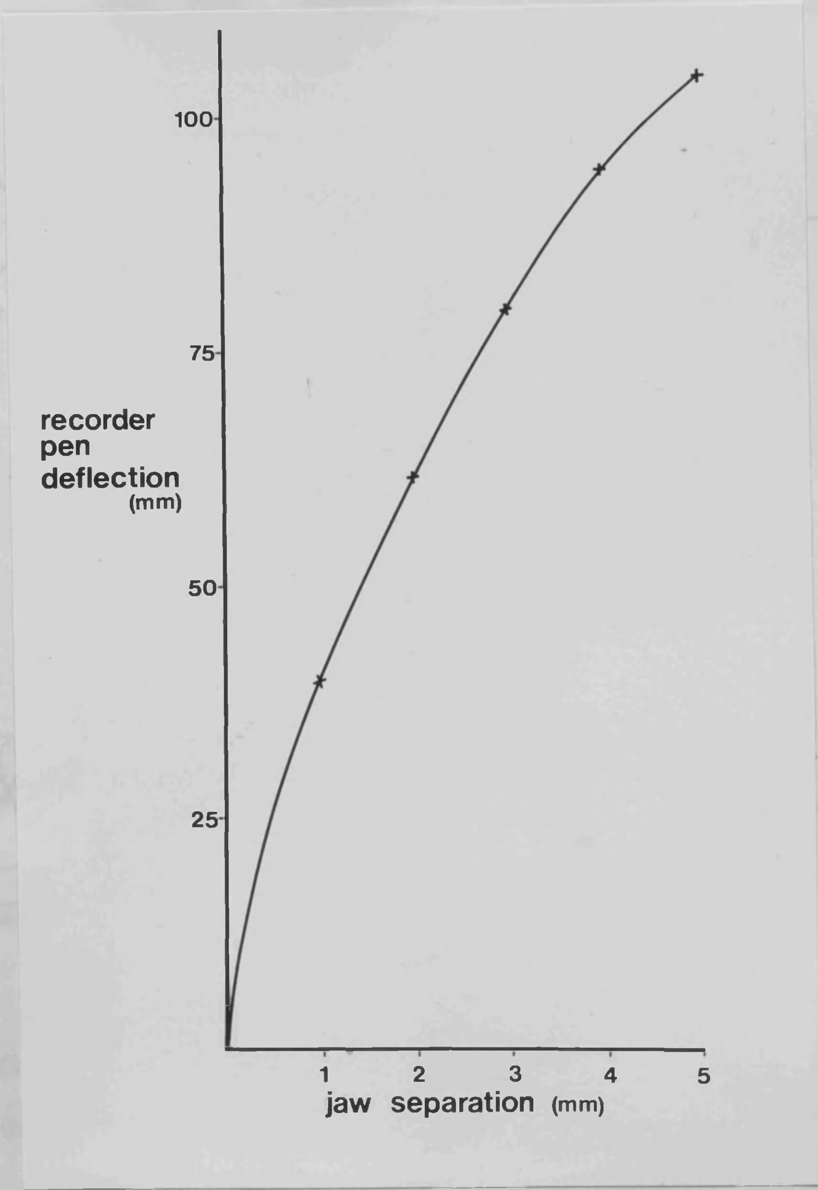
A subject with coils in place in the mouth and linked to the transmitting/receiving apparatus (A) and the potentiometric recorder (B).

Figure 3, 5



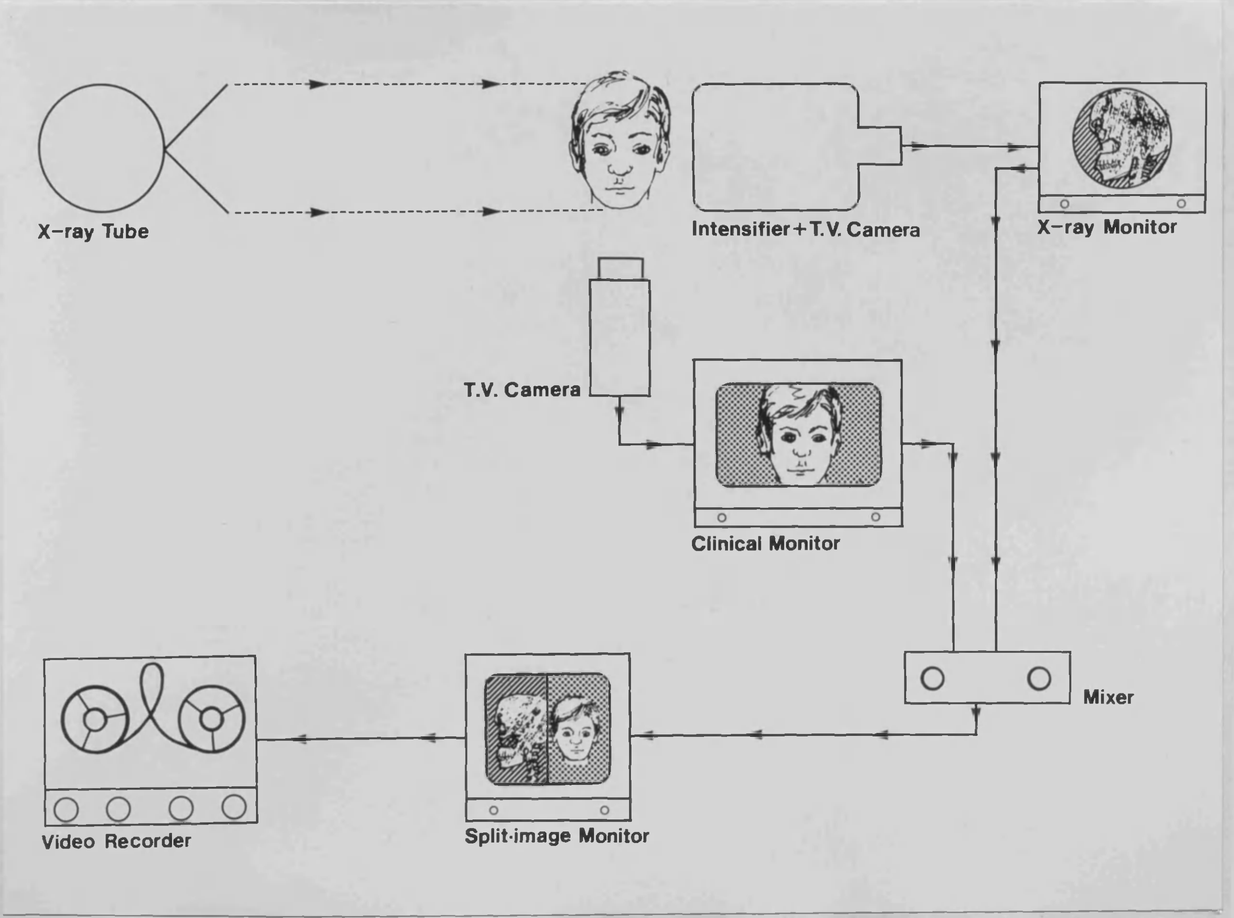
The relationship between the recorder pen deflection and the known coil separation during calibration tests. The maximum signal strength is obtained when the coils are in contact, and at this point there is maximum pen deflection.

Figure 3, 6



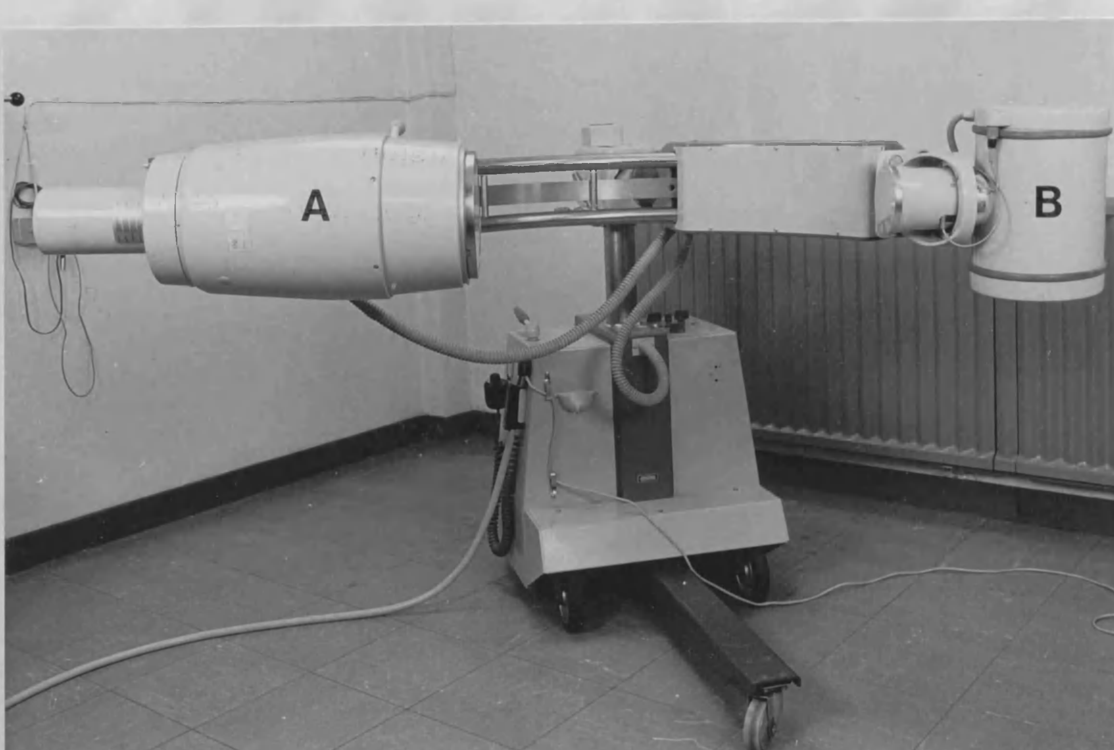
A calibration curve showing the relationship between the recorder pen deflection and jaw separation.

Figure 3, 7



Diagrammatic representation of the X-ray machine, television and recording apparatus.

Figure 3, 8



The image intensifier (A) and the X-ray tube (B) at opposite ends of the curved "C" arm.

Figure 3, 9

A general view of the X-ray, television and recording equipment with a subject in position prior to radiography

A. X-ray tube

B. Image intensifier

C. Television camera

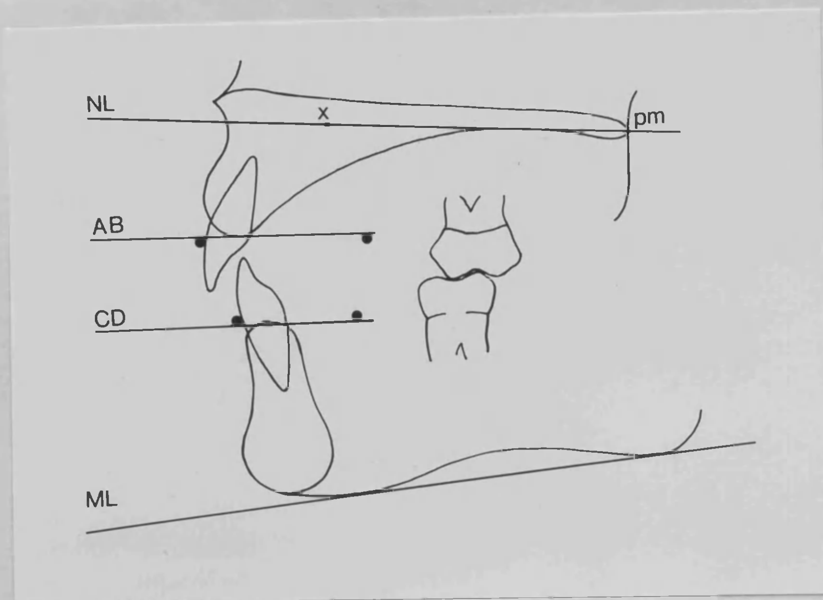
D. Television monitors

E. Video-recorder

Figure 3, 10

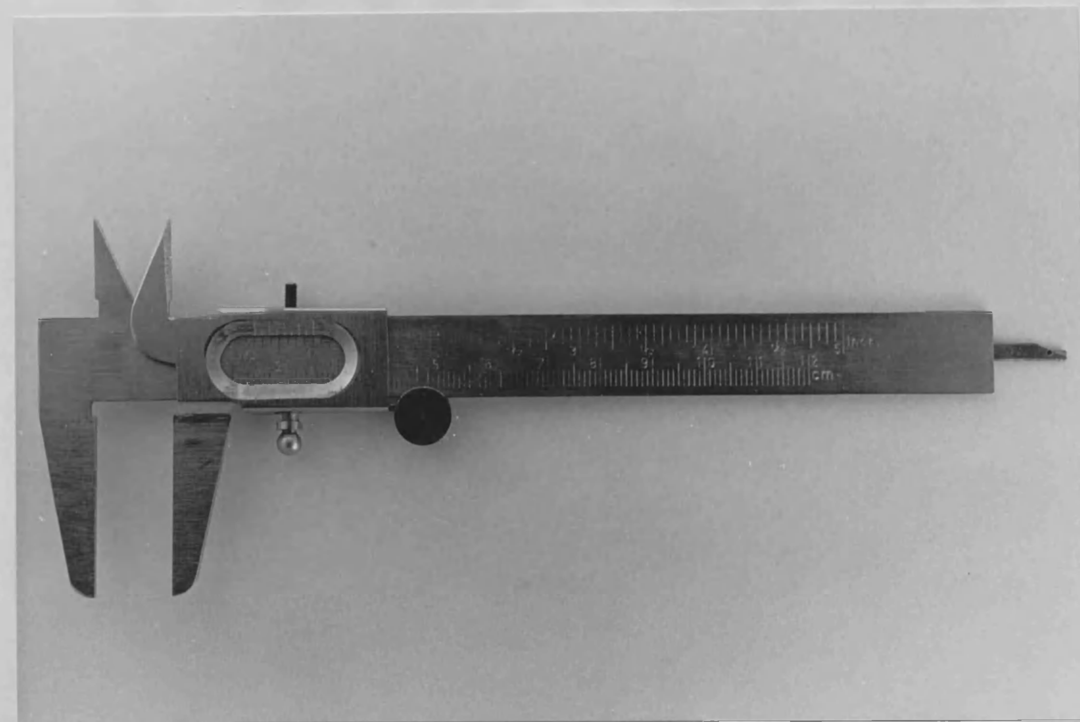
Subject positioned for a lateral jaw radiograph with the lateral surface of the face against the housing of the image intensifier, and the median plane of the head at right angles to the central X-ray beam.

