A BALLISTOCARDIOGRAPHIC STUDY
OF YOUNG PATIENTS
WITH DIABETES MELLITUS
AND THYROTOXICOSIS.

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Chapter 1.

INTRODUCTION.

1. Purpose of the Investigation.

The purpose of this investigation was to study the effects of diabetes mellitus and thyrotoxicosis on the heart. Common diseases may coexist in the same patient but the frequent association of heart disease with diabetes and hyperthyroidism suggests that there is a causal relationship. The precise nature of the link has been the subject of much speculation and sometimes controversy but it seems important because heart disease plays a significant part in determining the pattern of morbidity and even mortality in thyrotoxicosis and diabetes.

2. General Methods of Investigation.

Epidemiological methods of study have yielded much valuable information about this relationship but in the individual case this has almost inevitably proved of general rather than particular relevance. In contrast, more or less precise information about individual patients is obtained by the standard methods of clinical assessment, including physical and X-ray examination and electrocardiography. These have not, however, provided adequate answers to the problems involved in the association of heart disease with diabetes and thyrotoxicosis. Basic and detailed information may be gleaned from the results of more complex and elaborate techniques but greater precision is often achieved at the expense of simplicity, convenience or even freedom from hazard.

3. <u>Ballistocardiography</u>.

It has been shown that the principal systolic waves of the ballistocardiogram bear a close relationship to the cardiac ejection curve (Hamilton et al., 1945; Starr et al., 1950). It is therefore possible, admittedly in an indirect way, to study the funcional efficiency of the heart beat by beat. This method involves the patient in neither discomfort nor hazard. Its evident simplicity and safety are reassuring features and patients sometimes fall asleep during the taking of the record. Thus virtually basal conditions may be achieved without sedation. This is an important advantage because the effects of anaesthetic or sedative drugs, often used to induce a basal state in the patient, differ from subject to subject, may influence the circulatory dynamics to varying degrees in different persons and may modify or falsify the results obtained.

4. Clinical Use of the Ballistocardiogram.

Numerous ballistocardiographic studies have considered the application of the method to the examination of patients with a variety of cardiac or other diseases.

Because of the important effect of ageing on the ballistocardiogram, the method is of most value in the study of younger subjects, that is those under 40 years of age. If abnormal patterns appear in the records obtained from subjects over that age, the significance of these aberrant contours is quite uncertain.

The ballistocardiogram reflects the functional state of the heart. It is abnormal in most patients with overt heart disease and particularly in those subjects with more advanced or severe cardiac lesions. Characteristic patterns have been observed in a few specific types of heart disease such as aortic valve disease (Honig and Tenney, 1957) and mitral stenosis (Henderson, 1955). In most other conditions, including coronary artery disease, a variety of abnormal patterns may occur.

5. Outline of the Present Study.

a. The history and principles of ballistocardiography.

This section sketches the historical origins and development of ballistocardiography. It continues with a discussion of the physical basis of the method and the factors leading to the choice of the high-frequency table ballistocardiograph for this study. The place of stress tests is considered and the recording of ballistocardiograms before and after smoking is discussed in detail.

b. Materials and methods employed.

Details of the subjects studied and of the technical aspects of the method are given in this part. In order that subsequent sections may be complete in themselves some of this information is given again in later chapters. This inevitably results in some degree of repetition but it enables each section to remain self contained.

Similarly in this section, some of the material concerning the assessment of the ballistocardiogram has been outlined in the first part.

c. The Subjects Studied.

i. The control series.

There were two groups of subjects in the control series. The first consisted of apparently healthy volunteers from the hospital staff and medical students attending the Western Infirmary, Glasgow. These were the normal control subjects in the study. The results obtained from examination of their ballistocardiograms provided the normal standards for the study.

The second group consisted of patients with angina pectoris or previous myocardial infarction but without evidence of valvular heart disease. These patients were considered to have a cardiac abnormality resulting in potentially defective ventricular contraction and ejection. They provided a further control group whose hearts were likely to function in an abnormal way.

Because of the effect of age on the ballistocardiogram only persons aged less than 40 years were included in the investigation. The study of Elsbach (1954) provided a precedent for this decision.

ii. <u>The series of patients</u>.

The other three groups consisted of patients with diabetes mellitus, patients with thyrotoxicosis and those who were euthyroid after treatment. To minimise the part played by independently existing heart disease no patient was included in these three groups if there was overt clinical evidence of cardiovascular disease. All patients were less than 40 years of age.

The object of the investigation was therefore to detect cardiovascular abnormalities in young patients with endocrine disease but without clinical evidence of cardiovascular disease. In the case of the diabetic subjects, the finding of such abnormalities would suggest that an attempt to obtain better diabetic control should be made; while in the case of thyrotoxic patients it would suggest the need for immediate and vigorous treatment of the hyperthyroidism.

The most important point at issue in the case of the diabetic patients was the attempt to detect occult coronary artery disease. The ballistocardiographic smoking test has been proposed as a means of detecting coronary insufficiency (Henderson, 1953; Davis et al., 1953, 1956). This method has not been used previously in diabetic subjects. Comparisons were possible with the results obtained from the normal subjects on one hand and the patients with coronary disease on the other.

In the case of the thyrotoxic patients one of the main issues was the attempt to verify the suggestion of Somerville and Levine (1950) that there might be a metabolically determined and reversible form of coronary insufficiency during hyperthyroidism. The ballistocardiographic smoking test was again employed for the first time in the investigation of thyroid heart disease. Once more comparisons could be made with the records of the two control series.

The euthyroid patients were studied in order to show that the abnormalities observed during thyrotoxicosis were completely reversible and therefore likely to be due to the metabolic upset and not to an anatomical change in the heart.

d. Fresh applications of ballistocardiography.

The present study has extended the field of ballistocardiographic research in two ways.

A systematic quantitative analysis of the records of the normal subjects allowed expected normal standards to be calculated for subjects of each sex and age group. This permitted more detailed examination of the ballistocardiograms of the patients with endocrine disorders and revealed hitherto apparently unsuspected abnormalities.

Secondly, the use of the ballistocardiographic smoking test in the context of endocrine disease was a fresh application of an already existing method of cardiac investigation.

Summary.

The purpose of this investigation was to study the effects of diabetes mellitus and thyrotoxicosis on the heart. The problems chosen for particular investigation were the detection of occult

coronary artery disease in young diabetic patients who were apparently free from the cardiovascular complications of diabetes and secondly the study of a form of relative coronary insufficiency in thyrotoxicosis, whose occurrence was postulated by Somerville and Levine (1950).

The method employed in the study was ballistocardiography. The diagnostic precision of the method was augmented by the use of a stress procedure, namely cigarette smoking, in certain cases. This has been shown to be a useful method of detecting coronary insufficiency.

Systematic quantitative analysis of the ballistocardiogram and the employment of the smoking test were fresh applications of this investigative method.

PART I

Chapters 2 to 8

THE HISTORY AND PRINCIPLES OF BALLISTOCARDIOGRAPHY.

Chapter 2.

EVOLUTION OF BALLISTOCARDIOGRAPHY.

1. Observations of Body Movements due to the Heart Beat.

In 1786 Caleb Hillier Parry saw a young woman who was seriously ill with thyrotoxicosis and commented (Parry, 1825) that "each systole of the heart shook the whole trunk of the body". The brisk ejection and reflux of blood that occurs in severe aortic incompetence may also cause the body to move visibly in time to the heart beat (Starr, 1954; Rorvik, 1963). Occasionally these movements are so vigorous that the patient's bed is shaken with his body. This effect can, however, be produced even by physiological heart action. Henderson (1905) noted that "probably everyone has occasionally been kept awake by the rattling or creaking of his bed in unison with his heart beat. At such times one may notice slight but distinct vibrations of the entire body alternately headward and feetward." Also of great interest was the observation of the German geophysicist, Angenheister, that if he placed a seismograph on a rigid table and a subject lay down beside it, the instrument gave a record that showed movement in time to the heart beat (Angenheister and Lau, 1928).

2. Nineteenth Century Records.

J.W. Gordon seems to have been the first to obtain a record or ballistocardiogram although he did not use that term to describe it. He remarked (Gordon, 1877) that "a person standing erect in a perfectly easy posture on the bed of an ordinary spring weighing machine and maintaining, as far as possible, perfect stillness, will be found, if the instrument is delicately adjusted, to impart a rhythmic movement to the index, synchronous with the pulse." To record these body movements Gordon used a bed suspended from the ceiling, a set of levers and a smoked drum. His work was discussed later that year by Coutts Trotter (1877) who suggested that these movements of the body were directly related in time and magnitude to changes in the position of the body's centre of gravity caused by transfer of blood from the heart to the great vessels. Further comment on Gordon's paper followed from Landois (1880). In his "Lehrbuch der Physiologie des Menschen" he illustrated a simple vertical platform instrument that he had designed. With this apparatus Landois made the first clinical observation in the field by obtaining a record from a patient who had aortic insufficiency and finding it was of far greater amplitude than that of a healthy person.

3. <u>Earlier Twentieth Century Records.</u>

In 1905 Yandell Henderson who was seemingly unaware of this previous work built an instrument similar to that of Gordon (1877), having noticed like him that when he stood on spring scales the tip of the pointer moved in time to the beating of his heart. This led him to construct a table that was free to move longitudinally but not in other directions. These movements were magnified up to 100 times by a series of levers and were recorded on a smoked drum. Henderson suggested that there was a relationship between the amplitude of the recorded movements and the cardiac output. Because respiration caused relatively large movements that obscured the small deflections due to cardiovascular forces, breathing had to be stopped during the recording . Apparently this limitation led Henderson to abandon the technique although he employed a modification of the method in an attempt to measure the effects of altitude on cardiac output when he accompanied an expedition to Pike's Peak in Colorado (Douglas et al., 1913).

Satterthwaite (1913) described similar movements of the pointer of his scales in time to the heart beat. He lengthened the pointer, recorded its tip on a smoked drum and obtained tracings that resembled modern ballistocardiograms. Heald and Tucker (1922) were the first to employ electrical means of recording but their hot wire microphone did not distinguish headward from footward movements and their records do not resemble ballistocardiograms. The Swedish physiologist, Abramson (1933), built an instrument in which the subject sat upright. Possibly the problems involved in having the subject both relaxed and vertical proved intractable and led him to abandon the method for he did not continue his experiments.

4. The Modern Era of Ballistocardiography.

a. Development of the high-frequency bed ballistocardiograph.

The modern era of ballistocardiography stems from the publication of the first series of papers from Starr's laboratory (Starr et al., 1939). When Starr began his studies in ballistocardiography he used apparatus similar to that of Gordon (1877) and Henderson (1905). He recorded the displacement of the subject's body with a table which had a low natural frequency and like Henderson encountered difficulty with respiratory movements. It was necessary for the subject to hold his breath during recording. Some patients found this impossible and many subjects performed indifferently. This limitation led Starr to apply powerful springs to the bed which then had a high natural frequency and recorded acceleration instead of displacement. Thus the slow respiratory movements had a negligible effect on the record. Unfortunately the increased rigidity of the apparatus due to its heavy springing resulted in some movement of the subject on the table and raised further problems. These are discussed in Chapter 4.

Starr et al., (1939) were the first to term the records "ballistocardiograms." Subsequent publications from Starr's laboratory demonstrated many of the physiological events concerned in the genesis of the ballistocardiogram and clinical studies begun in 1939 have continued to the present day (Starr, 1965). No doubt influenced by Henderson (1905), Starr developed formulae to estimate cardiac output from the high-frequency ballistocardiogram. The results of his later experiments did not support these calculations and he expounded the current view that the high-frequency record is more closely related to the maximum strength of cardiac ejection than to stroke volume. (Starr et al., 1950).

b. <u>Development of the ultra-low frequency bed ballistocardiograph</u>.

About the same time, the ballistocardiographic method aroused the interest of Burger and his colleagues in the Department of Medical Physics at the University of Utrecht. They examined the physical basis of ballistocardiography taking Newton's Laws as their point of departure. They concluded from theoretical considerations that the original simple instruments of Gordon (1877) and Henderson (1905) which recorded pure mass displacements (as did Starr's original bed) were more satisfactory than later instruments with platforms whose movements were resisted by powerful springs. They described an "ultra-low frequency" ballistocardiograph which they had constructed and outlined the physical basis for their claim that it recorded body movements with greater fidelity than did high-frequency instruments (Burger et al., 1953; Burger and Noordergraaf, 1956A, 1956B). Essentially the same solution was reached by the American physicist Talbot and his associates who were also studying this problem (Talbot et al., 1954). Much of the more recent research into the fundamentals of ballistocardiography has employed the ultra-low frequency apparatus but greater precision has been achieved to some extent at the cost of ease of operation and robustness.

c. The direct-body ballistocardiograph.