Figure 3, 11



The reference points and lines from which measurements were made.

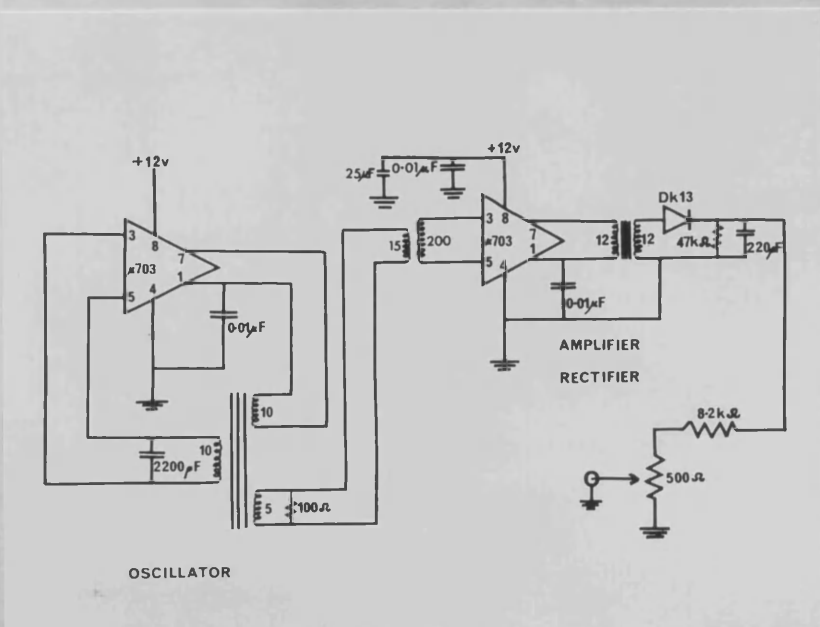
Figure 3, 12



The caliper gauge with the sliding vernier scale used in the measurement analysis.

SECTION 4

Figure 4, 1



The circuit diagram of the transmitting and receiving apparatus.

Figure 4, 2

A dentulous skull positioned for a lateral jaw radiograph with the premolar teeth at a distance of 40 mm from the housing of the image intensifier. The points of reference (lead pellets) may be seen in the premolar and incisor regions.

TABLE 4, 1

	Distance of skull from screen (mm)	Pellet separation on skull (mm)	Pellet separation on image (mm)	Correction factor
	40	25.7	17.9	1.436
A	50	25.7	18.0	1.428
	60	25.7	18.2	1.412
	40	25.5	17.8	1.433
B	50	25.5	17.9	1.425
	60	25.5	18.2	1.401

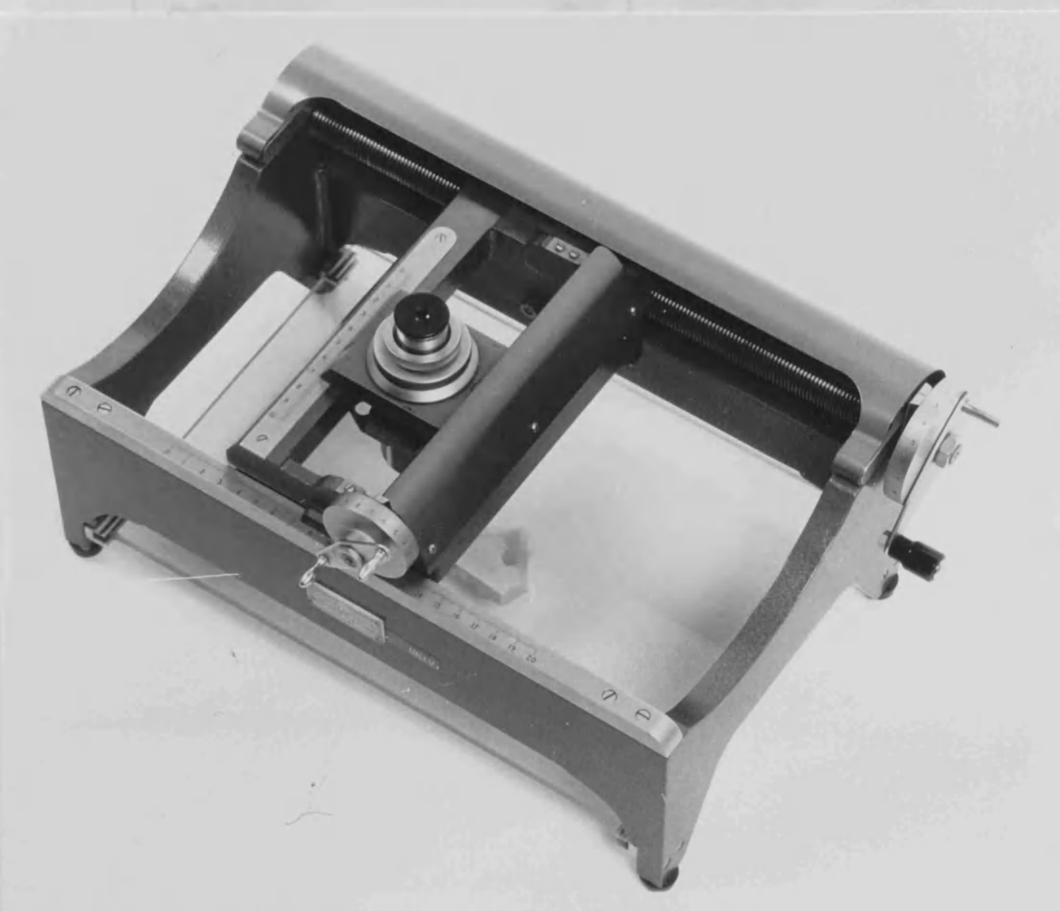
Correction factors for the premolar region (A) and the incisor region (B) of a dentulous skull positioned at various distances from the housing of the image intensifier.

TABLE 4, 2

Angle of skull		Pellet separation on skull (mm)	Pellet separation on image (mm)	Correction factor
A	15^{o}	25.7	18.0	1.428
	30^{o}	25.7	16.3	1.576
B	15^{o}	25.5	17.5	1.457
	30^{o}	25.5	16.0	1.593

Correction factors for the premolar region (A) and the incisor region (B) of a dentulous skull positioned at 50 mm from the image intensifier, and tilted at angles of 15^{o} and 30^{o} from the horizontal towards the screen.

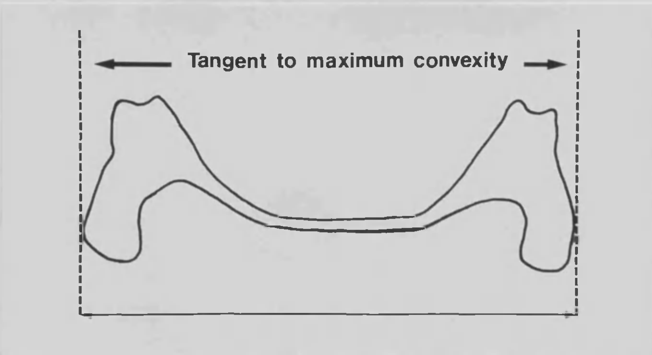
Figure 4, 3



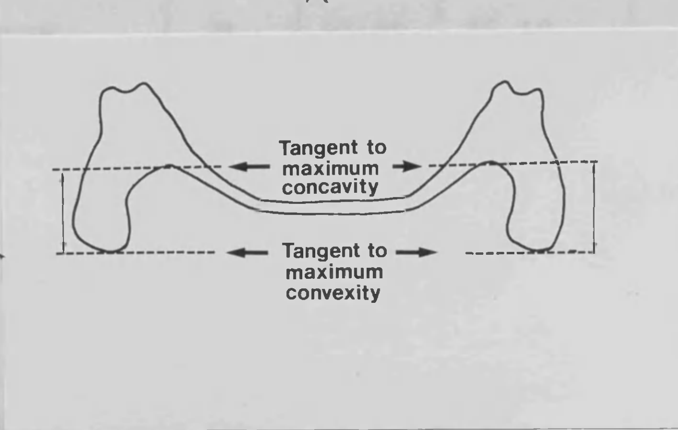
The Travelling Microscope

(W. G. Pye and Co. Ltd. , Cambridge)

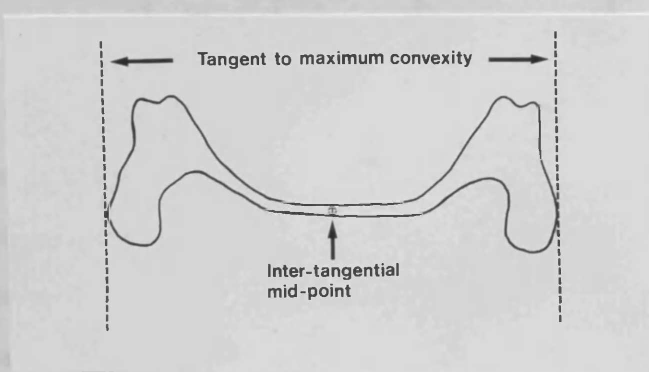
Figure 4, 4



A



B



C

The areas of measurement in the prepared sections of a complete denture :

A. The inter-buccal distance
B. Depth of sulcus
C. Thickness of palate.

TABLE 4, 3

Measurement	Section	Master Denture (mm)	Duplicate Denture (mm)	Difference (mm)
Inter-buccal distance	A	67.03	66.8	0.23
	B	47.89	48.18	0.29
Depth of sulcus (left)	A	8.94	8.68	0.26
	B	10.82	10.37	0.45
Depth of sulcus (right)	A	9.0	8.62	0.28
	B	8.62	8.67	0.05
Thickness of palate	A	2.16	2.3	0.14
	B	4.63	4.92	0.29

Measurements recorded (mm) from sections of a master and duplicate upper denture, cut vertically at the distal border of the first molar teeth (A) and at the distal border of the canine teeth (B).

TABLE 4, 4

Investigator	Occlusal Tooth Contact	
	Present	Absent
W. R. E. L. (1)	31	29
W. R. E. L. (2)	33	27
F. B. C.	29	31

The incidence of occlusal tooth contact in dentulous subjects during 60 swallowing sequences as determined by the author (W. R. E. L.) on two separate occasions, and by an independent investigator (F. B. C.) on one occasion.

TABLE 4, 5

Recorder Pen Deflection (mm)	Jaw Separation (mm)		Difference (mm)
	W. R. E. L.	M. H.	
0	0	0	0
10	0. 2	0. 2	0
20	0. 4	0. 4	0
30	0. 7	0. 7	0
40	1. 0	1. 0	0
50	1. 3	1. 35	+0. 05
60	1. 8	1. 8	0
70	2. 3	2. 3	0
80	2. 85	2. 85	0
90	3. 45	3. 55	+0. 1
100	4. 3	4. 45	+0. 15

Values of jaw separation derived from the recorder pen deflection on a calibration curve constructed by the author (W. R. E. L.) and an independent investigator (M. H.).

TABLE 4, 6

Measurement No.	Observer A (W. R. E. L.) (mm)	Observer B (M. S. S.) (mm)	Difference (mm)
1	26. 3	26. 4	+0. 1
2	29. 3	29. 3	0
3	35. 0	35. 0	0
4	31. 7	31. 8	+0. 1
5	38. 5	38. 5	0
6	32. 6	32. 6	0
7	29	29	0
8	33. 2	33. 2	0
9	30. 8	31	+0. 1
10	26. 5	26. 5	0

Differences (mm) recorded between the author (W. R. E. L.) and an independent investigator (M. S. S.) over 10 readings of a caliper gauge.

TABLE 4, 7

Measurement No.	Observer A (W. R. E. L.) (mm)	Observer B (M. S. S.) (mm)	Difference (mm)
1	41.1	41.1	0
2	36.5	36.4	-0.1
3	37.3	37.3	0
4	28.5	28.3	-0.2
5	28.8	28.8	0
6	27.5	27.5	0
7	31.4	31.5	+0.1
8	36.3	36.2	-0.1
9	39.7	39.7	0
10	32.6	32.7	+0.1
11	34.0	33.8	-0.2
12	35.6	35.6	0
13	38.9	38.7	-0.2
14	35.5	35.6	+0.1
15	36.8	36.6	-0.2
16	28.0	27.9	-0.1
17	40.5	40.3	-0.2
18	36.2	36.0	-0.2
19	38.0	37.7	-0.3
20	35.0	35.0	0

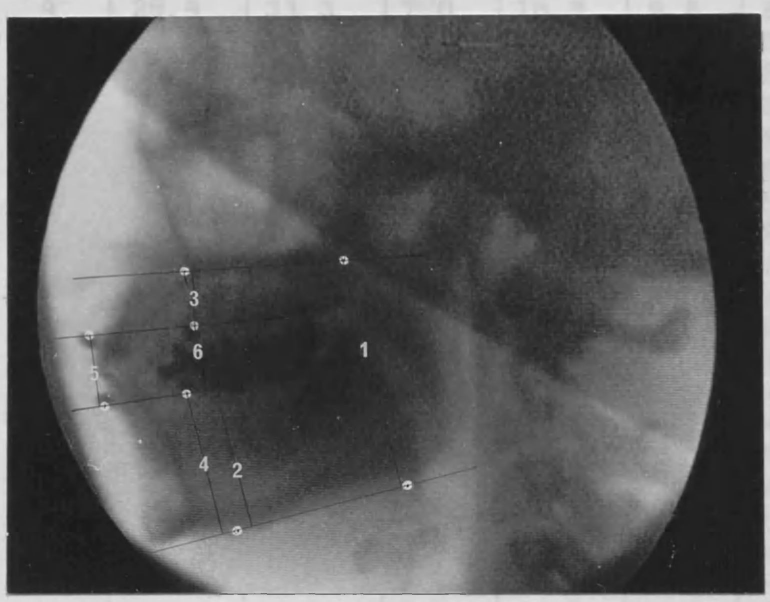
Differences in length measurement values (mm) between similar reference points on 20 subjects as recorded by the author (W. R. E. L.) and an independent investigator (M. S. S.).

TABLE 4, 8

Measurement No.	Original Observation (mm)	Second Observation (mm)	Difference (mm)
1	41.1	41.1	0
2	36.5	36.5	0
3	37.3	37.4	+0.1
4	28.5	28.6	+0.1
5	28.8	28.8	0
6	27.5	27.4	-0.1
7	31.4	31.5	+0.1
8	36.3	36.5	+0.2
9	39.7	39.6	-0.1
10	32.6	32.6	0
11	34.0	34.0	0
12	35.6	35.7	+0.1
13	38.9	39	+0.1
14	35.5	35.5	0
15	36.8	36.7	-0.1
16	28.0	28.0	0
17	40.5	40.6	+0.1
18	36.2	36.2	0
19	38.0	38.1	+0.1
20	35.0	35.1	+0.1

Differences in length measurement values (mm) between similar reference points on 20 subjects as recorded by the author on two separate occasions.

Figure 4, 5



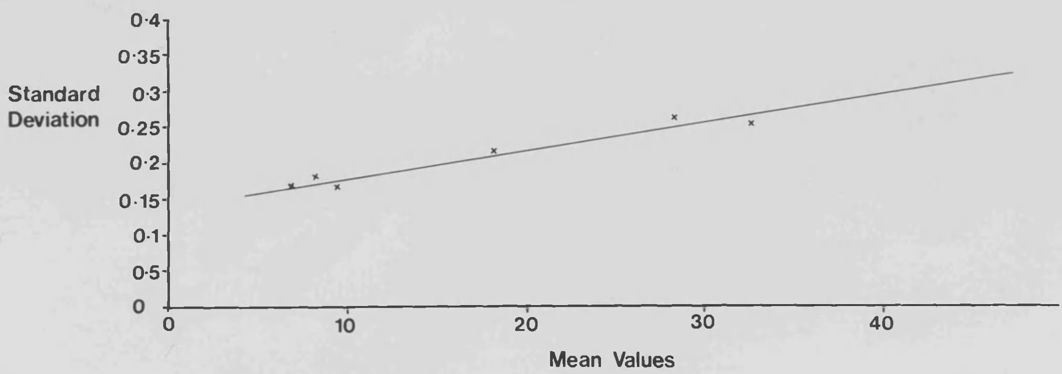
The lines of measurement used to determine the reliability of references. These are numbered to correspond with the measurement values presented in Table 4, 9.

TABLE 4, 9

Frame No.	Measurement Lines (mm)					
	1	2	3	4	5	6
1	28.3	33.0	7.1	18.4	9.7	8.1
2	28.4	32.7	6.7	18.5	9.7	8.2
3	28.4	32.7	6.9	18.5	9.1	7.9
4	28.4	33.3	7.0	18.8	9.6	8.4
5	18.8	32.5	6.7	18.3	9.5	8.1
6	28.1	32.3	6.9	18.0	9.4	8.3
7	28.2	33.0	6.8	18.7	9.4	8.4
8	28.7	32.5	6.9	18.1	9.6	8.4
9	28.1	32.8	7.3	18.2	9.5	8.3
10	28.7	32.8	6.9	18.3	9.5	8.5
11	28.5	32.6	6.9	18.6	9.5	8.0
12	28.4	32.7	7.1	18.3	9.3	8.0
13	28.3	32.7	7.0	18.3	9.3	8.3
14	19.0	32.9	7.0	18.7	9.7	8.1
15	28.0	32.9	7.3	18.4	9.6	8.0
16	28.4	33.0	7.0	18.2	9.5	8.3
17	28.5	32.8	6.7	18.6	9.5	8.2
18	28.7	32.5	6.8	18.2	9.4	8.4
19	28.5	32.6	6.8	18.5	9.5	8.2
20	28.0	32.0	6.8	18.5	9.4	8.3
21	28.5	32.7	7.1	18.3	9.4	8.3
22	29.0	32.5	7.1	18.2	9.3	8.2
23	28.7	32.8	7.0	18.4	9.4	8.1
24	28.5	32.4	6.7	18.0	9.5	8.6
25	28.4	32.6	6.8	18.3	9.6	8.1
26	28.2	32.7	7.0	18.4	9.7	8.0
27	28.4	32.8	7.0	18.5	9.8	7.9
28	28.7	33.1	7.2	18.4	9.4	8.2
29	28.8	32.8	6.9	18.1	9.3	8.6
30	28.6	33.0	6.8	18.8	9.7	8.3
Mean	28.473	32.723	6.94	18.383	9.493	8.223
St. Deviation	0.264	0.258	0.167	0.215	0.157	0.187

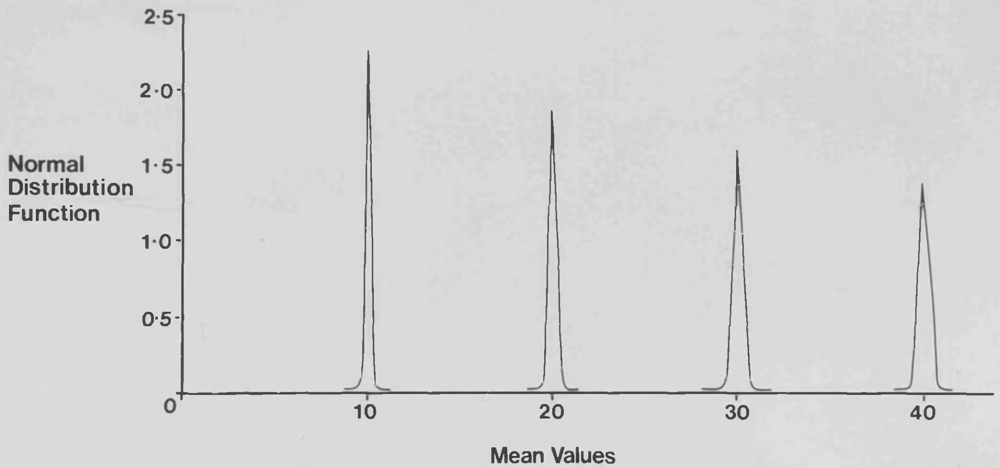
Measurement values (mm) of the distances between 6 separate pairs of reference points on 30 photographic frames of a dentulous subject at the intercuspal position, together with means and standard deviations. The lines of measurement are numbered to correspond with the numbering on Fig. 4, 5.

Figure 4,6



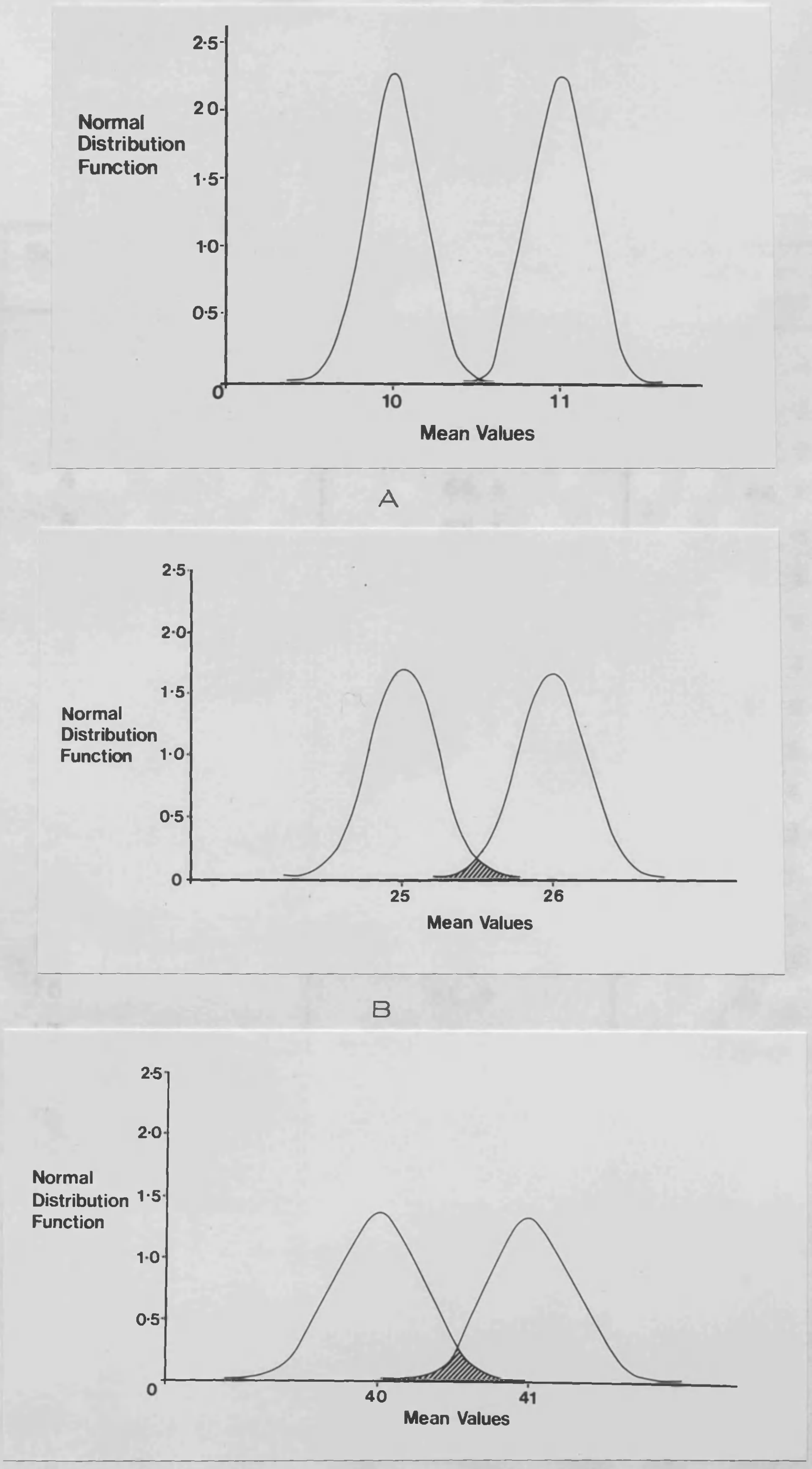
The relationship between the mean readings (mm) recorded from the dentulous subject at the intercuspal position, and their standard deviation.

Figure 4,7



Normal distribution curves for mean values of 10, 20, 30 and 40 mm. Constructed from the graph of standard deviation against the mean (Fig. 4, 6). As the mean increases the possible dispersion of readings about the mean also increases.

Figure 4,8



C

Normal distribution curves about adjacent mean values of 10 and 11 mm (A), 25 and 26 mm (B) and 40 and 41 mm (C), with values of standard deviation derived from Fig. 4, 6. As the value of the means increases so does the overlap of the dispersion about the mean.