Table or bed ballistocardiographs are relatively large, immobile and expensive pieces of equipment whatever their natural frequency. These disadvantages led to the production of the direct-body pick-up device by Dock and Taubman (1949). These simple devices are laid across the shins of the subject who lies supine. They record his movement on his own body tissues without restraint. Despite their obvious advantages which include portability, simplicity and cheapness they have proved of little fundamental value. These issues are discussed in Chapter 4.

Summary.

In severe thyrotoxicosis or aortic incompetence it has been noted that the hyperdynamic circulatory forces may visibly shake the patient's body and even his bed. Similar but slight movements may occur in normal persons.

The early investigators in the field of ballistocardiography conducted their studies largely unaware of each others' work. They often noticed that the pointer of spring scales moved in time to the heart beat and used a variety of physical methods and mechanical devices to record the movements of the body.

The modern era of ballistocardiography stems from the publication in 1939 of the first of a series of papers from Starr's laboratory. Three main types of ballistcardiograph have been developed: the high-frequency table by Starr, the ultra-low frequency table by Burger and others and the direct-body pick-up device by Dock.

Chapter 3.

PHYSICAL CONSIDERATIONS.

1. Effects of the Circulation on the Centre of Gravity of the Body.

a. The systemic circulation.

The human circulation consists essentially of a pump and a closed but elastic circuit filled with blood. This elasticity and the resultant distensibility allow the distribution of the blood mass to change during the cardiac cycle. With every contraction of the left ventricle blood is thrust into the aorta. An area of distension passes along the aorta and acts as if an extra mass were moving along it with the velocity of the pulse wave. This is true not only of the aorta but also of all other arteries (Burger et al., 1953). Thus a periodic mass displacement occurs in the body whose centre of gravity inevitably moves in concert with the fluid mass of blood. As the ascending part of the aorta dilates during early systole the centre of gravity moves toward the head. It changes direction footwards as the descending limb of the aorta distends progressively. The direction is reversed again early in diastole. Further alternating, oscillating movements occur during the rest of diastole. The centre of gravity reaches its original position just before the start of the next systole. These movements of the blood mass and of the centre of gravity of the body are highly consistent and are repeated beat after beat.

b. <u>The pulmonary circulation</u>.

The pulmonary circulation also contributes to this pattern of movement but its part is relatively small (Noordergraaf, 1961). A certain mass motion is associated with ejection of blood from the right ventricle into the main pulmonary artery but the distance is comparatively short and its effect is probably meagre. Beyond the pulmonary arterial bifurcation the vessels fan out radially. Thus their circulatory effects act in opposing directions and largely cancel one another.

c. <u>The venous system</u>.

The movement of blood in the veins is relatively slow and almost uniform. It probably plays a negligible part in producing movements of the centre of gravity of the body (Henderson, 1905) and contributes little or nothing to the mass movements that give rise to the ballistocardiogram.

2. Effects of the Physical Properties of the Body.

a. The coupling of the heart and body.

The pulsating and oscillating tissue mass consisting of the heart, great vessels and the blood they contain has been described as a central "cardiovascular generator" (Scarborough, 1959). It is coupled to the relatively less mobile and much larger mass of the rest of the body by a network of ligamentous and muscular tissue. There is little precise knowledge about the physical behaviour of this "internal coupling network" and the losses involved in the transmission of forces are quite unknown (Rappaport, 1956A) but it seems likely that there is some distortion of the movements initiated in the central mass. Nevertheless the external framework of the body moves more or less faithfully in response to the forces arising in the "central generator" and all parts of the body move with much the same amplitude and phase in response to the heart's action (Von Wittern, 1953).

b. Frequencies of the body tissues and circulation.

Recognition of the fact that forces generated by the cardiovascular system produce movements of the whole body raises the problem of selecting a recording method. The solution of this problem is largely determined by the physical characteristics of the body. In this connection two of the more important factors are the natural frequency of the body tissues and the frequencies of the forces arising in the cardiovascular system.

If a living or recently dead person lying supine is tapped once on the head, the body undergoes a series of vibrations which cease fairly quickly due to the intrinsic damping qualities of the tissues. The rate of these vibrations is termed the natural frequency of the body. This ranges from about 3.5 to 6 cycles per second (Tucker and Ostrom, 1955) but is usually around 5 or 6 cycles per second (Starr et al., 1939; Reeves et al., 1957). This applies not only when the movements are produced by an impact striking the body from outside but also when they are due to a force initiated within the body. Thus a movement arising in the central cardiovascular system and transferred to the body as a whole through its ligamentous network will tend to produce oscillation of the body at a rate of about 5 to 6 cycles per second due to the natural frequency and elasticity of the tissues. The frequency of the major forces arising in the normal circulatory system ranges from about 2 to 12 cycles per second (Reeves et al., 1957). Many of these forces are transmitted by the ligaments to the whole of the body and dominate the physical situation so that the general body movements may have a variety of frequencies between 2 and 12 cycles per second.

If this range of frequencies is to be reproduced faithfully, the natural frequency of the recording instrument should lie well outside it lest resonance between the natural frequency of the apparatus and the frequency being recorded result in distortion of the tracing. This has largely dictated the physical characteristics of the different ballistocardiographic systems which are considered in more detail in Chapter 4. It has resulted in the production of ultra-low frequency apparatus (natural frequency less than 1 cycle per second) and high frequency instruments (above 12 cycles per second) and largely accounts for some of the difficulties encountered in the use of direct-body equipment.

<u>Summary</u>.

The human circulation consists of a pump (the heart) and a distensible vascular circuit filled with blood. The position of the centre of gravity of the body is altered by movement of the blood, mainly in the systemic circulation. A small part is played by the pulmonary circulation but the contribution of the venous system is negligible.

The movements initiated by the "central cardiovascular generator," the heart and great vessels, are transmitted to the whole body by connecting ligaments. Due to their innate physical properties they probably distort these movements to some extent. Further difficulties in recording arise because of the need to avoid the natural frequency of the body (3 to 6 cycles per second) and the frequency of the main circulatory forces (2 to 12 cycles per second) in the design of the ballistocardiograph, as resonances might arise and distort the record of movements.

Chapter 4.

BALLISTOCARDIOGRAPHIC SYSTEMS.

1. Types of Ballistocardiograph.

The ballistocardiogram is a record of the oscillatory body motion that occurs with every heart beat and is attributed to forces produced by cardiac action. Ballistocardiographs are of two basic types. The first consists of a table or bed on which the subject lies so that the movements of the body are imparted to the table. The second is a light pick-up device that is attached to the subject's body, usually at the shins, as he lies supine on a rigid surface and moves to and fro on his own elastic tissues.

2. The Table or Bed Ballistocardiograph.

a. General features.

This consists of a light, rigid table or platform suspended from above or supported from below in various ways. The platform is uaually free to move in one direction, the longitudinal. It is attached to one or more steel springs which act as a restoring force and return the platform to its resting position when it has been displaced. The character and strength of the springs determine the natural frequency of the apparatus; that is, the rate at which it vibrates when struck by a single blow.

b. <u>The high-frequency ballistocardiograph</u>.

A high-frequency ballistocardiograph has very stiff and powerful springs which give the apparatus a natural frequency of from 10 to 15 cycles per second. When the table is unloaded or when it bears a dead weight such as bars of iron, it oscillates for an appreciable time after it has been set in motion by a blow; that is, the vibrations of the table are not subject to damping. These characteristics are greatly altered if the weight is replaced by a human body. When a recently dead body lying on a high-frequency bed ballistocardiograph is struck once on the head the system, consisting of the body and the apparatus, oscillates at a frequency of approximately 5 or 6 cycles per second. These movements are rapidly damped out and cease in a manner similar to that occurring when the body, lying on its own elastic tissues on a rigid surface, is tapped on its head.

This would suggest that the physical properties of the body dominate the entire system when the subject lies on a high-frequency ballistocardiograph (Scarborough et al., 1952) but the powerful resisting springs limit the travel of the platform and there is relative movement of the subject on it (Burger and Noordergraaf, 1956A, 1956B; Burger et al., 1956). The movements of the subject's body are greater than those of the table but they remain in phase with one another and the oscillations of the platform give a reasonably faithful impression of body motion. When the body is firmly attached to its surroundings, as in the high-frequency method, the recorded displacement of the table is roughly proportional to the acceleration of the internal circulatory mass and reflects cardiac strength or force (Reeves et al., 1957). Except for the inherent error of amplitude which may be largely corrected by mechanical calibration of the instrument, high-frequency apparatus with a natural frequency of 15 cycles per second reproduces reliably the acceleration of the subject's centre of gravity over a range of frequencies up to 10 cycles per second (Burger and Noordergraaf, 1956B).

Thus despite certain technical deficiencies it does reflect the major, slower cardiovascular forces. Because of its intrinsic strength of structure it is by far the most rugged and dependable apparatus available and yields the most consistently reproducible results (Scarborough, 1959).

c. <u>The ultra-low frequency ballistocardiograph.</u>

The main disadvantage of the high-frequency system is the movement of the body on the platform with resultant distortion of the ballistic record. In an attempt to overcome this difficulty extensive studies were undertaken by Burger et al.,(1953), von Wittern (1953), Talbot and Harrison (1955), Burger and Noordergraaf (1956A) and Rappaport (1956A, 1956B, 1956C). These authors were substantially in agreement and suggested that the solution lay in placing the body on a platform suspended or supported in such a manner that the coupling of the system to the earth was relatively weak, there being little or no resistance to movement of the subject and platform in space. It was to be expected that in these circumstances the body and platform would move as a unit and distortion would be minimal. The natural frequency of such systems is less than 0.5 cycles per second and they have been designated "ultra-low frequency" ballistocardiographs. The simplest method by which this may be achieved is the suspension of a light platform from the ceiling by a number of wires each about 10 feet in length (Burger et al., 1953). Other methods, such as flotation of the bed on mercury (Deuchar et al., 1955) or its support on ball bearings (Hollis, 1956) have also been employed. Whereas the high-frequency apparatus records only acceleration the ultra-low frequency tables can detect the displacement, velocity and acceleration of the centre of gravity of the body.

d. <u>Comparison of high and ultra-low frequency ballistocardiographs</u>.

The ultra-low frequency ballistocardiogram provides information, particularly concerning rapid movements, that is absent from the records obtained by the high-frequency table (Burger et al., 1953). On the other hand it is far from certain that the rapid waves and notches found in the records from the ultra-low frequency tables have their origin in the circulation. There is at present no evidence that important clinical information is contained in the notches and slurs recorded solely by the low-frequency instruments. It has been suggested that they may be due to shaking of the liver and other organs inside the abdomen (Starr and Noordergraaf, 1962).

These authors and Reeves et al.,(1957) have stressed the essential similarity of the results obtained from high and ultra-low frequency instruments both as regards the form of the record and its actual measurements. Since the high-frequency apparatus records only acceleration, ballistocardiograms obtained by this method are of course comparable only with acceleration records from the ultra-low frequency beds. The more sensitive low-frequency tables are much more delicate and fragile and are also immobile and relatively difficult to calibrate. Starr and

Noordergraaf (1962) noted the robustness and ease of calibration of the high-frequency apparatus. They suggested that for most purposes this instrument has considerable practical advantages over the theoretically more satisfactory ultra-low frequency ballistocardiograph.

3. <u>The Direct-Body Ballistocardiograph</u>.

This simple shin-bar device, introduced by Dock (Dock and Taubman, 1949), does have the advantages of simplicity, cheapness, portability and ease of operation but there are important adverse features to set against these.