TABLE 4, 10a

Subject	Incisor Distance (mm)	Premolar Distance (mm)
1	55.4	40.4
2	56.2	44.6
3	59.8	47.9
4	66.6	46.7
5	55.1	41.4
6	68.8	52.5
7	60.9	41.6
8	55.6	36.3
9	51.8	38.9
10	59.9	43.8
11	62.2	45.4
12	52.5	36.2
13	57.5	41.2
14	69.6	47.4
15	62.3	43.0
16	61.9	48.3
17	62.7	44.8
18	67.5	49.9
19	61.0	43.2
20	67.2	44.7
Mean	60.73	43.91
Standard Deviation	5.34	4.26

The distance (mm) from the housing of the image intensifier to the incisor and premolar teeth of 20 dentulous subjects positioned for a laterial jaw radiograph, together with means and standard deviations.

TABLE 4, 10b

Subject	Incisor Distance (mm)	Premolar Distance (mm)
1	55.4	40.4
2	59.8	47.9
3	66.6	46.7
4	69.6	47.4
5	62.3	43.0
6	61.9	48.3
7	62.7	44.8
8	67.5	49.9
9	61.0	43.2
10	67.2	44.7
Mean	63.4	45.63
Standard Deviation	4.302	2.916

The distance (mm) from the housing of the image intensifier to the incisor and premolar teeth of 10 dentulous male subjects positioned for a lateral jaw radiograph, together with means and standard deviations.

TABLE 4, 10c

Subject	Incisor Distance (mm)	Premolar Distance (mm)
1	56.2	44.6
2	55.1	41.4
3	68.8	42.5
4	60.9	41.6
5	55.6	36.3
6	51.8	38.9
7	59.9	43.8
8	62.2	45.4
9	52.5	36.2
10	57.5	41.2
Mean	58.05	42.19
Standard Deviation	5.08	4.81

The distance (mm) from the housing of the image intensifier to the incisor and premolar teeth of 10 dentulous female subjects positioned for a lateral jaw radiograph, together with means and standard deviations.

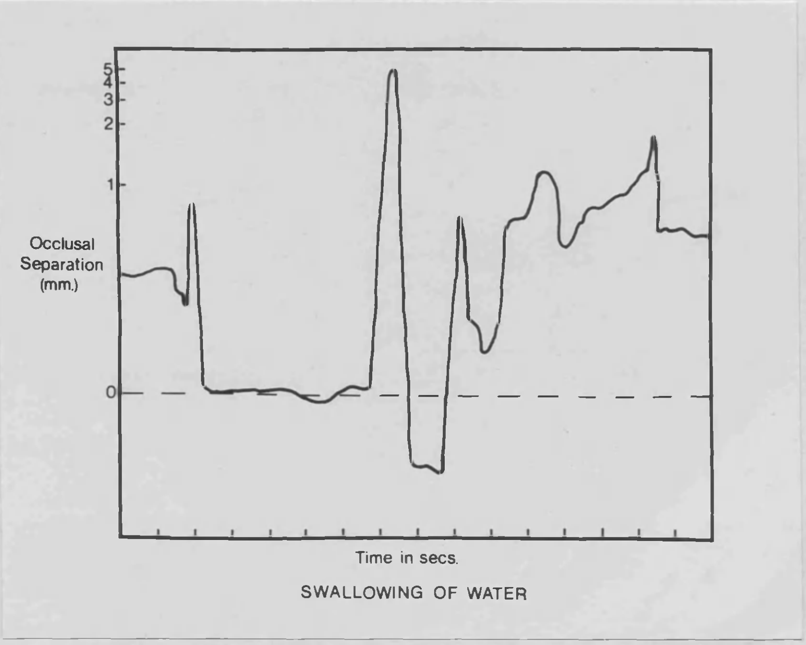
TABLE 4, 11

Subject	Water Volume (ml)
1	57
2	60
3	56
4	45
5	91
6	73
7	36
8	47
9	48
10	35
11	15
12	28
Mean	49. 25
Standard Deviation	20. 35

The volume of water swallowed over six swallowing sequences for 12 dentulous subjects, together with the mean volume and standard deviation.

SECTION 5

Figure 5, 1



Graphical recording of a typical swallowing sequence. The lack of uniformity on the scale of occlusal separation is due to the fact that the relationship between coil separation and signal intensity is non-linear. As the graph reaches zero value it indicates tooth contact in the intercuspal position. Below the zero value it indicates probable tooth contact outwith the intercuspal position as signal intensity is increased.

TABLE 5, 1

Subject	Time (secs)	Subject	Time (secs)
1	0.43	6	0.55
2	0.27	7	1.03
3	1.52	8	1.13
4	0.28	9	1.05
5	1.42	10	0.33

Mean length of time (secs) that the pre-swallow tooth contact or level of jaw separation was maintained by each subject.

TABLE 5, 2

Subject	Swallowing Sequences		Total
	With Contact	Without Contact	
1	2	4	6
2	6	0	6
3	6	0	6
4	4	2	6
5	6	0	6
6	4	2	6
7	6	0	6
8	5	1	6
9	0	6	6
10	6	0	6
Total	45	15	60

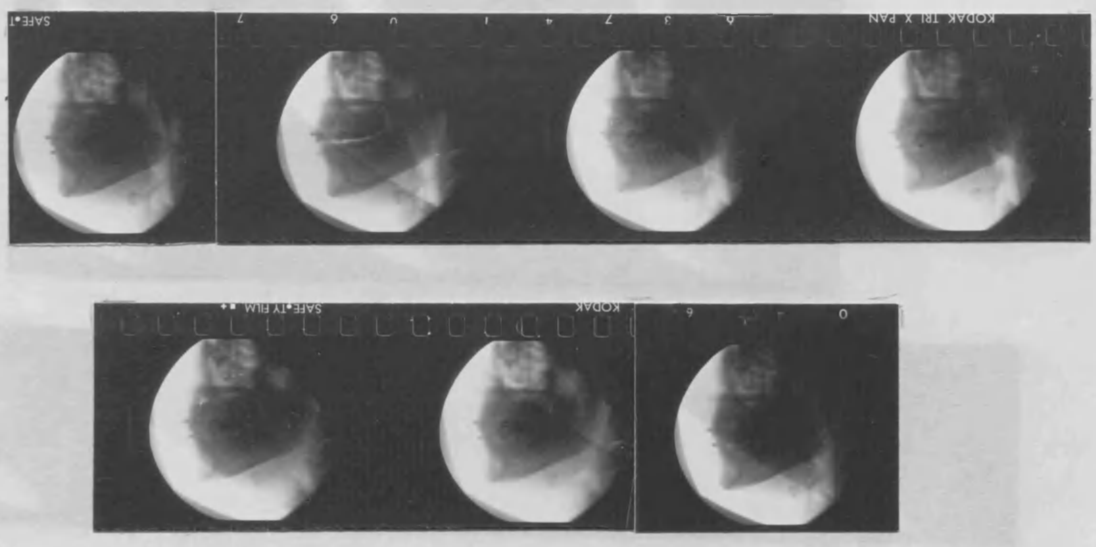
The incidence of occlusal tooth contact in dentulous subjects during swallowing. Six swallowing sequences were recorded for each subject.

TABLE 5, 3

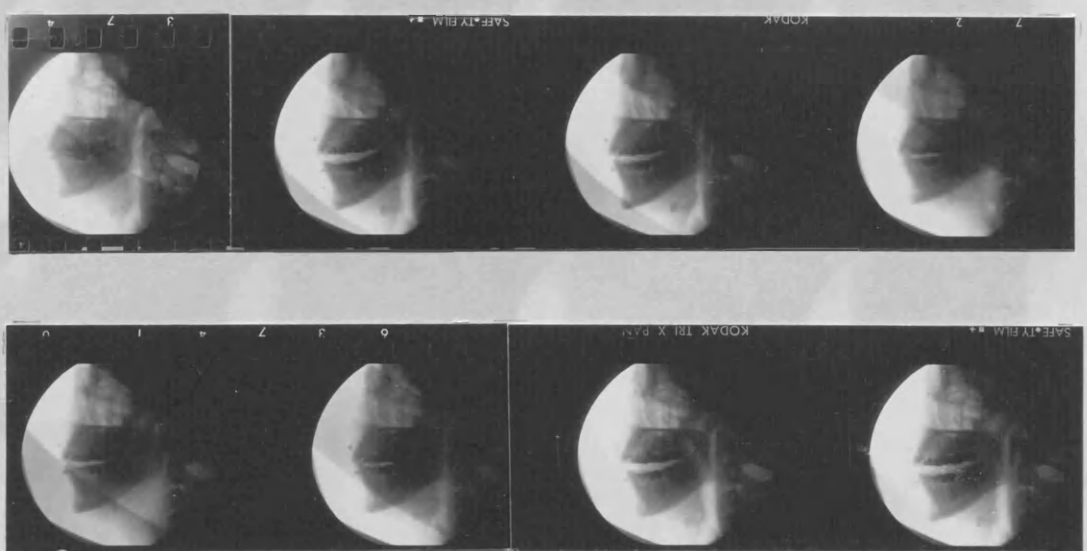
Subject	Swallowing Sequences		Total
	With Contact	Without Contact	
1	3	3	6
2	6	0	6
3	4	2	6
4	6	0	6
5	2	4	6
6	0	6	6
7	4	2	6
8	0	6	6
9	0	6	6
10	4	2	6
Total	29	31	60

The incidence of occlusal tooth contact in dentulous subjects at the termination of swallowing. Six swallowing sequences were recorded for each subject.

Figure 5, 2a



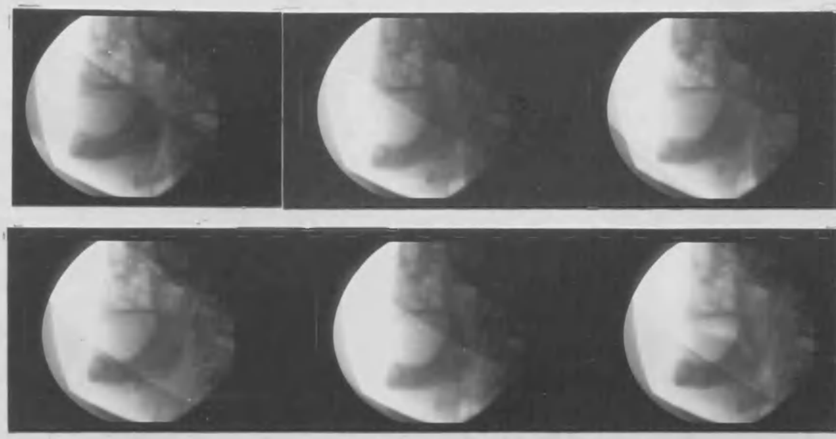
A



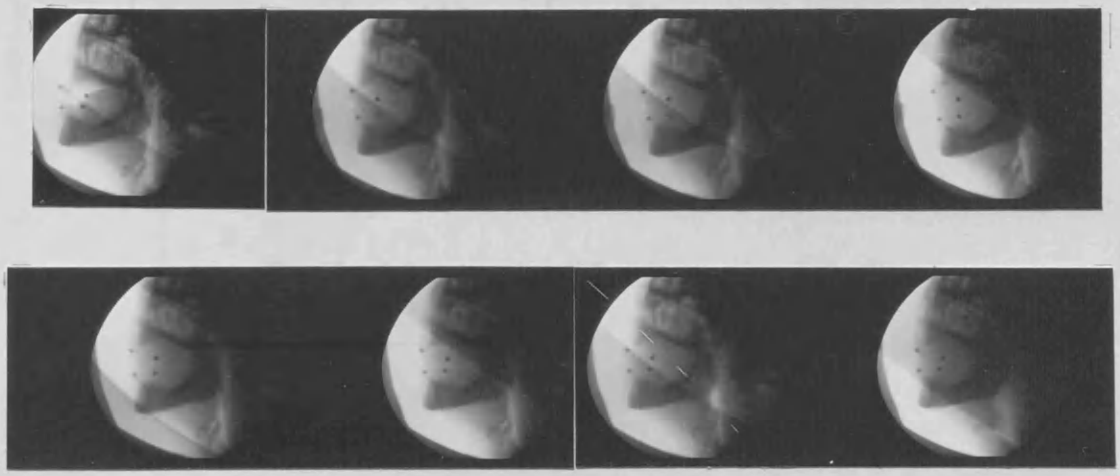
B

Swallowing sequences recorded from 2 dentulous subjects demonstrating swallowing with the teeth in contact (A) and swallowing with the teeth apart (B). Each subject commences from the intercuspal position.

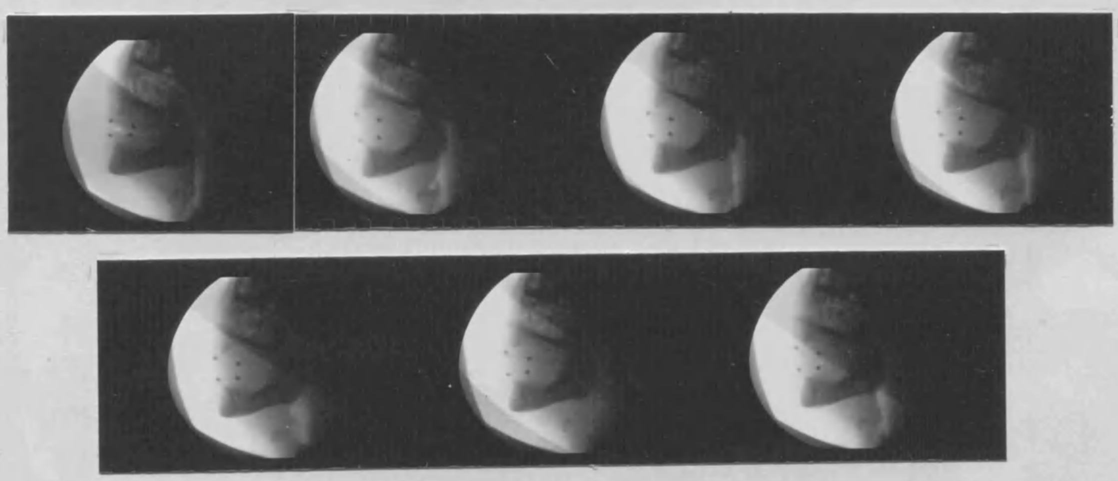
Figure 5, 2b



A



B



C

Swallowing sequences recorded from an edentulous subject (A) and an edentulous subject wearing dentures at the correct vertical dimension (B) and at a reduced vertical dimension (C). The edentulous subject commences from a relaxed position and the subject with dentures from the intercuspal position.

TABLE 5, 4

	Contact	No Contact	Total
Males	62	46	108
Females	41	30	71
Total	103	76	179

The incidence of occlusal tooth contact in dentulous subjects during swallowing as determined from the visual analysis of 179 sequences.

TABLE 5, 5a

Subject No.	Intercuspal Position	Swallowing Sequences 1	2	3	4	5	6
1	7.3 - 7.9	10.0	10.2	10.5	10.4	10.2	9.7
2	8.9 - 9.5	10.2	9.8	9.2	9.1	8.9	9.2
3	12.7 - 13.4	14.4	14.3	13.0	14.1	13.5	12.9
4	10.3 - 10.9	11.9	11.5	11.6	11.5	11.1	11.5
5	11.1 - 11.7	12.5	12.5	12.7	13.1	13.6	13.4
6	6.6 - 7.2	8.2	6.8	6.9	6.7	6.9	6.9
7	8.8 - 9.4	9.2	8.9	9.2	10.9	10.5	9.3
8	8.1 - 9.7	9.5	9.5	9.4	9.4	9.6	12.0
9	12.1 - 12.8	13.2	12.4	14.0	14.7	13.1	12.6
10	8.7 - 9.3	9.1	9.0	8.7	9.1	8.9	8.8
11	9.8 - 10.5	10.5	10.0	10.3	10.1	10.5	9.8
12	10.1 - 10.7	12.6	11.6	10.5	10.5	10.7	10.7
13	8.6 - 9.2	9.0	9.6	9.2	8.6	8.7	8.8
14	8.2 - 8.8	8.4	10.0	9.8	9.0	10.0	10.1
15	7.9 - 8.5	9.9	9.5	10.3	10.6	9.5	10.6
16	9.7 - 10.3	10.4	9.8	10.0	9.9	9.9	9.9
17	9.6 - 10.2	12.0	11.8	12.6	12.7	12.4	12.9
18	9.6 - 10.2	11.9	11.9	12.1	11.6	12.1	12.3
19	9.7 - 10.3	10.0	10.1	9.7	10.6	9.9	9.7
20	7.6 - 8.2	10.3	10.1	11.0	12.4	11.7	10.4
21	8.7 - 9.3	9.0	8.8	8.9	8.9	9.2	9.0
22	12.4 - 13.0	12.6	12.4	12.6	13.0	12.5	-
23	9.6 - 10.2	9.8	9.7	9.7	9.7	9.7	10.0
24	7.8 - 8.4	8.1	8.0	8.2	7.8	8.1	8.3
25	9.3 - 9.9	12.1	9.8	11.9	12.1	9.8	11.4
26	7.9 - 8.5	9.8	10.2	10.3	10.9	10.2	9.8
27	9.4 - 10.0	9.6	11.9	10.6	11.5	10.9	10.7
28	10.2 - 10.8	12.0	12.7	11.1	12.5	10.8	15.3

The distance (mm) from the upper lead pellet in the incisor region perpendicular to the line CD, for dentulous subjects both at the intercuspal position and during swallowing sequences. The distance at the intercuspal position has been expressed as a range as explained in the text (Chapter 15).

TABLE 5, 5b

Subject No.	Intercuspal Position	Swallowing Sequences 1	2	3	4	5	6
1	8.6 - 9.2	11.2	11.0	11.1	10.9	11.0	9.8
2	8.5 - 9.1	10.5	9.3	8.8	8.7	8.7	8.9
3	8.2 - 8.8	9.2	8.9	8.2	8.9	9.1	8.2
4	7.2 - 7.8	8.0	8.0	7.9	8.0	7.9	8.1
5	8.9 - 9.5	10.7	10.1	10.5	10.9	10.6	10.1
6	8.7 - 9.3	9.7	9.1	9.0	8.7	8.9	8.9
7	10.2 - 10.9	10.6	10.7	10.9	12.2	12.0	10.5
8	9.1 - 9.7	9.5	9.5	9.4	9.7	9.7	11.8
9	8.9 - 9.5	10.6	9.5	11.0	11.8	10.8	9.5
10	8.0 - 8.6	8.5	8.3	8.4	8.2	8.2	8.4
11	9.7 - 10.3	10.3	9.9	10.0	9.7	10.3	9.9
12	7.5 - 8.1	9.0	8.5	7.8	8.0	8.1	7.9
13	11.0 - 11.6	11.4	11.7	11.3	11.6	11.4	11.2
14	8.1 - 8.7	8.4	9.6	9.7	9.0	9.2	9.6
15	7.9 - 8.5	9.6	9.1	9.9	10.1	9.6	10.2
16	8.7 - 9.3	9.6	9.1	9.3	9.3	9.3	9.3
17	8.0 - 8.6	9.6	9.5	9.1	9.9	9.6	9.5
18	9.8 - 10.4	10.9	10.5	10.8	11.2	11.0	11.3
19	9.2 - 9.8	9.5	9.7	9.4	10.2	9.1	9.5
20	8.7 - 9.3	10.2	10.1	10.8	11.5	11.4	11.0
21	7.5 - 8.1	8.0	7.8	8.0	7.7	7.8	7.8
22	9.7 - 10.3	10.1	10.0	10.1	10.2	9.7	-
23	8.5 - 9.1	8.8	8.7	8.8	8.5	8.5	8.9
24	6.3 - 6.9	6.4	6.4	6.5	6.5	6.4	6.4
25	7.2 - 7.8	8.7	7.6	8.6	8.7	7.7	8.2
26	6.7 - 7.3	7.5	8.7	7.8	7.9	7.5	7.4
27	8.4 - 9.0	8.7	10.5	9.2	10.5	10.0	9.6
28	9.8 - 10.4	11.5	11.8	11.0	11.8	10.3	13.7

The distance (mm) from the upper lead pellet in the premolar region perpendicular to the line CD for dentulous subjects both at the intercuspal position and during swallowing sequences. The distance at the intercuspal position has been expressed as a range as described in the text (Chapter 15).

TABLE 5, 6

	Contact	No Contact	Total
Males	44	52	96
Females	38	33	71
Total	82	85	167

The incidence of occlusal tooth contact in dentulous subjects during swallowing as determined from the measurement analysis of 167 sequences.

TABLE 5, 7

Subject No.	Swallowing Sequences 1	2	3	4	5	6
2	o	+	+	+	+	+
3	o	o	+	o	o	+
6	o	+	+	+	+	+
7	+	+	+	o	o	+
8	+	+	R,1	R,1	R,1	o
9	o	+	o	o	o	P, 0.8
10	+	+	+	+	+	+
11	+	R,0.7	+	+	R,1	+
12	o	o	+	+	+	+
13	+	o	+	R,0.8	+	+
14	+	o	o	o	o	o
16	o	+	+	+	+	+
19	+	+	+	o	+	+
21	+	R,1.1	R,1.2	R,1.2	R,1.1	R,1.1
22	+	+	+	+	+	o
23	+	+	+	+	+	+
24	+	R, 1	R, 1	R, 1	R,1.2	R, 1
25	o	+	o	o	+	o
27	+	o	o	o	o	o
28	o	o	o	o	+	o

The position of occlusal tooth contact in dentulous subjects during swallowing, with reference to the intercuspal position.

o no contact

\+ intercuspal position

R retrusive to intercuspal position (mm)

P protrusive to intercuspal position (mm)

TABLE 5, 8

Subject	1	2	3	4	5	6	7
Premolars	2.1	0	0	1.0	0	0	0
Incisors	3.1	0	0	1.7	0	0	0

Subject	8	9	10	11	12	13	14
Premolars	1.8	4.1	0	0	1.2	3.8	2.4
Incisors	1.8	4.1	0	0	1.8	4.4	3.4

Subject	15	16	17	18	19	20	21
Premolars	0	0	1.7	0	0	0	0
Incisors	0	0	4.1	0	0	0	0

Subject	22	23	24	25	26	27	28
Premolars	-	0	0	1.7	1.9	0	7.7
Incisors	-	0	0	3.2	4.1	0	8.7

The amount of interocclusal clearance (mm) in dentulous subjects in both premolar and incisor regions after completion of the swallowing sequences. No recording was available for subject number 22.

TABLE 5,9

Investigator	Contact	No Contact	Total
LAIRD (1973) radiographic	20	8	28
CLEALL (1965) radiographic	16	11	28
MØLLER (1966) electromyographic	23	13	36
RIX (1946) visual	65	28	93

The incidence of occlusal tooth contact in dentulous subjects during swallowing as reported by separate investigators using different methods of investigation.

TABLE 5, 10a

Sequence No.	Subjects 1	2	3	4	5	6	7	8	9	10
1	30.9	30.5	42.6	38.6	38.8	32.5	39.9	49.5	31.4	39.0
2	31.5	29.9	41.5	38.5	38.6	32.5	39.2	49.5	31.1	38.5
3	31.9	30.0	42.8	37.8	38.9	33.6	39.9	49.2	30.2	39.9
4	31.1	30.8	41.2	37.9	38.5	32.5	38.2	49.2	31.2	36.8
5	31.5	29.8	42.8	39.3	39.9	34.8	39.9	49.8	30.2	39.8
6	30.5	30.8	41.6	40.7	40.6	33.0	37.8	50.0	30.2	39.1
Mean	31.2	30.3	42.1	38.7	39.2	33.1	39.2	49.4	30.7	38.8

Sequence No.	11	12	13	14	15	16	17	18	19	20
1	39.6	41.0	33.3	39.6	44.9	47.2	39.9	34.2	40.7	42.8
2	42.7	44.4	32.6	39.3	44.8	46.8	38.8	33.9	40.5	43.9
3	42.7	43.9	33.9	39.4	46.5	46.4	37.9	32.7	41.3	39.6
4	41.2	42.7	33.3	40.1	44.8	46.7	36.3	33.7	40.6	42.1
5	42.4	43.7	37.2	39.1	41.5	45.9	38.8	34.1	42.5	41.5
6	39.7	44.0	33.5	39.4	42.9	45.9	37.5	34.4	41.1	43.7
Mean	41.4	43.3	33.9	39.5	44.2	46.5	38.2	33.8	41.1	42.3

Individual and mean values (mm) for vertical jaw separation in the incisor region during six swallowing sequences in 20 edentulous subjects.

TABLE 5, 10b

Sequence No.	Subjects 1	2	3	4	5	6	7	8	9	10
1	30.7	27.2	38.7	34.4	35.6	28.7	34.7	40.7	29.0	37.4
2	31.2	26.7	38.6	34.1	35.0	28.7	34.6	39.4	29.5	36.9
3	31.6	26.6	38.4	33.8	35.9	28.7	34.8	39.6	28.3	37.7
4	31.1	26.9	37.6	33.5	35.6	28.2	34.0	39.5	29.5	35.4
5	31.4	26.3	38.6	34.3	36.3	29.7	34.9	40.4	28.8	37.8
6	29.8	26.8	38.0	35.1	36.4	28.5	33.5	41.2	28.8	37.1
Means	31.0	26.7	38.4	34.1	36.0	28.7	34.5	40.1	29.0	37.0

Sequence No.	Subjects 11	12	13	14	15	16	17	18	19	20
1	37.9	35.5	28.7	36.8	35.5	40.5	38.3	33.5	35.2	39.6
2	40.7	36.9	28.3	36.8	35.6	40.9	36.8	33.4	34.6	40.8
3	40.4	36.6	29.0	37.1	36.9	40.4	36.8	32.6	35.2	36.5
4	39.1	36.0	28.5	37.7	36.0	40.3	34.9	33.0	35.2	38.9
5	40.3	36.7	30.5	36.9	35.0	40.3	36.2	32.9	35.4	36.3
6	38.2	36.2	29.0	37.3	35.9	39.9	36.0	33.5	35.0	38.2
Means	39.4	36.3	29.0	37.1	36.5	40.4	36.5	33.2	35.1	38.4

Individual and mean values (mm) for vertical jaw separation in the premolar/molar region during swallowing sequences in 20 edentulous subjects.