When the subject lies on a rigid surface, the natural frequency of the tissues of the body is close to the frequency of the major waves of the ballistocardiogram. This close correspondence may create problems of interpretation since not all the waves recorded in these circumstances will necessarily be of cardiovascular origin. In addition the degree of damping of body motion is so slight that oscillations initiated by one heart beat may continue into the ensuing cardiac cycle and distort the record. In an attempt to overcome this defect Walker et al., (1953) fixed their subjects in putty or sand. This had the effect of increasing the natural frequency of the body and eliminated much of the after vibration. Noordergraaf (1961) showed that if the subject lay on a non-slip pad with his feet pressed tightly against a wall, the natural frequency of the body tissues was greatly increased and the outline of the shin-bar record was much improved. This method was recommended with slight modification by Ambrosi and Starr (1964) but they remarked that no reliable means of calibration was available.

Inability to calibrate the record satisfactorily is the second main disadvantage of the technique. Calibration methods were devised by Smith (1952), Bixby and Henderson (1953) and Reeves et al.(1953) but the essential simplicity of the shin-bat technique was thereby lost. In addition the physical properties of the body tissues vary widely from subject to subject. The internal ligamentous network of the body, which provides the restoring force in direct-body ballistocardiography, varies greatly from person to person. Thus the same cardiac force may be absorbed differently by the tissues of various subjects. This is the source of some of the calibration difficulties and may also result in abnormal wave contours. Jokl (1959) reported that very powerful young men such as professional weight lifters had abnormal shin-bar ballistocardiograms. It seems highly unlikely that their hearts were abnormal. Arbeit et al. (1957) demonstrated improvement in the high-frequency ballistocardiogram during periods of intensive physical training. Their unusually well developed musculature may have altered the physical properties of their body tissues sufficiently to produce changes in the direct-body records.

Lastly, in direct-body ballistocardiography the subject moves much more in space with each heart beat than is the case when the table method is used (Ambrosi and Starr, 1964). It is therefore not unlikely that some distortion of the ballistic waves will be caused by shaking of certain organs, especially inside the abdomen. Some small notches in the records from ultra-low frequency ballistocardiographs may be produced in this way (Starr and Noordergraaf, 1962).

4. Conclusions.

Although the direct-body or shin-bar method has certain obvious advantages the unsatisfactory features that have been discussed seriously limit its usefulness. Its defects have led Fulton et al. (1961) to conclude that it is of little or no value. While this judgment is perhaps somewhat harsh the limitations of this method have enabled the more complex table or bed ballistocardiographs to maintain their leading position in this field of investigation. Of these the ultra-low frequency method provides slightly more accurate records but the robustness and ease of operation of the high-frequency apparatus commend it strongly as a practical method.

Summary.

The ballistocardiogram is a record of the body movements that are attributed to the action of the heart. These movements may be detected by placing the subject on a table or platform whose motion is recorded or by attaching a pick-up device to the subject's legs as he lies supine on a rigid surface.

The natural frequency of the table apparatus may be higher or lower than the range of frequencies of the body and the circulatory forces, which vary from 2 to 12 cycles per second. The ultra-low frequency method yields the most accurate record of body movements but the apparatus is immobile, delicate and often difficult to calibrate and to operate. The high-frequency technique provides similar although less accurate results but has the advantages of robustness and ease of calibration and operation which makes it perhaps more suitable for routine clinical use.

The direct-body method using a pick-up device is simple, cheap and portable but there are serious disadvantages that render it of considerably less value as an investigative technique.

Chapter 5.

THE WAVES OF THE BALLISTOCARDIOGRAM.

1. General features.

The normal ballistocardiogram consists of a procession of regular and reproducible waves representing forces produced by the action of the heart (von Wittern, 1953). These were designated H, I, J, K and L by Starr et al. (1939). This nomenclature has been adopted generally for all types of ballistocardiogram and was used with slight modification by the Committee on Ballistocardiographic Terminology (Scarborough and Talbot, 1956). The H, I, J and K waves have been associated with systolic events and the remaining waves including the L wave with diastole. Fundamental studies by Hamilton et al. (1945), Starr et al. (1950) and Richman and Littmann (1963) have suggested that both the contour and amplitude of the systolic waves of the ballistocardiogram are related to the cardiac ejection curve.

Figure 1.

Diagrammatic representation of the normal ballistocardiogram, showing the outline of the waves and the letters attached to them. The H, I, J and K waves represent systolic events and the L,M, N and O waves occur in diastole.

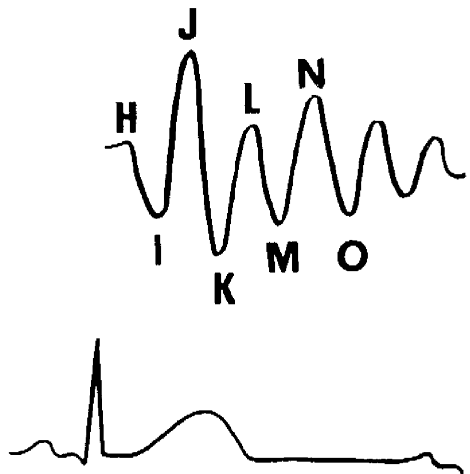
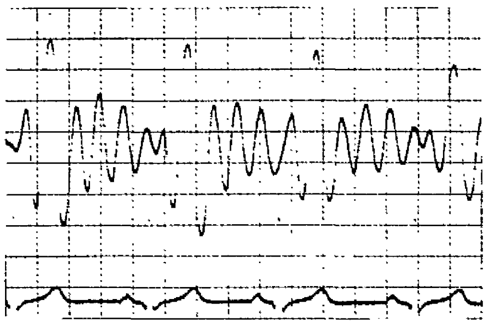

J
N
L
H
I
K
M
O

Figure 2.

Normal ballistocardiograms of healthy men. They resemble one another in general contour. The individual complexes are also similar in each ballistocardiogram.



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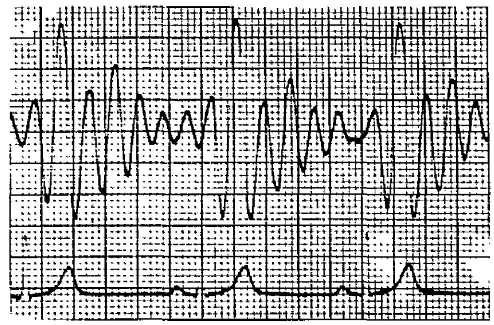

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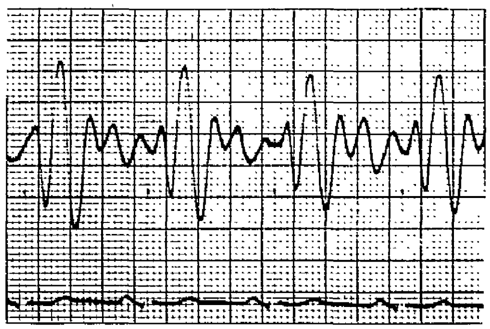

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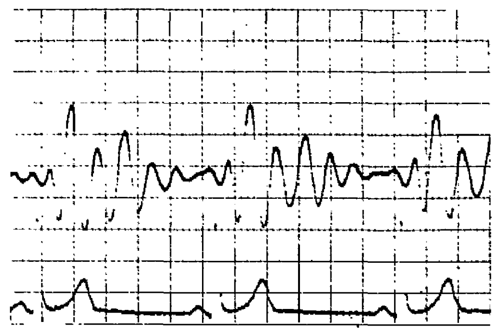

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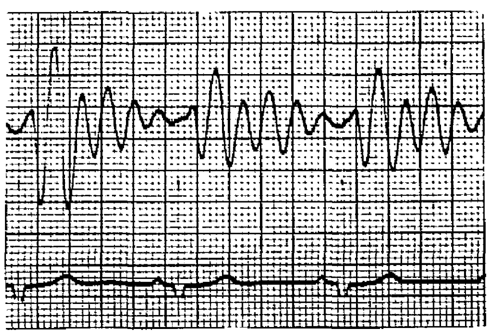

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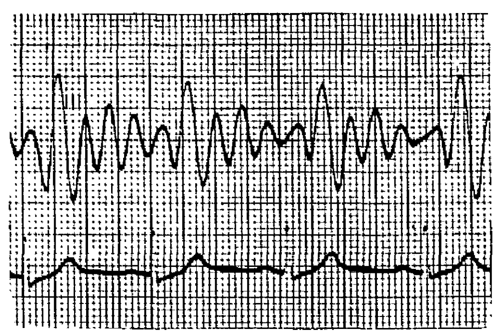


6.

In a normal ballistocardiogram, a representation of which is shown in Figure 1, the actual size of the complexes varies somewhat from beat to beat but the configuration of all the complexes is similar. There is a family resemblance among the complexes of an individual record and normal ballistocardiograms from different subjects also resemble one another. This is illustrated in Figure 2.

2. Systolic Waves.

a. The H wave.

This headward deflection begins its ascent at or near the peak of the electrocardiographic R wave (Richman and Littmann, 1963). It ends at or near the beginning of ventricular ejection (Scarborough and Talbot, 1956). Its precise origin has not been clearly defined and it is the most variable of all the systolic waves, changing even from one cardiac cycle to another (Hamilton et al., 1945; Frankel and Rothermich, 1952). It has been suggested that the H wave is due to atrial contraction (Nickerson, 1949; De Lalla et al., 1950) and certainly in some cases of complete heart block distinct complexes follow each electrocardiographic P wave, in which event the H wave of the next ventricular complex is usually absent (Scarborough et al., 1952).

On the other hand headward deflections closely resembling

H waves may be seen in records from patients with atrial fibrillation (Gubner et al., 1953; Richman and Littmann, 1963). It is likely that other factors such as the thrust of the heart during isometric contraction also play some part in its production (Hámilton et al., 1945; De Lalla et al., 1950; Richman and Littmann, 1963). Much information can probably be gleaned from the study of this wave and its relation to the I wave (Moss, 1960) but in practice examination of the H wave may prove difficult since it may disappear in the final diastolic undulations of the preceeding cardiac cycle. Thus it may be impossible to locate or measure it.

b. The I wave.

The I wave is the sharp footward recoil deflection that follows the H wave in normal records. It occurs early in systole and is associated with the ejection of blood from the heart into the aorta and pulmonary artery (Hamilton et al., 1945; Starr, 1954; Richman and Littmann, 1963). As the wave of pressure impacts on the crown of the arch of the aorta and pulmonary bifurcation the direction of the forces is abruptly reversed and the next prominent headward wave follows.

c. The J wave.

The J wave is the largest headward wave in the normal record and follows immediately on the I wave. It has a complex origin late in systole due to deceleration of blood in the ascending aorta and pulmonary artery and acceleration of flow in the descending aorta (Hamilton et al., 1945).

d. The K wave.

This is the prominent footward deflection that follows the J wave. It occurs near the end of systole. It was initially regarded by Starr et al. (1939) as being largely an artefact due to overshooting from the preceding J wave, a view reiterated by Richman and Littmann (1963), but Hamilton et al. (1945) considered that it represented definite cardiovascular forces produced by the impact and reflection of the pulse wave at the periphery of the arterial tree. Jacobs (1954) found that the depth of the K wave was increased by the inhalation of amyl nitrite and suggested that the lowering of peripheral resistance was the principal factor involved in this lengthening of the K wave.

The opposite situation is found in coarctation of the aorta where the K wave was noted to be much shortened (Hamilton et al., 1945; Brown et al., 1949; Nickerson, 1949; Murphy, 1950). Further, surgical correction of the aortic abnormality by aorto-aortic end-to-end anastomosis resulted in a return of the K wave almost to normal form (Murphy, 1950) whereas aorto-subclavian end-to-end anastomosis did not appreciably alter the

the preoperative pattern (Nickerson, 1949; Murphy,1950). Additional reports of a return of the shortened K wave pattern towards normal after surgical correction of the aortic anomaly have been made by Reissman and Dimond (1953) and Yuceoglu et al. (1957).

Marquis and Logan (1955) reported that the K wave might be shortened in aortic valve stenosis and added that surgical treatment was followed by a reversion towards the normal pattern. Aortic thrombosis causing the Leriche syndrome may also produce a decrease in the length of the K wave (Elkin and Cooper, 1949; Murphy, 1950).

Nickerson (1949) used a model "heart-aorta" circulation to demonstrate that variation in the length of the descending aorta caused changes in the depth of the K wave and suggested that this was one of the main factors in determining its depth in the human ballistocardiogram. In practice its precise length is influenced by other factors including the amount of pressure between the subject's feet and the footboard of the ballisto-cardiograph. An increase in pressure causes shortening of the K wave.