TABLE 5, 11a

Subject No.	Mean Swallowing Level (mm)	Range of Variability of Mean (mm)	Swallowing Sequences	
			Within Range	Without Range
1	31.2	30.6-31.8	6	0
2	30.3	29.8-30.9	6	0
3	42.1	41.4-42.8	6	0
4	38.7	38.0-39.4	5	1
5	39.2	38.5-39.9	5	1
6	33.1	32.5-33.7	5	1
7	39.2	38.5-39.9	5	1
8	49.4	48.6-50.1	6	0
9	30.7	30.1-31.3	6	0
10	38.8	38.2-39.4	4	2
11	41.4	40.7-42.1	2	4
12	43.3	42.6-44.0	5	1
13	33.9	33.3-34.5	4	2
14	39.5	38.8-40.2	6	0
15	44.2	43.5-44.9	3	3
16	46.5	45.8-47.2	6	0
17	38.2	37.6-38.8	4	2
18	33.8	33.2-34.4	5	1
19	41.1	40.4-41.8	6	0
20	42.3	41.6-43.0	3	3
Total	-	-	98	22

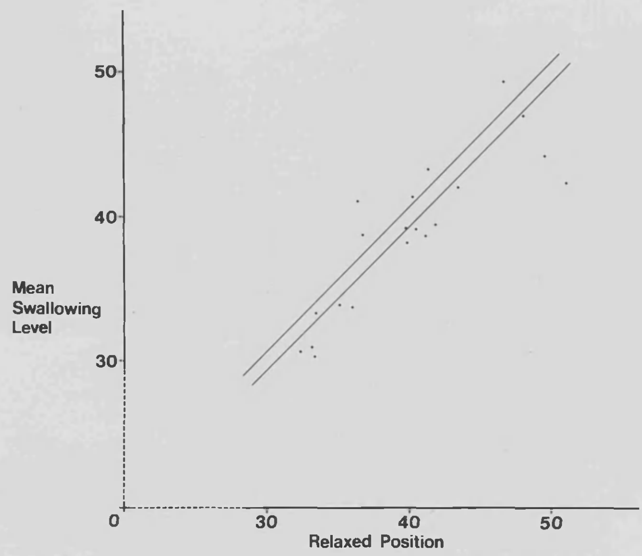
The number of swallowing sequences in edentulous subjects in which the vertical jaw separation fell within or without the range of variability of the mean vertical jaw separation during swallowing. (Measurements taken in the incisor region).

TABLE 5, 11b

Subject No.	Mean Level (mm)	Range of Variability of Mean (mm)	Swallowing Sequences	
			Within Range	Without Range
1	31.0	30.4-31.6	5	1
2	26.7	26.2-27.2	6	0
3	38.4	37.8-39.0	6	0
4	34.1	33.5-34.7	5	1
5	36.0	35.4-36.6	5	1
6	28.7	28.2-29.2	5	1
7	34.5	33.9-35.1	5	1
8	40.1	39.4-40.8	5	1
9	29.0	28.5-29.5	6	0
10	37.0	36.4-37.6	5	1
11	39.4	38.8-40.1	2	4
12	36.3	35.7-36.9	6	0
13	29.0	28.5-29.5	5	1
14	37.1	36.4-37.7	6	0
15	36.5	35.9-37.1	3	3
16	40.4	39.7-41.1	6	0
17	36.5	35.9-37.1	4	2
18	33.2	32.6-33.8	6	0
19	35.1	34.5-35.7	6	0
20	38.4	37.8-39.0	2	4
Total	-	-	99	21

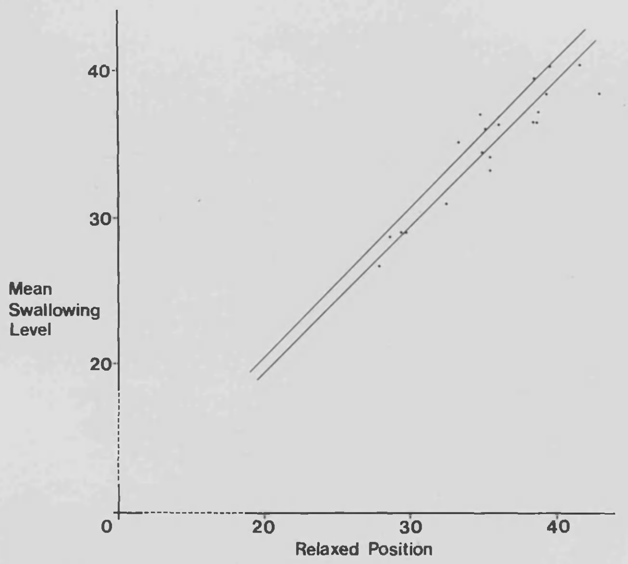
The number of swallowing sequences in edentulous subjects in which the vertical jaw separation fell within or without the range of variability of the mean vertical jaw separation during swallowing (Measurements taken in the premolar region).

Figure 5, 3a



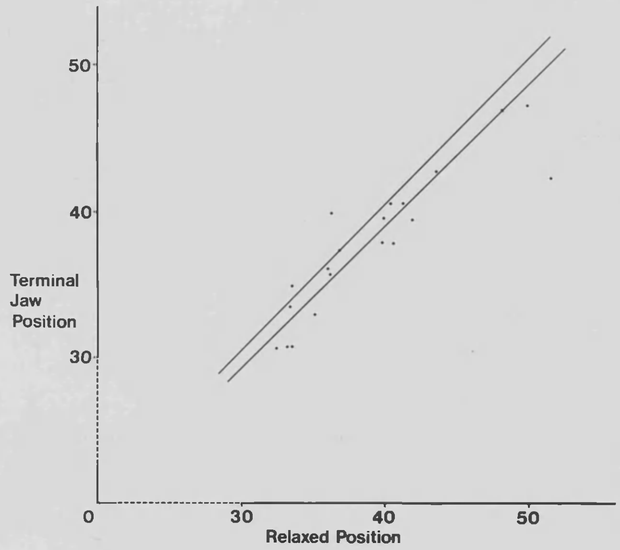
Comparison between the mean vertical jaw separation (mm) at the swallowing level with that at the relaxed position (mm) in the incisor region. The double lines indicate the range of variability about the measurement at the relaxed position.

Figure 5, 3b



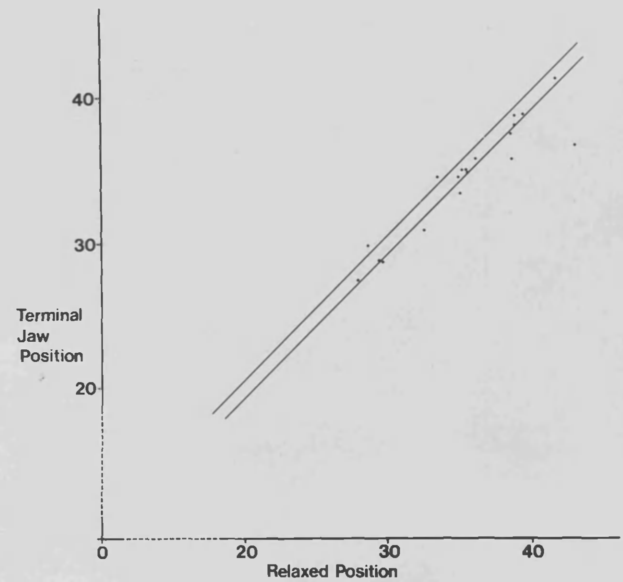
Comparison between the mean vertical jaw separation (mm) at the swallowing level with that at the relaxed position (mm) in the premolar region. The double lines indicate the range of variability about the measurement at the relaxed position.

Figure 5, 4a



Comparison between the vertical jaw separation (mm) at the completion of swallowing sequences with that at the relaxed position (mm) in the incisor region. The double lines indicate the range of variability about the measurement at the relaxed position.

Figure 5, 4b



Comparison between the vertical jaw separation at the completion of swallowing sequences with that at the relaxed position (mm) in the premolar region. The double lines indicate the range of variability about the measurement at the relaxed position.

TABLE 5, 12a

Subject No.	Intercuspal Position	Swallowing Sequences 1	2	3
1	10.0 - 10.6	11.5	12.0	10.1
2	11.1 - 11.9	11.5	11.6	11.6
3	10.7 - 11.4	11.0	10.8	10.8
4	11.7 - 12.4	12.0	11.8	11.7
5	12.0 - 12.8	14.5	14.0	14.0
6	10.5 - 11.1	10.8	11.9	14.7
7	10.6 - 11.2	13.5	13.0	13.2
8	10.7 - 11.3	11.2	10.9	10.7
9	11.5 - 12.1	12.0	12.3	11.5
10	8.3 - 8.9	8.4	8.6	8.4

Distances (mm) from the upper lead pellet in the incisor region perpendicular to the line CD, at both the intercuspal position and during swallowing sequences for 10 edentulous subjects with dentures at the original vertical dimension. The intercuspal position is expressed as a range (Chapter 15).

TABLE 5, 12b

Subject No.	Intercuspal Position	Swallowing Sequences 1	2	3
1	7.4 - 8.0	8.2	8.9	7.4
2	9.0 - 9.7	9.4	9.4	10.3
3	8.7 - 9.3	9.3	9.2	9.0
4	10.1 - 10.7	10.6	10.5	10.2
5	8.2 - 8.8	9.6	9.3	9.5
6	8.9 - 9.5	9.3	10.4	11.9
7	9.9 - 10.5	11.9	11.9	12.2
8	6.7 - 7.3	7.2	6.8	6.9
9	8.9 - 9.5	9.5	9.4	9.4
10	7.4 - 8.0	7.7	7.5	7.5

Distances (mm) from the upper lead pellet in the premolar region perpendicular to the line CD, at both the intercuspal position and during swallowing sequences for 10 edentulous subjects with dentures at the original vertical dimension. The intercuspal measurement is expressed as a range (Chapter 15).

TABLE 5, 13a

Subject No.	Intercuspal Position	Swallowing Sequences 1	2	3
1	8.1 - 8.7	13.4	13.0	12.0
2	9.8 - 10.4	10.2	11.5	10.5
3	8.6 - 9.2	10.7	11.1	10.6
4	10.2 - 10.9	11.0	10.9	10.7
5	10.9 - 11.6	14.2	14.3	16.4
6	8.6 - 9.2	13.9	14.6	14.0
7	11.3 - 12.0	14.2	14.7	14.3
8	7.7 - 8.3	10.6	10.9	11.0
9	9.4 - 10.0	11.8	11.9	11.6
10	6.0 - 6.6	7.3	6.2	6.4

Distances (mm) from the upper lead pellet in the incisor region perpendicular to the line CD, at both the intercuspal position and during swallowing sequences in 10 edentulous subjects with dentures at a vertical dimension reduced by 3 mm. The intercuspal measurement is expressed as a range (Chapter 15).

TABLE 5, 13b

Subject No.	Intercuspal Position	Swallowing Sequences 1	2	3
1	7.3 - 7.9	11.3	10.4	10.0
2	8.7 - 9.3	8.9	10.5	8.9
3	6.1 - 6.7	7.8	8.0	8.0
4	8.6 - 9.2	9.2	9.2	9.2
5	7.7 - 8.3	9.4	9.0	10.5
6	6.6 - 7.2	11.4	11.7	11.0
7	9.6 -10.2	11.6	12.3	12.0
8	4.9 - 5.4	7.0	7.3	7.3
9	7.8 - 8.4	9.6	9.9	9.6
10	5.7 - 6.3	6.7	6.1	6.2

Distances (mm) from the upper lead pellet in the premolar region perpendicular to the line CD, both at the intercuspal position and during swallowing sequences in 10 edentulous subjects with dentures at a vertical dimension reduced by 3 mm. The intercuspal measurement is expressed as a range (Chapter 15).

TABLE 5, 14

Subject No.	Original Vertical Dimension			Reduced Vertical Dimension		
1	o	o	+	o	o	o
2	+	+	o	+	o	+
3	+	+	+	o	o	o
4	+	+	+	+	+	+
5	o	o	o	o	o	o
6	+	o	o	o	o	o
7	o	o	o	o	o	o
8	+	+	+	o	o	o
9	+	+	+	o	o	o
10	+	+	+	o	+	+

The incidence of occlusal tooth contact during swallowing sequences for subjects with complete dentures at the original vertical dimension and at a reduced vertical dimension.