3. Diastolic Waves.

Honig and Tenney (1957) considered that the initial diastolic vibrations or waves were related to the magnitude and rate of change of the cardiovascular forces that occur with closure of the aortic valve. The pulmonary valve contributes to the formation of these waves only in the presence of increased flow or pressure in the lesser circulation. The two smaller headward waves which follow the K wave in normal ballistocardiograms are termed L and N while the small footward wave between them is described as the M wave (Scarborough and Talbot, 1956). Small waves occur later in diastole in some records but the only one named is the O wave which is a footward deflection following the N wave (Hamilton et al., 1945). These authors considered that the diastolic waves were related to specific circulatory events and suggested that the L wave, for example, was associated with deceleration of blood in the ascending aorta at the end of systole. There is, however, little precise information regarding either this wave or the other diastolic waves and they have generally been regarded as variable and less important than the systolic deflections.

It is convenient to mention at this point that the large diastolic waves sometimes observed in abnormal ballistocardiograms are not described by these letters since they are believed to be due to forces quite different from those which produce the normal diastolic waves. Scarborough and Talbot (1956) suggested that they should be described by their direction and occurrence in time, for example " a large headward wave in late diastole."

4. <u>Relation of the Waves to the Cardiac Ejection Curve</u>.

To clarify the fundamental origins of the waves of the ballistocardiogram Starr et al. (1950) carried out a series of experiments in fresh human cadavers. At post mortem examination, large cannulae were tied into the root of the aorta and pulmonary artery. The body was placed on the ballistocardiograph table and fluid was injected into these great vessels. The amount, speed and force of the injection were recorded photographically and at the same time a ballistocardiogram was obtained. The authors studied the mathematical relationship between the "cardiac ejection curve" and the ballistocardiogram associated with it. They concluded that the ejection curve could be reproduced qualitatively by mathematical analysis of the systolic waves of the ballistocardiogram. It was not possible to estimate the "cardiac output" by this method but there was a close correspondence between the force of ejection and the size of the ballistocardiogram and also between the shape of the ejection curve and the form of the ballistocardiogram.

When the injection of blood into the great vessels of the cadaver was rapid and regular, a ballistocardiographic curve similar to that found in healthy young adults and generally accepted as normal was constantly obtained. Slow, irregular or jerky injection produced abnormal waves in the ballistocardiogram. Most of the abnormal forms seen in clinical records could be produced at will.

These experiments suggested that in the human subject the waves of the ballistocardiogram are closely related to cardiac ejection. Their form is largely determined by the outline of the cardiac ejection curve and their amplitude is related to the force of ejection. It is not necessary to apply complex mathematical analysis to the ballistocardiographic record on each occasion and the ballistocardiogram may be assessed and interpreted in its own right as an empirical means of estimating the mechanical efficiency of the heart.

Summary.

The normal ballistocardiogram consists of a series of regular and reproducible waves. The larger systolic waves H, I, J and K have been related to specific events in the cardiovascular dynamics. The origins of the diastolic waves L, M, N and O are less clearly defined.

It has been shown that the systolic complex of the ballistocardiogram is related to the curve of cardiac ejection. The form of the record is largely determined by the outline of the cardiac ejection curve and its amplitude is related to the force of cardiac ejection. The ballistocardiogram may be used as an empirical measure of the mechanical efficiency of the heart.

Chapter 6.

ASSESSMENT OF THE BALLISTOCARDIOGRAM.

1. Introduction.

Ballistocardiograms can be assessed in two ways. The simpler and hitherto more popular method has been purely qualitative and concerned essentially with the contour of the record. The quantitative method presents more difficulty. In order to determine the significance of the amplitude and other measurements of a ballistocardiogram one must possess an instrument that can be calibrated and normal standards derived from the records of normal subjects examined with it. To some extent the two methods are complementary because a change in the form of a wave may well result in alteration of the amplitude or duration of that wave.

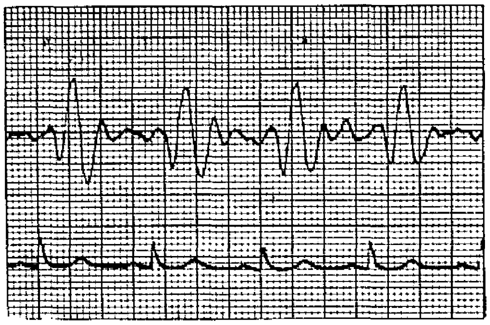
2. Qualitative Assessment.

a. Normal patterns.

General inspection of a ballistocardiogram reveals a

Figure 3.

Normal ballistocardiograms of healthy women. The large waves represent systolic events and the small waves are associated with diastole.



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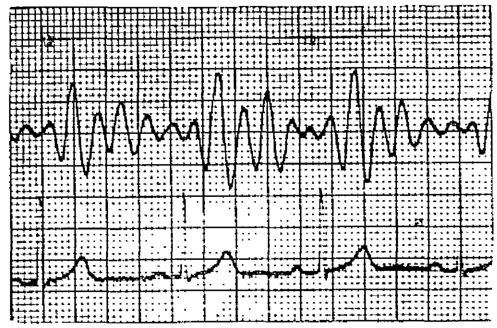

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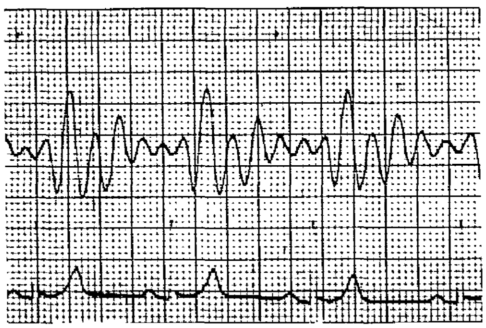

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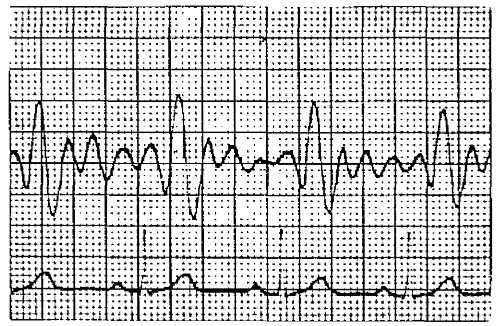

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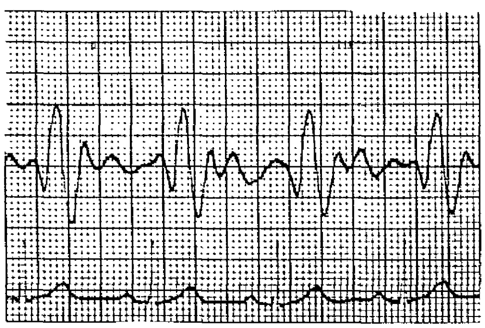

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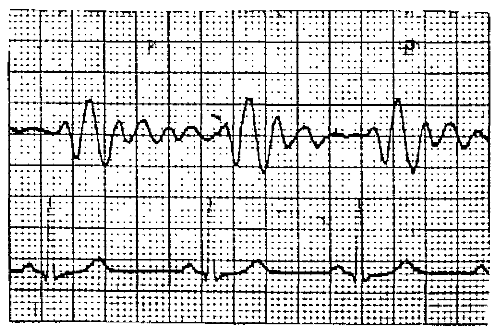

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series of more or less regular waves. In the normal record these are repeated from one cardiac cycle to the next and are highly consistent. Each cardiac cycle is represented by a complex of systolic and diastolic waves. This is shown in the ballistocardiograms in Figure 3. It is quite exceptional for the record of a healthy young adult to deviate from this normal pattern (Henderson, 1953).

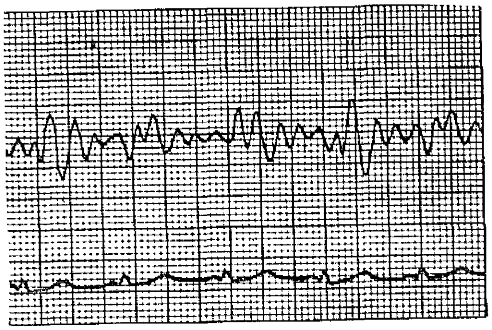
b. Abnormal patterns.

The normal wave pattern of the ballistocardiogram was first described by Starr et al. (1939). These authors found certain well defined and commonly occurring abnormalities of wave contour usually associated with cardiac disease. Three of these variants were named the early M, late M and late downstroke patterns. Henderson (1953) noted that "detailed description of a ballistic abnormality is never easy because the contour so often changes from beat to beat within the respiratory cycle." Like Starr, however, he found three main combinations of ballistocardiographic abnormality. Two of these variants were essentially the early M and late downstroke patterns. The third type showed a decrease in the depth of the I wave and lessening of the height of the J wave which might also be deformed by slurring or notching. Many

Figure 4.

Ballistocardiograms with abnormal wave pattern.

1. The 2nd and 5th complexes from the left show late M pattern.
2. The 3rd, 4th and 5th complexes show early M pattern and prominent headward late diastolic waves.
3. The 3rd complex shows late downstroke pattern and the 5th complex shows a marked example of early M pattern. The others are bizarre complexes.
4. All complexes show abnormal HI pattern. The 1st and 4th complexes show reversal of the slope of the HI segment, which is upward instead of downward.
5. The 2nd complex from the left shows short K pattern and the 5th shows early M pattern. The 1st complex is an intermediate form of short K pattern.
6. The 2nd complex shows prominent L pattern (the K wave also being deep) and the 4th complex shows early M pattern.



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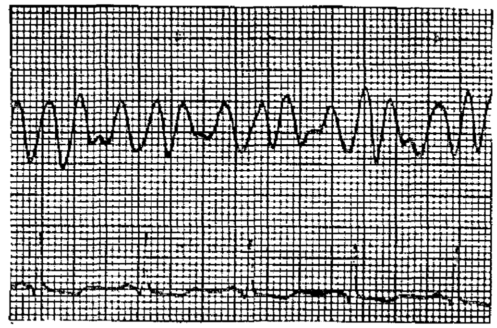

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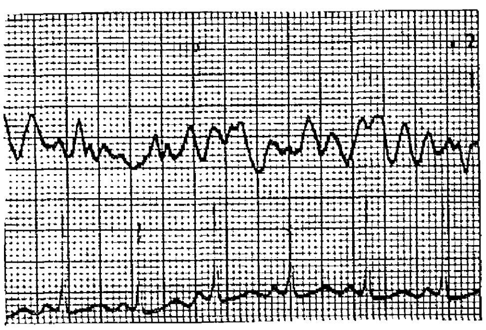

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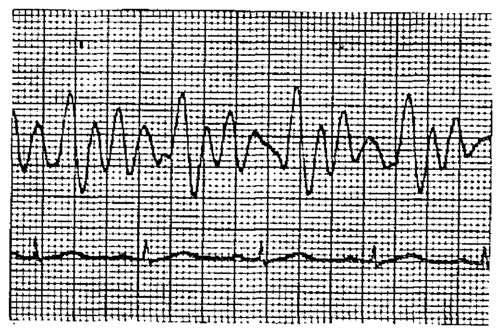

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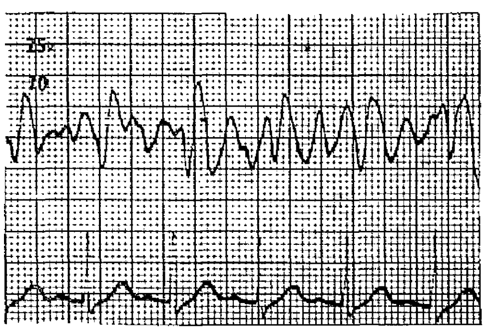

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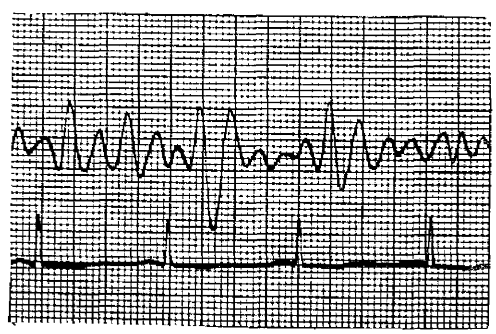


6.

other ballistic wave abnormalities have been described. These include slurring or notching of various systolic waves, absence or truncation of the K wave, unduly large diastolic waves and bizarre contours whose wave forms cannot be clearly distinguished, (Pordy et al., 1951). Figure 4 shows ballistocardiograms with various abnormalities of form.

Abnormal ballistocardiograms may show a considerable variety of wave pattern. Several different types of abnormal contour may exist in a single record. This makes it difficult to devise a compact yet precise classification of wave abnormality in a ballistocardiogram. Some ballistocardiograms are clearly more abnormal than others but this depends essentially on the proportion of complexes affected by wave deformity.

c. Degree of ballistocardiographic abnormality.

In an attempt to clarify this point Brown et al. (1950) devised criteria for the assessment of ballistocardiograms. Five degrees of abnormality were arbitrarily defined. Normal records were classified as grade 0. In grade 1 the normal form of all complexes was preserved but the complexes registered during expiration were relatively small and there was therefore an unduly great variation in the size of the complexes. When at least half of the complexes were abnormal, usually during expiration, the ballistocardiogram was placed in grade 2. In grade 3 the complexes showed varying degrees of abnormality during all phases of respiration but all complexes could be clearly defined. Grade 4 records had totally abnormal complexes usually of low amplitude with individual waves that were difficult or impossible to identify with confidence. This system represented a substantial contribution to the assessment of ballistocardiograms but it did not provide for abnormal records in which less than half the complexes were deformed in successive respiratory cycles. Ballistocardiograms of this type are not uncommon and cannot be regarded as normal. Thus it seems desirable to subdivide grade 2 into grade 2A in which less than half the complexes are abnormal and grade 2B in which more than half are abnormal.

d. <u>Artefacts in ballistocardiograms</u>.

It is essential that only abnormalities that recur regularly in a record should be considered significant; a solitary abnormal complex must always be regarded as an artefact until the reverse is proved. Ballistocardiograms must be read with several sources of error constantly in mind. Any small movement, voluntary or involuntary, made by the patient on the table may distort a complex of the ballistocardiogram. Even overbreathing by the patient lying flat on the table may produce diaphragmatic impacts on the record. Movements in the building may also affect the record but these are usually relatively fine vibrations which are not likely to be mistaken for abnormal waves of cardiac origin.

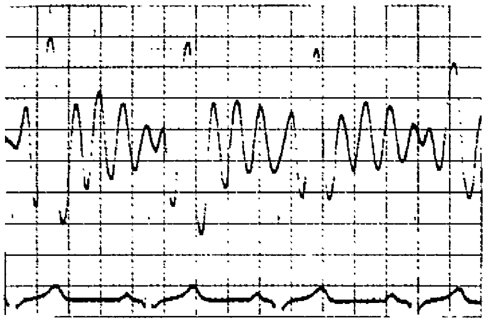
e. Equivocal ballistocardiograms.

In some ballistocardiograms the abnormality or abnormalities may be minimal or slight. It may be very difficult for the observer to decide if the deviation from the classically normal pattern is of real significance. This difficulty arises essentially because the normal proceeds into the overtly and obviously abnormal by imperceptible steps. Thus any group of examiners or even a single observer may not classify a group of x-ray films or electrocardiograms in exactly the same way on different days (Dock et al., 1951). This problem of observer variation or error arises in many clinical observations. Difficulty has been found in the detection of emphysema (Fletcher, 1952) and finger clubbing (Pyke, 1954). Considerable variation in the interpretation of chest x-rays (Birkelo et al., 1947) and electrocardiograms (Davies, 1958) is widely recognised as inevitable. Thus it is not surprising that occasions arise when great difficulty is experienced in deciding whether a ballistocardiogram is normal or slightly

Figure 5.

Normal ballistocardiograms of healthy men. In each record the complexes are alike in contour but vary in size due to respiratory factors.

This is the same illustration as Figure 2.



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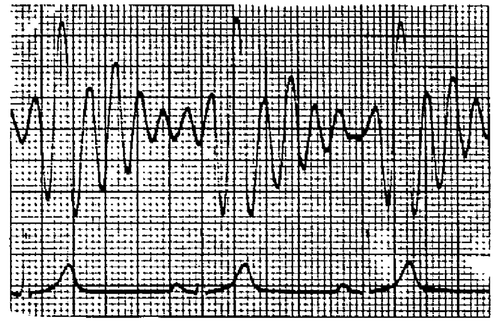

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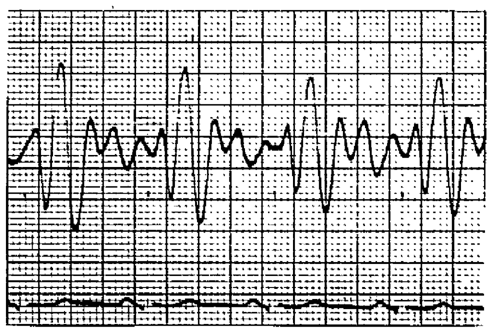

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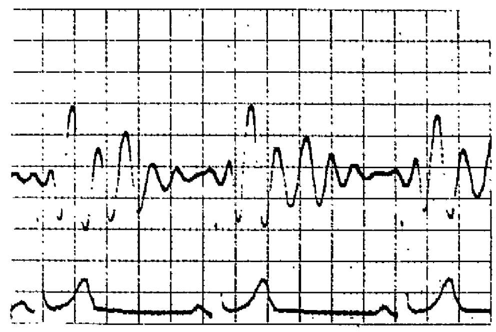

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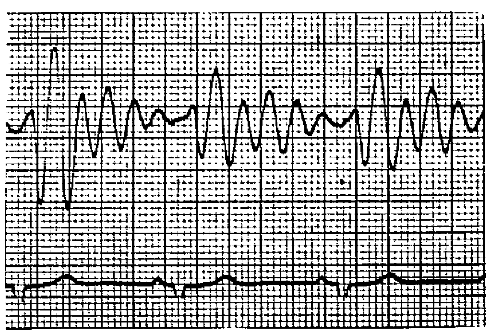

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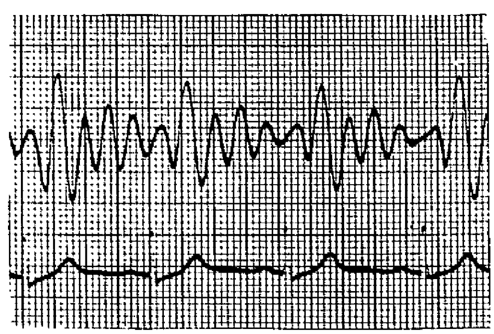

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abnormal. It is wise to record these borderline ballistocardiograms as equivocal but to place them in grade 0 or grade 1 (Brown et al., 1950). They are thereby recorded as essentially normal in form. This bias may result in a few abnormal records being placed in a normal category but this is probably a more acceptable error than the reverse. Only what is clearly and unequivocally abnormal should be recorded as such.

3. Quantitative Assessment.

a. Methods of measurement.

Successive complexes of normal ballistocardiograms resemble one another in form but vary in size due to respiratory factors. This may be seen in the records shown in Figure 5. Since the amplitude of the complexes varies with each heart beat, measurement of any single complex or wave will provide little finite information about the ballistocardiogram as a whole. Starr et al. (1939) suggested that the average value derived from a single large inspiratory complex and a single small expiratory complex would yield figures applicable to the entire record. Starr (1958) added that this average was very close to the mean value obtained from the measurement of large numbers of complexes. By chance, however, the selected pair of large and small complexes might not be representative of the whole ballistocardiogram. Thus it is preferable to measure typical inspiratory and expiratory complexes from three consecutive respiratory cycles (Scarborough et al., 1953).

The line that traces the ballistocardiogram varies in width for a number of technical reasons. Measurements are usually made from either the upper or lower edge of the tracing. This provides a "line of no thickness" and the variable width of different records may be ignored. The amplitudes of waves or segments are usually measured to the nearest 0.5 mm. and the duration may be measured in fractions of a second.

The number of measurements and calculations that may be derived from ballistocardiograms is almost unlimited. These are time consuming and not all are profitable. It has been shown that the IJ segment is closely related in many ways to factors concerned with cardiac ejection. It is usually a prominent and readily identified part of the ballistocardiogram (Masini and Rossi, 1953; Van Lingen et al., 1956). It thus seems suitable for quantitative study and has been used in most reports of this nature. A number of indices can be derived from its measurement. These may be helpful in distinguishing normal from abnormal ballistocardiograms.

It must be stressed that these measurements and indices are essentially meaningless unless the ballistocardiograph can be

Figure 6.

The shift of the baseline of the ballistocardiogram by 10mm. that occurs when a force of 280 grammes is applied to the table. Calibration is performed while the subject lies on the ballistocardiograph.

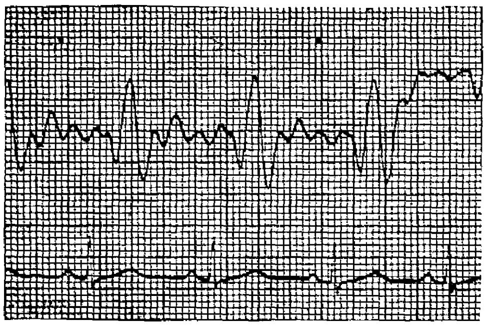
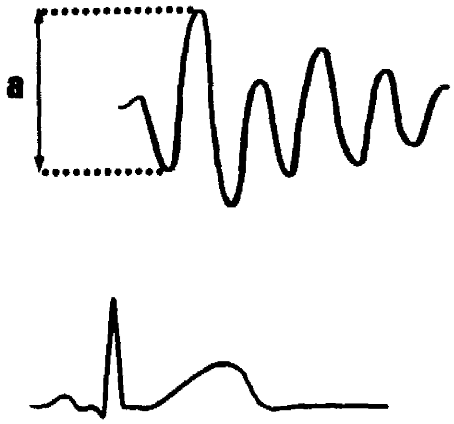
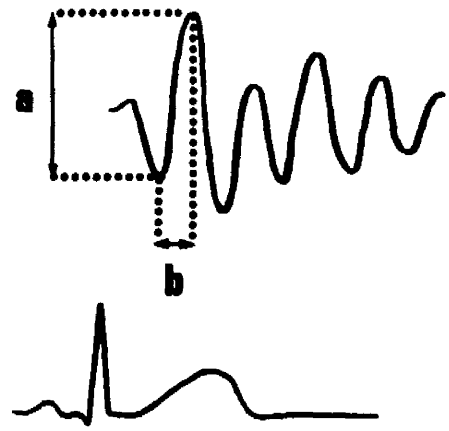


Figure 7.

The diagram on the left shows the method of measuring the amplitude of the IJ segment and the figure on the right shows measurement of the theoretical triangle under the IJ segment of the ballistocardiogram.



a = IJ Amplitude



$\frac{a \times b}{2}$ = IJ Area

calibrated. It is customary to adjust the apparatus so that a force of 280 grammes applied to the table causes the baseline of the ballistocardiogram to be deflected by 10 mm. as shown in Figure 6.

b. Amplitude of the IJ segment.

The method of measuring the IJ amplitude is shown diagrammatically in Figure 7. If the ballistocardiograph has been calibrated in the way described above, it is unnecessary to calculate the precise mechanical force represented by the mean amplitude of the IJ segment. The standard practice is to use this result as an empirical measure of force in its own right.

It was first suggested by Starr et al. (1950) that the amplitude of the IJ segment was related to the maximum force of cardiac ejection or the "strength of the heart." At first it was thought that the IJ amplitude was related also to surface area but this view was later found untenable. It has generally been agreed, however, that the age and sex of the subject have an important bearing on this amplitude.

In an analysis of the ballistocardiograms of 369 apparently healthy persons Scarborough et al. (1953) detected a progressive and significant decrease in the size of the ballistocardiogram as age increased. Review of his own results by Starr (1955) revealed a similar trend. This raised an important if partly philosophical problem, namely whether a person's ballistocardiogram should be judged by standards based on his own age group or by those derived from a young and healthy population. This matter has remained controversial. Starr (1958) preferred to use standards based on the records of healthy young adults for the evaluation of all ballistocardiograms, in the belief that ageing of the heart with consequent loss of strength would be shown more readily by the comparison, but Scarborough et al. (1953) compared their patients' records with those of apparently healthy contemporaries.

It has generally been agreed that the ballistocardiograms of men are appreciably larger than those of women. The reason for this is not clear but it is not due entirely to differences in body size. Differences in muscular strength may be at least partly responsible. The decrease in the size of the ballisto-cardiogram with advancing age is seen in both sexes when they are considered separately but at all ages women's records are distinctly smaller than men's.