\+ contact

o no contact

TABLE 5, 15

Subject No.	Original Vertical Dimension			Reduced Vertical Dimension		
1	o	o	+	o	o	o
2	+	+	o	+	o	+
3	+	+	+	o	o	o
4	+	+	+	+	+	+
5	o	o	o	o	o	o
6	+	o	o	o	o	o
7	o	o	o	o	o	o
8	R,0.8	+	+	o	o	o
9	R,1.4	R,1.4	+	o	o	o
10	+	+	+	o	+	+

The position of occlusal tooth contact during swallowing sequences for subjects with complete dentures at the original vertical dimension and at a reduced vertical dimension.

o no contact

\+ intercuspal position

R retrusive to intercuspal position (mm)

TABLE 5, 16

Subject No.	Incisor Region		Premolar Region	
	Original	Reduced	Original	Reduced
1	0	0	0	0
2	0	2.1	0	0.9
3	1.4	2.2	0.9	2.5
4	0	0	0	0
5	4.2	2.1	3.9	0.9
6	5.4	7.0	3.7	5.7
7	0	5.8	0	4.2
8	0	5.6	0	4.4
9	4.2	2.6	2.8	1.9
10	0	3.0	0	1.2

Measurements of interocclusal clearance (mm) at the termination of swallowing sequences for subjects with complete dentures. Measurements were recorded from the incisor and premolar regions at both the original vertical dimension and a reduced vertical dimension.

TABLE 5, 17a

Subject No.	Region	Original Vertical Dimension I.C.P.	1	2	3	Reduced Vertical Dimension I.C.P.	1	2	3
1	i	9.7-10.4	10.2	9.8	10.0	9.5-10.2	10.1	9.9	10.1
	p	8.7- 9.4	9.2	8.9	9.1	8.6- 9.3	9.0	8.9	9.1
2	i	7.6- 8.2	8.0	8.1	-	7.1- 7.7	7.7	7.8	7.4
	p	7.9- 8.5	8.4	8.3	-	7.3- 7.9	7.6	7.8	8.0
4	i	10.6-11.3	11.3	11.2	10.7	10.8-11.5	11.1	10.7	11.2
	p	9.9-10.6	10.4	10.4	10.0	10.0-10.7	10.2	10.7	10.2
5	i	12.1-12.8	12.5	12.7	12.7	11.9-12.6	12.2	12.3	12.5
	p	12.7-13.7	13.2	13.0	13.0	12.9-13.6	13.0	13.1	13.1
6	i	14.6-15.3	15.1	15.0	14.9	12.7-13.4	13.0	13.0	12.9
	p	13.5-14.2	14.2	13.8	13.8	12.8-13.5	12.8	13.0	13.2
7	i	10.5-11.2	10.5	10.6	10.7	10.2-10.9	10.5	10.2	10.5
	p	11.5-12.1	11.8	12.2	11.9	11.7-12.4	12.2	12.0	12.7*
8	i	10.7-11.4	11.2	11.1	11.2	10.3-11.0	10.8	10.3	10.7
	p	9.3-10.0	9.8	9.9	9.9	9.5-10.2	9.9	9.6	10.0
9	i	7.0- 7.6	7.7	7.7	7.4	6.7- 7.3	7.4	6.7	7.2
	p	8.0- 8.6	8.7	8.7	8.2	8.1- 8.7	8.7	8.2	8.5
10	i	11.7-12.4	11.9	11.8	11.6	12.0-12.7	12.3	12.5	12.0
	p	11.7-12.4	11.6	11.7	11.4	11.9-12.6	12.1	11.9	12.0
4	i	9.8-10.5	10.5	10.5	10.4	9.8-10.5	10.2	10.4	10.5
	p	9.3-10.0	9.6	10.0	9.8	10.6-11.3	10.9	11.2	11.3

Distances (mm) from the upper denture to the nasal line during six swallowing sequences at both the original vertical dimension and a reduced vertical dimension. Comparison to similar measurements at the intercuspal position (expressed to show the range of variability) indicates the amount of vertical displacement.

I.C.P. intercuspal position
i incisor region
p premolar region
* displacement

TABLE 5, 17b

Subject	Region	Original Vertical Dimension I.C.P.	1	2	3	Reduced Vertical Dimension I.C.P.	1	2	3
1	i	21.5-22.4	22.0	22.0	22.3	21.6-22.5	22.0	22.1	21.9
	p	19.0-19.9	19.3	18.9	19.3	19.5-20.4	19.9	20.3	19.8
2	i	18.2-19.1	18.6	18.9	18.3	18.6-19.5	19.3	19.0	19.1
	p	18.0-18.9	18.2	18.5	18.0	17.4-18.2	18.2	17.9	18.3
3	i	17.5-18.4	18.1	18.0	18.3	16.6-17.5	17.4	17.6	17.0
	p	14.6-15.4	15.3	14.8	15.4	14.6-15.4	15.3	15.5	15.0
4	i	21.3-22.2	21.9	21.9	22.1	21.6-22.5	22.3	22.6	22.4
	p	18.3-19.2	18.9	18.7	18.9	19.0-19.9	19.4	19.6	19.3
5	i	16.3-17.1	17.0	16.9	17.9*	15.6-16.4	17.5	16.5	16.9*
	p	14.9-15.7	16.4*	16.*0	17.0*	14.2-15.0	16.5*	16.3*	16.8*
6	i	21.0-21.9	21.8	21.6	21.7	21.0-21.9	21.6	21.9	21.8
	p	16.8-17.7	17.6	17.5	17.8	16.6-17.5	17.2	17.5	18.1*
7	i	23.8-24.7	24.4	24.8	24.4	22.1-23.0	24.1*	23.1	25.2*
	p	17.2-18.1	17.9	17.9	17.8	16.7-17.6	17.4	16.9	18.2*
8	i	18.6-19.5	18.9	18.9	19.2	17.8-18.7	17.9	17.9	18.6
	p	17.9-18.8	18.2	18.2	18.1	16.6-17.5	16.7	16.8	16.5
9	i	20.0-20.9	20.7	20.4	20.7	19.6-20.5	20.0	20.1	20.2
	p	16.5-17.4	17.5	17.4	17.1	16.9-17.6	17.3	17.3	17.2
10	i	16.6-17.5	17.6	17.6	17.7	16.9-17.8	17.7	17.0	17.2
	p	16.0-16.9	16.6	16.6	17.0	14.2-15.1	14.4	14.7	14.9

Distances (mm) from the lower denture to the mandibular line during six swallowing sequences at both the original vertical dimension and a reduced vertical dimension. Comparison to similar measurements at the intercuspal position (expressed to show the range of variability) indicates the amount of vertical displacement.

ICP intercuspal position
i incisor region
p premolar region
* displacement

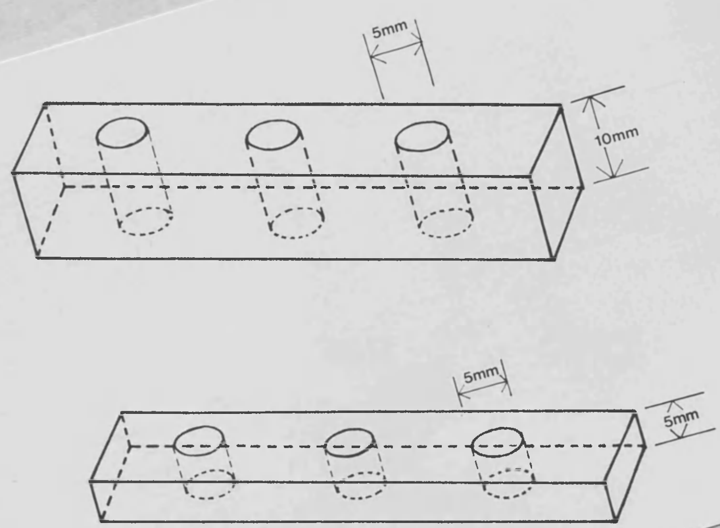
SECTION 6

TABLE 6, 1

Wax	Supplier
Ash Modelling Wax	Amalgamated Dental Trade Distributors Ltd., London
Beeswax	Amalgamated Dental Trade Distributors Ltd., London
Dentina Ribbon Wax	Browning's Dental Supply Co. Ltd., Hull
Korecta - wax No. 4	Kerr Manufacturing Co., Romulus, Michigan
Red Boxing-in Wax	Cottrell and Co. Ltd., Hull
Trubyte Equalizing Wax	Dentists' Supply Co., New York

The waxes used in the investigation and the sources of supply.

Figure 6, 1

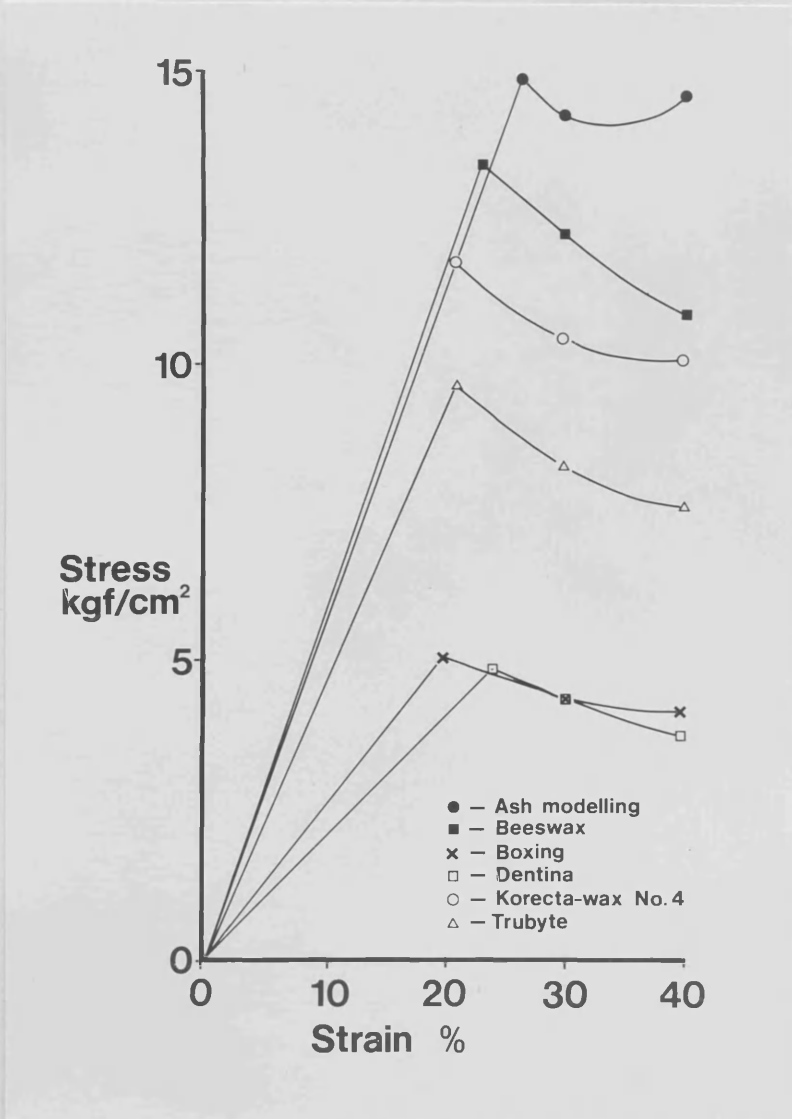


Diagrammatic representation of the moulds used in the preparation of the test specimens.

Figure 6, 2

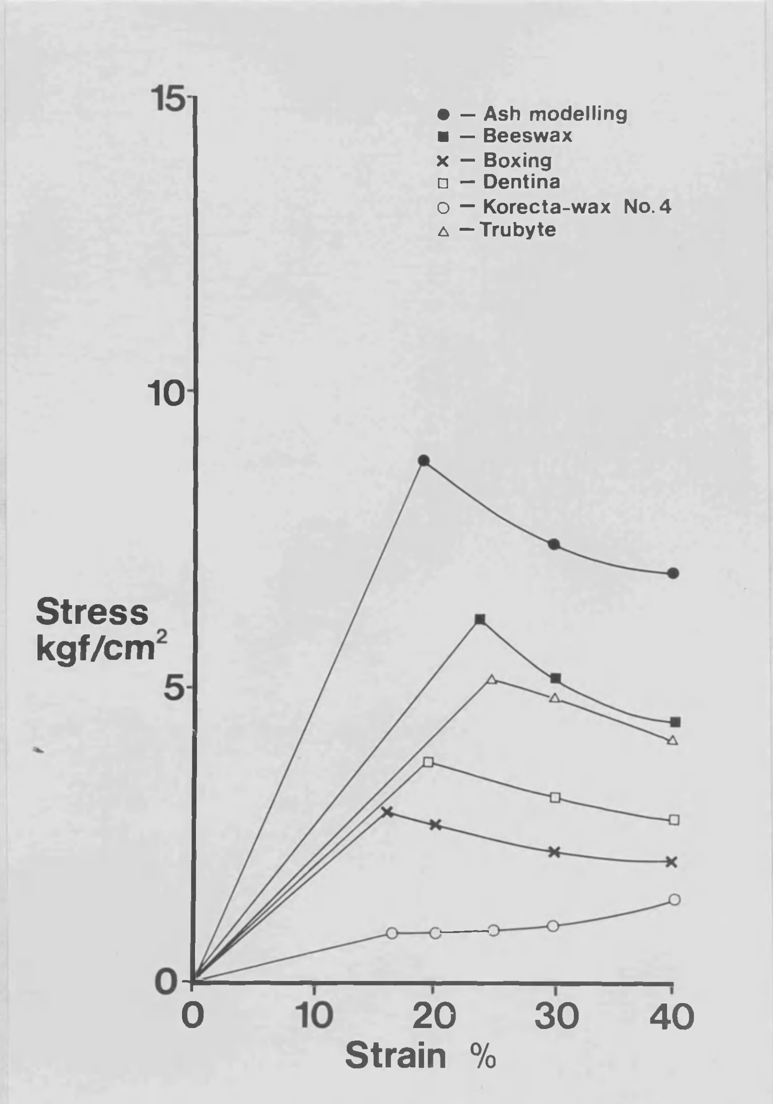
The Instron Universal Testing Machine Model TTCM,
with the water bath attachment (A).