Thus it is necessary to consider both age and sex when standards for the amplitude of ballistocardiograms are being prepared.

c. Area under the IJ segment.

The method of measuring the IJ area is shown diagrammatically in Figure 7.

The value of measuring the IJ amplitude has been fairly firmly established but certain advantages are obtained by estimation of the area of the theoretical triangle under the slope of the IJ segment. For example, varying pressures of the subject's heels on the footboard of the ballistocardiograph table may alter the amplitude of the IJ segment, just as the depth of the K wave may be changed. Careful attention to the accurate placing of the subject on the table will minimise this source of error but it is difficult to estimate precisely the slight variations that will inevitably occur during a series of recordings. In these circumstances the duration of the IJ segment increases to some extent as its height decreases (Starr, 1955) and the area formula lessens the effect of minor technical variations of this nature.

Further, differences in the weight of the actual table of the ballistocardiograph have less effect on the IJ area than on its amplitude, as judged by the effect produced by weighting the bed with iron bars (Starr and Schroeder, 1940). Fine vibrations superimposed on the ballistocardiogram have only a slight influence on wave areas although they may produce distinct alterations in wave amplitude. Starr et al. (1950) showed by cadaver experiments that asynchronous injection of fluid into the systemic and pulmonary circulations distorted the ballistocardiogram. The amplitudes of the distorted waves were much more affected than their areas.

Finally, Starr and Noordergraaf (1962) compared the ballistocardiograms obtained from a group of subjects both by high-frequency and ultra-low frequency apparatus. The area of the IJ segment was found to be closely related in absolute terms in the two types of record, that is ballistocardiograms recorded by the two methods yielded area results that were essentially the same for any single subject. There are theoretical grounds for believing that the ultra-low frequency instrument provides records with fewer distortions of the major waves than does the high-frequency table but in this instance the accuracy of the quantitative method applied to the high-frequency record approached that of the ultra-low frequency ballistocardiogram. This alone would seem a strong indication for making the area measurement.

d. Respiratory variation of the IJ segment.

A method of measuring the amount of respiratory variation

Figure 8.

Diagrammatic representation of the measurement of the "Ra" ratio of respiratory variation. The smaller figure on the left represents a typical expiratory complex and the larger figure on the right represents a typical inspiratory complex.

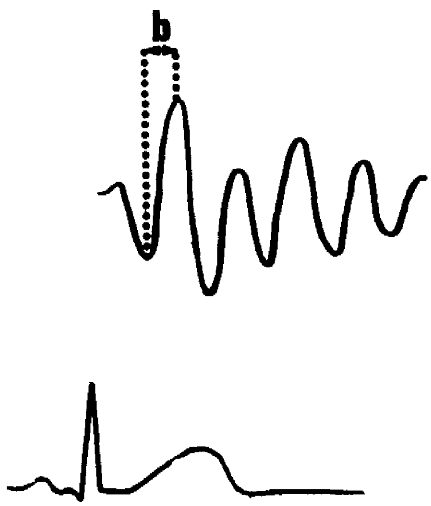
$$\text{"Ra"} = \frac{ij}{IJ}$$

is illustrated in Figure 8.

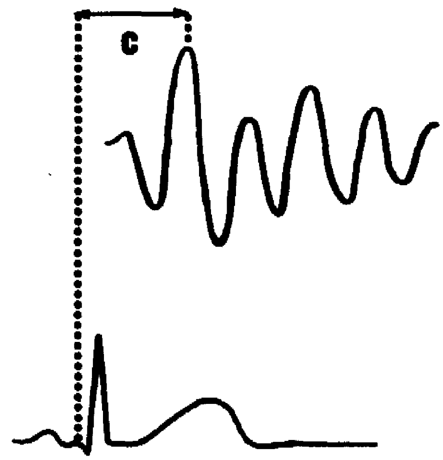
The regular phasic variation in the IJ amplitude that occurs with respiration may be expressed in quantitative terms. To this end a variety of formulae has been evolved. Brown et al. (1950) developed a "respiratory variation index" based on calculation of the stroke volume of the heart from the ballistocardiogram. The great difficulty of siting a base-line accurately on the ballistocardiogram renders this a somewhat dubious undertaking. The problem becomes acute when the record is abnormal in form. Scarborough et al. (1953) and Anderson et al. (1954) preferred to use a ratio calculated simply from the IJ amplitude. This is usually readily measured even in very abnormal ballistocardiograms, which confers a crucial advantage unless one is confined to assessing only normal or slightly abnormal records. A ratio, termed "Ra" by Scarborough et al. (1953), is obtained by expressing the mean amplitude of the small expiratory IJ segments from three consecutive respiratory cycles as a decimal fraction of the mean amplitude of the three corresponding large inspiratory IJ segments (Figure 8). This method is applicable to ballistocardiograms even with gross abnormalities of contour. The ratio decreases in value as age advances but does not differ appreciably in men and women.

Figure 9.

The diagram on the left shows the method of measuring the duration of the IJ segment. The measurement of the QJ interval is also shown in the figure on the right.



b= IJ interval



c = QJ interval

e. <u>Duration of the IJ segment</u>.

The method of measuring the duration of the IJ segment is shown diagrammatically in Figure 9.

Scarborough et al. (1953) noted that the duration of the IJ segment decreased as age advanced. They suggested that this variation might be related to changes in the elasticity of the aorta. Increased rigidity of the aortic wall in older persons might produce greater pulse wave velocity. Thus the IJ segment was terminated sooner than in younger persons whose great vessels were more distensible. It was also found that the duration of the IJ interval was related to some extent to the size of the body possibly because the aorta is slightly longer in taller persons. The relationship was not a particularly close one and the usual practice has been to disregard body size.

<u>Summary</u>.

Ballistocardiograms may be assessed qualitatively and quantitatively. The latter method entails the use of a ballistocardiograph which can be calibrated.

The qualitative method of assessment is concerned with wave contour. Detailed description of abnormal patterns is not easy because of the variation in form that occurs from one respiratory cycle to another even in the same record. Nevertheless certain basic types of abnormal complexes can be described. The degree of ballistocardiographic abnormality is related to the proportion of abnormal complexes present in a record and a classification for grading abnormality has been devised.

It is essential that only regularly recurring abnormalities be considered significant. Sporadic deviants from normal are probably artefacts. On occasion it is difficult to be certain if a complex shows significant abnormality or not. Decisions on such matters may vary between observers and a single observer may give different opinions on different days. This problem is not peculiar to ballistocardiography. It is wise to record doubtful cases as equivocal and to consider them as essentially normal. This may result in a few records being incorrectly classified as normal but this error is probably more acceptable than the reverse.

The quantitative method involves measurement of wave amplitude and duration. The IJ segment has usually been chosen for this purpose because of its relationship to the cardiac ejection curve. In the ballistocardiograms of normal persons the amplitude and duration of the IJ segment decrease as age advances and the degree of respiratory variation increases.

From the records of normal subjects it is possible to construct normal standards for a ballistocardiograph which can be calibrated. Quantitative deviations from the normal can then be detected in abnormal records. Because age influences the measurements of a ballistocardiogram it is difficult to decide whether to judge a record by standards derived from the tracings of healthy young adults or by standards based on the records of persons of equivalent age. This matter has remained controversial. There is general agreement, however, that men's ballistocardiograms are of greater amplitude than women's although the reason is not clear. Thus the age and sex of the subject are important factors in the quantitative assessment of the ballistocardiograms.

Chapter 7.

STRESS TESTS IN BALLISTOCARDIOGRAPHY.

1. Limitation of the Ballistocardiogram taken after rest.

In an extensive study of ballistocardiograms, taken in the standard manner after a period of rest, from patients with coronary artery disease, Scarborough et al. (1952) reported an unduly high incidence of abnormal records but stressed that the proportion of young patients with abnormal ballistocardiograms was relatively small. Thus in the age group in which ballistic wave abnormality was low in apparently normal subjects it was relatively low in patients with overt ischaemic heart disease. Conversely, in the decades in which abnormal ballistocardiograms were very common in patients with coronary disease they were frequent in seemingly healthy persons.

Advancing age is a highly consistent factor in the production of ballistocardiographic abnormalities and this effect prevails to some extent whether the subject has overt heart disease or not (Fulton et al., 1961). Thus the ballistocardiogram recorded after the subject has been resting for a period is of limited value in the diagnosis of ischaemic heart disease (Penneys and Thomas, 1950; Richman et al., 1963). This led to the introduction of stress procedures in association with ballistocardiography in an attempt to make cardiac abnormalities more readily detectible by this method.

2. <u>External Stimuli and the Ballistocardiogram</u>.

It has long been recognised that the cardiovascular system is affected by external factors which include variations in altitude and temperature (Lewis, 1929-31), exercise (Cotton et al., 1917; Wayne and Laplace, 1933), food (Wayne and Graybiel, 1934) and tobacco smoking (Parkinson and Koefod, 1917; Roth and Shick, 1958). To some extent these changes in circulatory dynamics are reflected by the ballistocardiogram. For example, mention was made in Chapter 2 of its use by Henderson in an attempt to assess the effect of altitude on cardiac output (Douglas et al., 1913). Observation that external stimuli could affect the ballistocardiogram led to the view that important information might be gained by comparing the response of normal and diseased hearts to tests of this type, provided that they were standardised. These stress tests have included the effects of exercise, induced hypoxia and the ingestion of food.

The use of certain drugs in this way has essentially been a pharmacological extension of the more physiological stress procedures. The most commonly used drug has been nicotine, given sublingually or intravenously or inhaled from a cigarette. Because of its special importance, the effect of smoking on the ballistocardiogram is considered separately in Chapter 8. Other drugs used in stress tests have included ergonovine, an alkaloid of ergot (Davis, 1960A) and noradrenalin (Kelly, 1960; Davis, 1960B) but the smoking test has proved more satisfactory (Davis, 1960A).

3. Effect of Exercise on the Ballistocardiogram.

Physicians have often sought to secure objective means of assessing cardiac function by examining the heart during or after exercise. A test which measured the response of blood pressure and pulse rate to a standardised two-step exercise was developed by Master and Oppenheimer (1929) who considered this a practical means of assessing circulatory fitness. A similar procedure was adopted by Wayne and Laplace (1933) and Wayne and Graybiel (1934) in their studies of angina pectoris.

Later, electrocardiograms were used in conjunction with the two-step test to estimate the state of the coronary circulation. Master (1950) suggested that alterations of the electrocardiogram with exercise were due to a myocardial oxygen debt because similar changes might occur during induced hypoxia.

The effect of exercise on the ballistocardiogram was first studied in Starr's department in 1938 by Stroud and Evans but because of war-time restrictions their work was interrupted. Makinson (1950) noted that ballistocardiograms had been recorded almost universally from subjects who had been resting. He suggested that a more delicate test would be secured if records were taken while the heart was subjected to a strain, as a slightly diseased heart might be unable to cope with the demand for increased work. He recorded ballistocardiograms from 41 normal persons and 57 cardiac patients before and shortly after a standard two-step exercise. He found abnormal responses to exercise in patients with rheumatic heart disease, angina pectoris, thyrotoxicosis and myxoedema. Alterations in amplitude and form occurred in the ballistocardiograms of these patients.

Davis et al. (1953) examined 114 normal subjects and 86 patients with coronary artery disease. They obtained ballistocardiograms before and after two-step exercise tests and found that the records of the cardiac patients were more often adversely affected by exercise than those of the normal subjects but the difference between the two groups was too small to be of diagnostic significance.

Similar observations were made by Pordy et al. (1951), Chesky et al.(1951) and Mandelbaum and Mandelbaum (1951).

Considerable technical difficulties may be encountered when ballistocardiograms are recorded after exercise. Artefacts are common, because subjects tend to make small movements for some time after exertion. Cardiac patients in particular may breathe more rapidly or deeply and diaphragmatic impacts may distort the ballistocardiogram. Several minutes may elapse before satisfactory recording can be resumed (Davis et al., 1953). There may also be great difficulty in obtaining reproducible records. Adverse features of these types have perhaps contributed to the failure of the ballistocardiographic exercise test to gain favour.