Figure 6, 3a



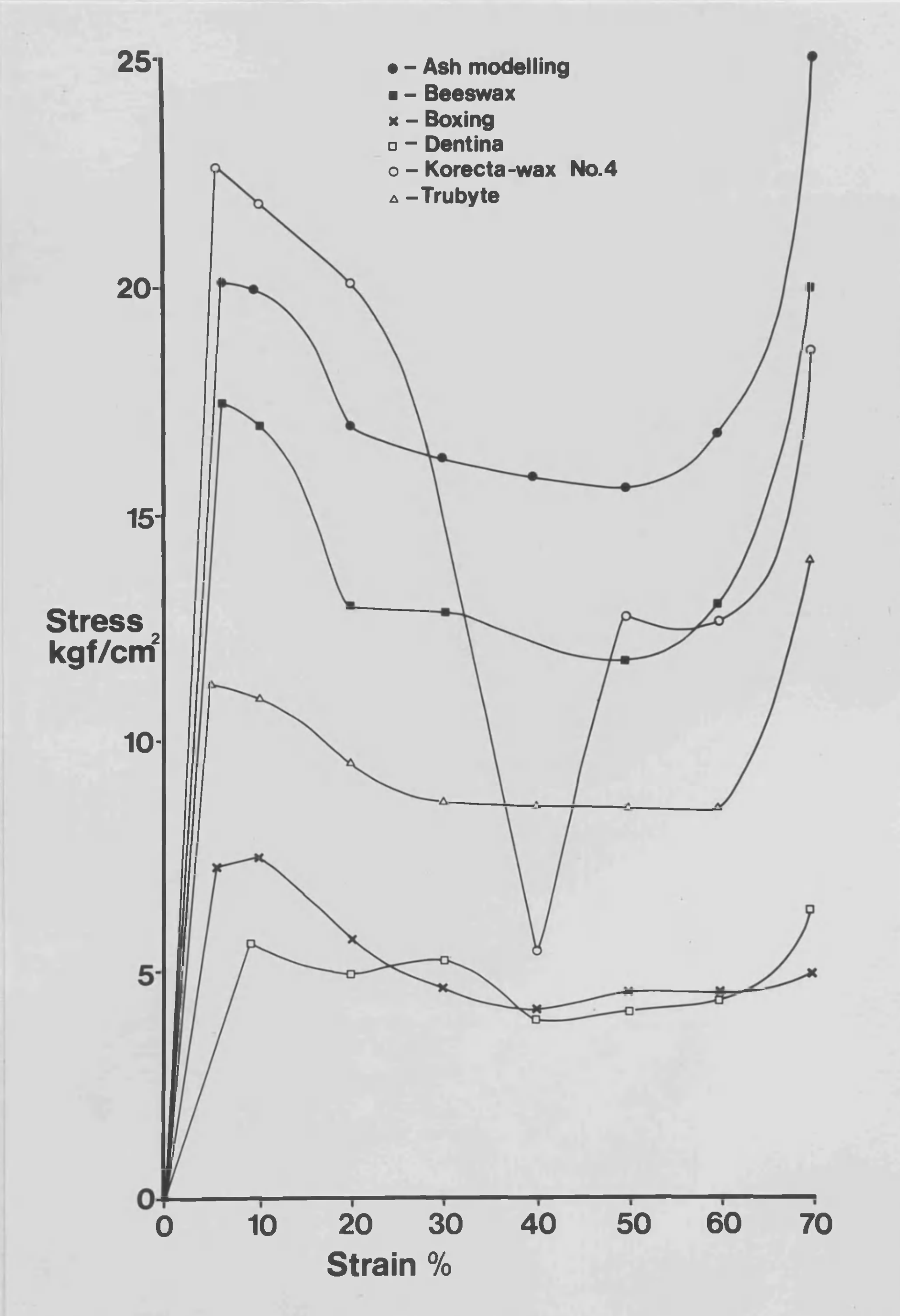
Stress-strain diagrams for 5mm specimens of each wax at room temperature (approximately 24°C).

Figure 6, 3b



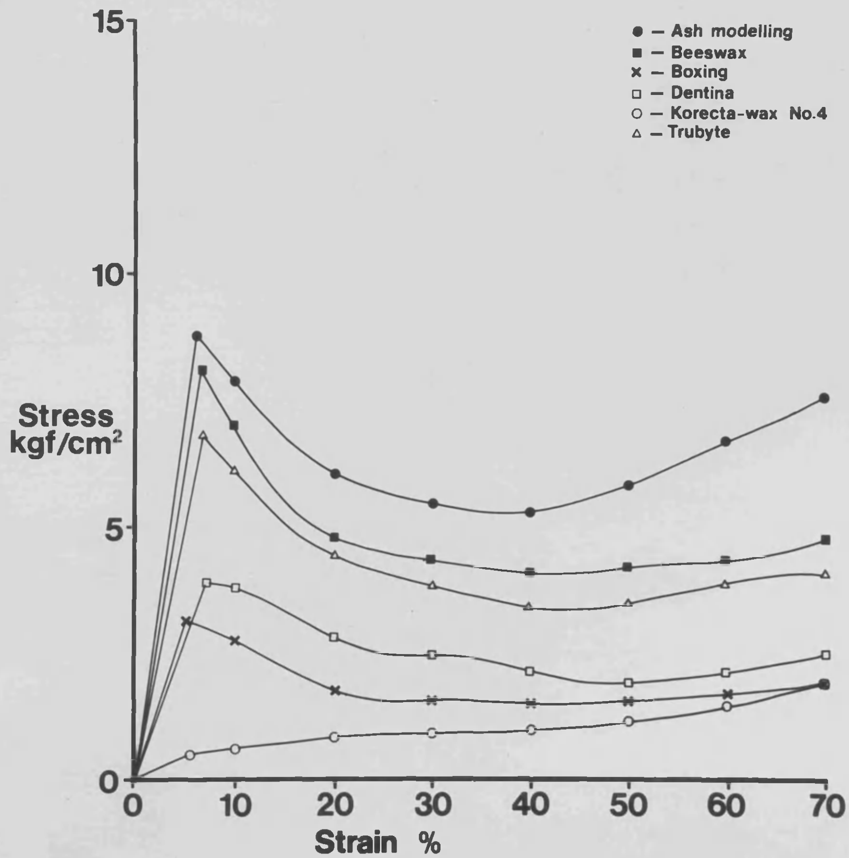
Stress-strain diagrams for 5 mm specimens of each wax at $37^{o}C$.

Figure 6, 4a



Stress-strain diagram for 10 mm specimens of each wax at room temperature (approximately 24°C).

Figure 6, 4b



Stress-strain diagrams for 10 mm specimens of each wax at $37^{o}C$.

TABLE 6, 2

	Room Temperature		Mouth Temperature	
Wax	5mm	10mm	5mm	10mm
Modelling	15.0 s.d. 1.1	21.7 s.d. 0.8	9.0 s.d. 0.3	9.0 s.d. 0.5
Beeswax	13.4 s.d. 0.4	16.7 s.d. 1.0	5.7 s.d. 0.2	8.0 s.d. 0.4
Boxing	5.3 s.d. 0.3	7.9 s.d. 0.5	2.6 s.d. 0.2	3.0 s.d. 0.3
Dentina	5.0 s.d. 0.1	6.1 s.d. 0.5	3.7 s.d. 0.1	4.1 s.d. 0.1
Korecta No. 4	11.3 s.d. 0.9	23.2 s.d. 3.0	0.9 s.d. 0.1	0.6 s.d. 0.1
Trubyte	9.8 s.d. 0.8	12.3 s.d. 0.7	5.1 s.d. 0.3	6.7 s.d. 0.3

The mean proportional limits (kgf/cm^2) for 5mm and 10mm specimens of wax in compression at both room temperature (24^oC) and mouth temperature (37^oC). The standard deviations (s.d.) are also listed.

TABLE 6, 3

	Room Temperature		Mouth Temperature	
Wax	5mm	10mm	5mm	10mm
Modelling	73.8 s.d. 3.5	379.1 s.d. 21.8	60.1 s.d. 4.2	132.3 s.d. 17.1
Beeswax	77.3 s.d. 2.9	345.5 s.d. 43.9	30.2 s.d. 1.5	123.5 s.d. 10.5
Boxing	31.1 s.d. 2.1	132.8 s.d. 9.5	19.9 s.d. 1.2	48.1 s.d. 3.3
Dentina	26.8 s.d. 1.3	82.4 s.d. 15.5	23.2 s.d. 1.2	58.7 s.d. 3.7
Korecta No. 4	72.1 s.d. 7.0	411.5 s.d. 57.9	8.2 s.d. 1.3	8.9 s.d. 2.9
Trubyte	62.5 s.d. 4.3	263.3 s.d. 24.9	28.5 s.d. 1.7	109.4 s.d. 5.2

The mean stress-strain moduli (kgf/cm^2) in compression for 5mm and 10mm specimens of wax at both room temperature (24°C) and mouth temperature (37°C). The standard deviation (s.d.) are also listed.

TABLE 6,4

	Room Temperature		Mouth Temperature	
Wax	5mm	10mm	5mm	10mm
Modelling	14.1 s.d. 0.8	26.6 s.d. 1.0	7.1 s.d. 0.2	7.5 s.d. 0.3
Beeswax	11.0 s.d. 0.4	19.5 s.d. 1.0	4.5 s.d. 0.1	4.9 s.d. 0.3
Boxing	3.9 s.d. 0.2	4.4 s.d. 1.1	2.0 s.d. 0.1	1.8 s.d. 0.1
Dentine	3.8 s.d. 0.1	6.2 s.d. 0.4	2.7 s.d. 0.1	2.5 s.d. 0.1
Korecta No. 4	10.4 s.d. 0.8	14.5 s.d. 2.2	1.6 s.d. 0.2	1.8 s.d. 0.3
Trubyte	7.5 s.d. 0.5	13.5 s.d. 0.7	4.0 s.d. 0.3	4.1 s.d. 0.3

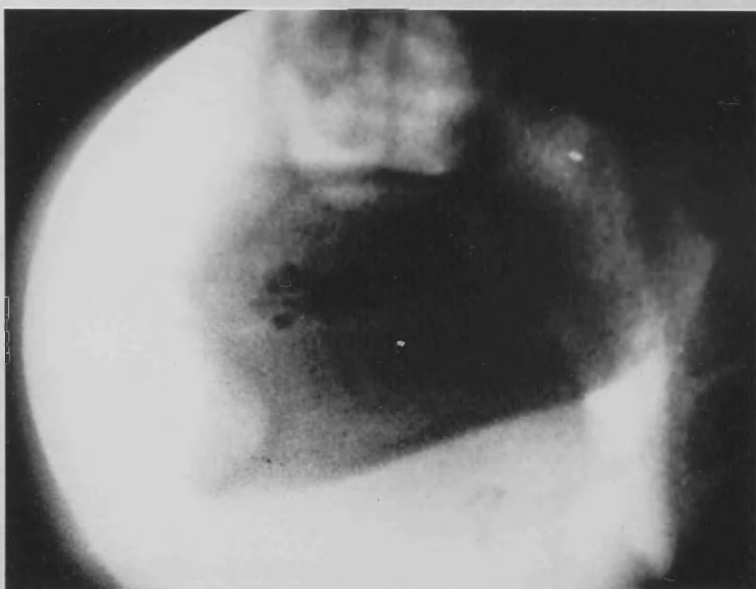
The mean terminal stress (kgf/cm^2) required to compressively strain 5mm specimens of wax by 40% and 10mm specimens by 70% at both room temperature (24°C) and mouth temperature (37°C). The standard deviations are also listed.

Figure 6, 5

Still Screen Photography

A print of a television screen image obtained with 5 in x 4 in. Sheet film exposed at f/8 for $^{1}/_{10}$ second.

Figure 6, 6



Motion Film Photography

A print of a television screen image obtained from a single frame of 16 mm motion film exposed at f/4 for $^1/_{25}$ second.

Figure 6, 7

Recording television screen images from the videotape on to 35 mm film.

A. Videorecorder

B. Television monitor

C. Camera with motorised transport system.

Figure 6,8

A print of a television image obtained with 35 mm still film exposed at f/3.5 for $^{1}/_{30}$ second.