4. <u>Effect of Hypoxia on the Ballistocardiogram.</u>

Induced hypoxia has also been employed as a method of assessing the state of the coronary circulation. In a review of the field Stewart and Carr (1954) found that the incidence of positive tests in patients with coronary artery disease ranged from 30 to 61 per cent and was usually about 50 per cent. They noted the general agreement that a negative test did not exclude coronary artery disease. The results of exercise and induced hypoxia were not invariably similar and one test might be positive when the other was negative .

Wood (1956) regarded induced hypoxia as less useful than the effort test, being more difficult to perform and to interpret, more dangerous and less frequently positive.

Despite these defects the hypoxia test had one clear advantage over the exercise test: it could be performed while the subject was at rest and recumbent. This probably led to its use by Penneys and Thomas (1950) who demonstrated striking alterations during hypoxia in the ballistocardiograms of patients suspected of having coronary artery disease. The deterioration in the ballistocardiograms occurred before the onset of anginal pain and also before electrocardiographic changes had taken place. The effect of induced hypoxia was studied also by Scarborough et al. (1951) who reported that the amplitude of the records was increased and the wave form of some ballistocardiograms was distorted. Penneys (1961) examined 141 patients with suspected coronary artery disease and found that 47 had angina pectoris or abnormal electrocardiograms during induced hypoxia. Of these patients 75 per cent had abnormal resting or initial ballistocardiograms but during hypoxia 91 per cent had abnormal records. There were 94 other patients with a negative clinical and electrocardiographic response to hypoxia: 53 per cent of these patients had abnormal resting ballistocardiograms and 63 per cent had abnormal tracings during hypoxia. Penneys also studied

14 healthy middle aged control subjects none of whom had angina or electrocardiographic changes with hypoxia. All their ballistocardiograms were normal before and during hypoxia. Penneys concluded that the usefulness of the ballistocardiogram in the detection of coronary insufficiency was enhanced by its employment during induced hypoxia. Moss (1960) found that the ballistocardiograms of healthy volunteers did not change in form but did develop greater amplitude during hypoxia. The calculated force of cardiac ejection was increased in each case. Moss suggested that these changes might be due at least partly to a decrease in peripheral resistance. The stress test using induced hypoxia has not been widely employed in ballistocardiographic studies probably because it has proved somewhat difficult to perform and is not entirely free from hazard.

5. Effect of Food on the Ballistocardiogram.

Many patients with angina pectoris say that pain occurs more readily if they take exercise after food. Heberden (1786) stated that "those who are afflicted with it are seized while they are walking, and more particularly if they walk soon after eating." The greater incidence of anginal pain after meals is probably due to increased energy expenditure by the heart during digestion. The heart rate is increased and exercise tolerance is reduced by an average of 25 per cent after the ingestion of food (Wayne and Graybiel, 1934).

Paine and Shock (1950) observed the effect of food on the ballistocardiograms of 10 persons who showed no evidence of cardiovascular disease. They calculated the "cardiac output" by means of a formula based on the amplitude of the IJ segment of the ballistocardiogram and found that there was a mean increase of 12 per cent from one to three hours after food. A similar study by Berman et al. (1950) showed a mean increase of 24 per cent in the "cardiac output" of 6 normal subjects after a meal. These authors also examined 23 patients with angina pectoris. Before food 18 had abnormal ballistocardiograms and of these 4 showed a slight increase in amplitude, 3 had decreased amplitude and 11 showed no apparent change after eating. Five patients with angina had records of normal contour. A calculation of "cardiac output" was made from these records. There was a mean decrease of 4 per cent after food in these cardiac patients compared with the mean increase of 24 per cent that had been found in the normal control subjects. It was considered that the stress of a meal seemed to aid in the differentiation of the cardiac patients from the normal subjects.

Summary.

The ballistocardiogram obtained when the subject has been resting is of limited value in the diagnosis of ischaemic heart disease. This is partly due to the important effect of ageing on the ballistocardiogram.

Observation that external stimuli could affect the ballistocardiogram led to the view that additional information might be obtained by comparing the response of normal and diseased hearts to standardised external stresses.

Ballistocardiograms of cardiac patients were more often adversely affected by exercise than those of normal subjects but the difference between the two groups was too small to be of diagnostic value and the method involved certain technical difficulties. Greater separation of normal subjects from patients with coronary disease was achieved by recording ballistocardiograms during induced hypoxia but this method proved cumbersome and not entirely free from hazard. A similar effect was noted when ballistocardiograms were taken after meals but these were not standardised.

Certain drugs, including nicotine and ergonovine, may also affect the ballistocardiogram adversely, particularly in patients with coronary artery disease.

Chapter 8.

THE BALLISTOCARDIOGRAPHIC SMOKING TEST.

1. Effect of Smoking on the Cardiovascular System.

a. Constituents of tobacco smoke.

Tobacco smoke has many constituents but its effects are practically entirely due to nicotine (Sollman, 1957). Most ordinary cigarettes contain about a gramme of tobacco (Oram and Sowton, 1963) but the amount of nicotine absorbed is about 0.4 mg. (Ling and Wynn Parry, 1949). This is in keeping with the report of Burn et al.(1945) that the antidiuretic effect obtained by smoking a cigarette is less than that of the injection of 0.5 mg. of nicotine base.

b. Earlier views on smoking and the heart.

Graves (1848) was one of the first to report disturbed cardiac action produced by heavy smoking. Beau (1862) described eight patients in whom excessive smoking was associated with attacks of anginal pain and suggested that this was due to the nicotine content of the tobacco. A ship's surgeon, Gelineau (1862) described an almost epidemic occurrence of angina pectoris on a long voyage in the South Seas. Initially he was inclined to attribute this to a combination of extremely arduous physical work and anaemia, perhaps of scorbutic type. After reading the article by Beau (1862) he recalled the incessant smoking and tobacco chewing of the sailors and felt he could not dismiss that as a possible cause. Favarger (1877) suggested that attacks of angina could be produced by nicotine causing spasm of the coronary arteries. Huchard (1899) coined the term "tobacco angina" to describe the entity. Acceptance of this name led to much confusion regarding the action of nicotine on the heart and the coronary arteries.

c. Action of Nicotine on the Myocardium.

Kottegoda (1953) suggested that nicotine acted on chromaffin tissue in the heart to liberate an adrenalin-like substance. Bertler et al. (1956) showed that the injection of reserpine caused almost complete disappearance of the catecholamines from the heart and Burn and Rand (1958) found that the augmentor response of nicotine was prevented by the prior administration of reserpine. It was considered that the effects of nicotine were due to its release of adrenalin and noradrenalin from the chromaffin tissue of the heart, usually found near the coronary arteries, especially the left, (Busacchi, 1912).

d. <u>Action of nicotine on the coronary arteries</u>.

It was suggested first by Favarger (1877) and then by Huchard (1899) that nicotine could cause angina by constricting the coronary arteries. Laubry et al. (1933) confirmed that large doses of nicotine caused coronary constriction in animals but they emphasised that small amounts constantly produced an increase in the coronary arterial flow.

The argument that nicotine could constrict the coronary arteries in man seemed to be supported by the admittedly rare occurrence of angina pectoris precipitated directly by tobacco smoking (Gallavardin, 1924; Ralli and Oppenheimer, 1928; Wilson and Johnston, 1941; Pickering and Sanderson, 1945; Bryant and Wood, 1947; Arai et al., 1951; von Ahn, 1954; Oram and Sowton, 1963) but Graybiel et al. (1938) and Pickering and Sanderson (1945) considered that such attacks of anginal pain were more likely to be due to augmented cardiac work caused by an increase in heart rate or blood pressure or both. This rise in rate and blood pressure is regularly observed after smoking (Parkinson and Koefod, 1917). The increased heart rate is probably due to release of catechol-amines from the myocardium and the rise in blood pressure to peripheral vasoconstriction. Burn (1960) stated that nicotine enhances the release of catechol-amines from the adrenals and thus causes dilatation of the coronary arteries. The net result is likely to be an increase in coronary blood flow. On the other hand, nicotine also stimulates the posterior lobe of the pituitary to release vasopressin but the amount of vasopressin liberated by the smoking of a cigarette is insufficient to cause coronary constriction despite the occurrence of an antidiuretic effect (Burn et al., 1945; Burn, 1960).

Bargeron et al. (1957) catheterised the coronary sinus in 30 normal adults and found that the smoking of one ordinary cigarette resulted in a significantly increased coronary blood flow. In no case was there evidence of coronary constriction. Regan et al. (1960) made a similar study of seven patients who had had myocardial infarcts from 7 to 24 months previously. In three cases the coronary blood flow was unaltered while in three there was a slight decrease and in one an increase. The changes were small and the authors concluded that smoking in patients with coronary disease resulted in no appreciable change in coronary blood flow.

2. Cigarette Smoking and the Ballistocardiogram.

The interesting and important effect of cigarette smoking on the ballistocardiogram was first observed when a young man engaged in ballistocardiographic research discovered that on some occasions his own tracings were normal but on others remarkably abnormal (Caccese and Schrager, 1951). He never felt discomfort or chest pain while smoking but it became evident that this was the cause of the change in his ballistocardiogram. This finding led to the introduction of cigarette smoking as a stress procedure in ballistocardiography. The method was used in conjunction with direct-body apparatus (Caccese and Schrager, 1951; Mandelbaum and Mandelbaum, 1952) and high-frequency table instruments (Henderson, 1953; Davis et al., 1953, 1956; Davis, 1959, 1960A) but for some reason that is not clear the changes after smoking are not usually seen in records obtained from ultra-low frequency ballistocardiographs (Davis, 1960B). Occasionally nicotine has been given sublingually or intravenously with comparable results (Davis et al., 1956; Davis, 1960A, 1960B; Talbot, 1965) but Starr (1960) doubted if the use of nicotine itself was justifiable particularly in the older patients.

3. <u>Reports of Ballistocardiographic Studies after Smoking.</u>

The first report of alterations in the ballistocardiogram after smoking was made by Boyle et al. (1947) who used the method in an attempt to assess changes in cardiac output but did not comment on the wave contour of the records before or after smoking. Dock (1951) mentioned that smoking might alter the wave pattern of the ballistocardiogram but the first systematic study was that of Caccese and Schrager (1951). Adverse changes of ballistocardiographic contour occurred in 18 of the 31 subjects they studied. Serious changes were found after smoking in seven records, four from the 23 apparently normal persons and three from the eight patients with cardiovascular disease.

Mandelbaum and Mandelbaum (1952) reported that 28 per cent of 50 apparently healthy subjects aged between 16 and 60 years had abnormal ballistocardiograms after smoking. In patients with coronary artery disease or hypertensive heart disease, most of whom had abnormal resting ballistocardiograms, the incidence of positive smoking tests was more than twice that obtained in persons without heart disease. In a few subjects no abnormalities occurred in the ballistocardiogram recorded immediately after smoking but abnormal patterns were then induced by exercise even when that had previously failed to affect the record adversely.

Henderson (1953) studied the effects of smoking in healthy persons and patients with coronary artery disease. He found no abnormal records before or after smoking in 50 healthy subjects between 20 and 40 years of age but there were four abnormal records after smoking in a group of 30 healthy persons aged from 40 to 60 years. There were 40 patients with coronary artery disease. Of these 10 of the 19 with normal initial records developed abnormalities of form, while five of the 21 with abnormal initial records developed more severe abnormalities. A further four patients with hypercholesterolaemia, diabetes mellitus with hypertension or Buerger's disease all had abnormal smoking tests.

Davis et al. (1953) studied 118 normal subjects and 82 patients with coronary artery disease. No changes occurred with smoking in 110 of the normal persons and 21 of the patients with coronary disease but with advancing age the incidence of positive tests increased in each group. In those aged less than 40 years, 27 of the 28 control subjects had normal tests but only five of the 14 patients with coronary disease behaved similarly. This study was later extended to include 252 healthy persons and 190 patients with coronary artery disease, (Davis et al., 1956). Negative tests were found in 155 healthy subjects and 47 of the patients with coronary disease. No abnormal initial pattern occurred in the ballistocardiograms of the normal subjects under 40 years of age but over the age of 50 years there was a rapid rise in the number of abnormal resting records although deterioration of the pattern ensued in less than 15 per cent. The patients with coronary artery disease showed a considerably higher incidence of abnormal initial records and of alteration in the pattern with smoking. Thus not only the presence of clinically evident coronary artery disease but also advancing age seemed to play a part in producing these ballistocardiographic abnormalities. On this account the authors suggested that for clinical purposes this technique was of most value in patients aged less than 50 years.

The effect of smoking on the ballistocardiograms of 100 high school youths from 14 to 18 years of age was studied by Kelly et al. (1954). All records were essentially normal before and after smoking. Similarly Simon et al.(1954) and Thomas et al. (1956) found no significant change in the form of ballistocardiograms of healthy young men and women after smoking.

Kuo and Joyner (1955) found that 11 of 14 patients with clinical evidence of coronary artery disease had negative smoking tests but they emphasised that almost all of these patients had very abnormal resting ballistocardiograms. They suggested that a marked degree of circulatory change would be required to cause significant deterioration in the pattern of such abnormal ballistocardiograms. Although these smoking tests were technically negative all the ballistocardiograms concerned showed a high degree of wave abnormality.

Buff (1955) reported that he had obtained positive smoking tests in apparently healthy younger subjects. In those between 20 and 30 years abnormal responses to smoking were found in four of 82 women and five of 112 men, while in those aged from 30 to 40 years there were 11 abnormal tests from 68 women and 22 from 138 men. These figures were essentially in agreement with the results of Strober (1956) who had studied more than 2,000 apparently healthy men of less than 40 years of age. Strober also found that as age advanced the proportion of abnormal records after smoking steadily increased and in addition noted a relationship between positive tests and obesity. Thomas and Murphy (1960) reported that 7.4 per cent. of the 245 students whose ballistocardiograms they recorded had abnormal or equivocal records after smoking two cigarettes. Their results are not strictly comparable with those of other authors.

4. Cause of ballistocardiographic changes after smoking.

The basic cause of the ballistocardiographic abnormalities that may occur after smoking is uncertain. It seems likely that there is an increase in the energy expenditure of the heart due to a rise in heart rate and blood pressure. Kelly (1960) stated, however, that ballistocardiographic wave abnormalities could appear before significant change in heart rate or blood pressure occurred. Russek et al. (1955) suggested that the effect of smoking on the ballistocardiogram was associated with increased peripheral resistance. They reported that alcohol, which produced peripheral vasodilatation, prevented the changes in about half of the subjects tested whereas glyceryl trinitrate (which they regarded as a coronary vasodilator) was ineffective. This observation was not confirmed by Davis (1960B), Kelly (1960) nor by Dock (1963) who all stated that trinitrin was effective in preventing or in reversing the ballistic wave abnormalities.

Kelly (1960) administered noradrenalin by intravenous infusion to 10 healthy subjects and 10 patients with abnormal smoking tests until the blood pressure equalled or slightly exceeded that found during the corresponding smoking tests. In no case was ballistocardiographic wave alteration observed. It was deduced that an increase in peripheral resistance alone was not the responsible factor. Kelly (1960) concluded that nicotine or smoking stressed the heart by producing both increased blood pressure and heart rate. The increased ventricular work and the resulting enhanced oxygen demand caused relative myocardial hypoxia in the susceptible subject, whose coronary arteries might be unable to dilate to meet the greater oxygen requirement. In these circumstances it was considered that the myocardium contracted ineffectively and produced abnormal ballistocardiograms (Kelly, 1960; Regan et al., 1960).

<u>Summary</u>.

The principal constituent of tobacco smoke is nicotine. The amount absorbed in the smoking of an ordinary cigarette is about 0.4 mg..

The association between tobacco smoking and angina pectoris was recognised in the nineteenth century. It was believed that nicotine might produce anginal pain by causing spasm of the coronary arteries. This view was not upheld by later experimental studies which showed that, whereas large doses of nicotine could cause coronary constriction in animals, the amount of nicotine contained in a cigarette tends to dilate normal coronary vessels in man.

Cigarette smoking has become the most important and widely used stress procedure in the field of ballistocardiography. A smoking test is considered to be positive if the ballistocardiogram becomes abnormal (or more abnormal if initially not normal) after the smoking of a cigarette. It is rare for a healthy person aged under 40 years to have a positive test but as age advances there is a steadily increasing incidence of positive tests in apparently healthy subjects. Patients with coronary artery disease show a significantly higher incidence of abnormal resting ballistocardiograms and also of alteration in the pattern with smoking.

The basic cause of this change in the ballistocardiogram with smoking is not certain but it has been suggested that as a result of increased heart rate and blood pressure the energy expenditure of the heart is increased. In the susceptible subject whose coronary arteries may be unable to dilate to meet the greater oxygen demand, the myocardium becomes hypoxic and contracts ineffectively, thus producing ballistocardiographic abnormalities.

PART II

Chapters 9 to 11

MATERIALS AND METHODS EMPLOYED
IN THE PRESENT STUDY.

Chapter 9.

SUBJECTS STUDIED, APPARATUS AND RECORDING METHOD.

1. Subjects Studied.

a. Groups of Subjects.

The subjects were divided into five groups:

i. Normal subjects.

ii. Patients with coronary artery disease.

iii. Patients with diabetes mellitus.

iv. Patients with thyrotoxicosis.

v. Patients with treated thyrotoxicosis, now euthyroid.

The normal subjects and the patients with coronary artery disease formed two groups of control subjects. They provided a normal and an abnormal series of ballistocardiograms with which the records of the other patients might be compared. The numbers, sex and ages of these subjects are shown in Table 1. Similar details of the other three groups of patients are shown in Table 2. These tables appear overleaf.

Sex and Age	Normal subjects	Coronary patients
M15 - 19	3	0
M20 - 29	43	4
M30 - 39	19	18
F15 - 19	10	0
F20 - 29	51	0
F30 - 39	33	4
TOTALS	159	26

Table 1. Numbers of normal subjects and patients with coronary disease, showing sex and age.

M = male, F = female.

Sex and age	Diabetic	Thyrotoxic	Euthyroid
M15 - 19	0	0	0
M20 - 29	11	0	0
M30 - 39	8	0	0
F15 - 19	3	9	8
F20 - 29	9	40	21
F30 - 39	6	44	37
TOTALS	37	93	66

Table 2. Numbers of diabetic, thyrotoxic and euthyroid patients, showing sex and age. M = male, F = female.

b. Presence of cardiovascular disease.

As far as possible the presence of independently existing cardiovascular disease was excluded from the normal control subjects, the patients with diabetes mellitus or thyrotoxicosis and the treated patients who were euthyroid. This was done in order to minimise or eliminate the occurrence of ballistocardiographic abnormalities not relevant to the issue being studied, namely the effect of the metabolic or endocrine disorder on the heart. In a similar way no patient with coronary artery disease was included if there was clinical evidence of a cardiac valvular lesion or of a metabolic or endocrine disturbance, since the object of studying this group was to observe the effect of ischaemic heart disease on the ballistocardiogram.

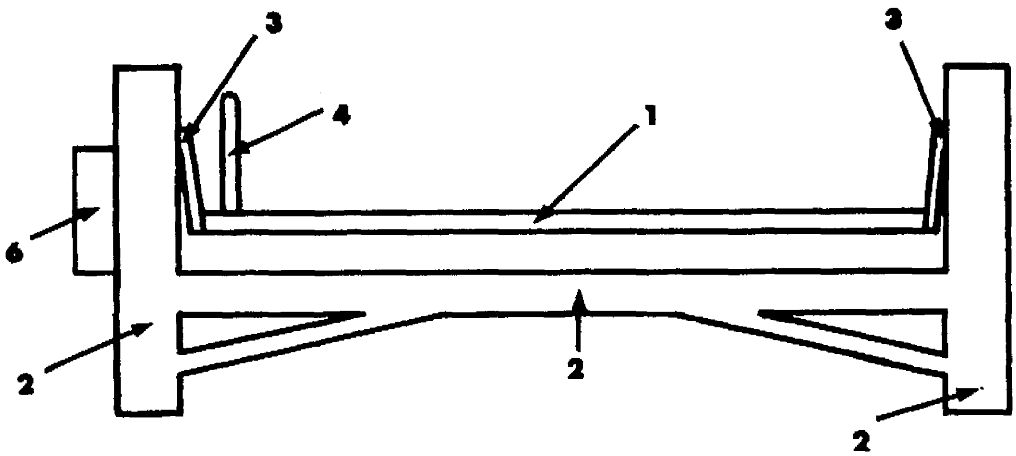
c. Age of subjects.

There is a progressive increase in the incidence of abnormal ballistocardiograms obtained from apparently healthy persons as their age increases beyond 40 years (Scarborough et al., 1953; Strober, 1956). It was suggested by Fulton et al. (1961) that ageing was a dominant factor in the production of abnormal records. In his clinical study Elsbach (1954) concentrated his attention on normal subjects and patients under 40 years of age. He did this in order to avoid the problem posed by uncertainty

Figure 10.

Schematic representation of the high-frequency ballistocardiograph. In the upper illustration, it is viewed from the side. In the lower figure, it is viewed from above.

1. The light rigid table on which the subject lies.
2. The heavy rigid and immobile outer steel framework.
3. The four steel springs.
4. The vertical footboard.
5. The transducer.
6. The amplifier.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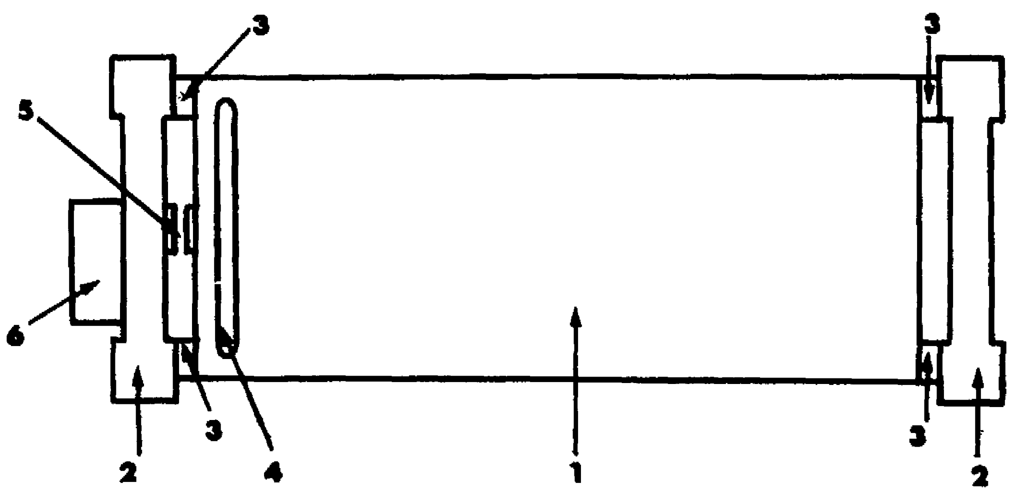
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regarding the significance of abnormalities in the records of older persons. It was for the same reason that no person aged 40 years or more was included in the present study.

Since the ballistocardiograms of healthy children under 15 years of age may be of relatively low amplitude, only subjects aged 15 years or more were included in the investigation.

2. The Ballistocardiograph.

The instrument used in this study was manufactured by Messrs Joyce, Loebl and Company Limited of Newcastle-on-Tyne. It was a table or bed ballistocardiograph of the Starr high-frequency type. Its main features are shown diagrammatically in Figure 10. It consisted of a light but rigid table, constructed from fibrous material braced by narrow metal strips. This was suspended from a heavy and virtually immobile outer steel framework by four strong vertical steel springs which were sited at each corner of the table. The powerful springs gave the apparatus a natural frequency of 14.5 cycles per second. They permitted only longitudinal movement which was detected by means of a transducer placed at one end of the platform. The output was amplified and led to the recording apparatus.

3. <u>The Recording Apparatus.</u>

This was a standard Philips Cardiopan-2 twin channel direct-writing electrocardiograph. The ballistocardiogram and lead 1 or lead 2 of the electrocardiogram could thus be recorded simultaneously.

4. <u>Recording of Ballistocardiograms.</u>

a. <u>Preparatory measures.</u>

Because the ingestion of food may alter the amplitude and contour of the ballistocardiogram (Paine and Shock, 1950; Berman et al.,1950; Buff, 1959) it has become customary to take records at least two hours after the previous meal. In a similar way cigarette smoking may produce alterations of the ballistocardiogram. This effect is usually short-lived and in most cases has disappeared within five or ten minutes. Occasionally the changes may persist for almost an hour. In the present study the subjects were asked not to eat or smoke during the two hours before their ballistocardiograms were recorded.

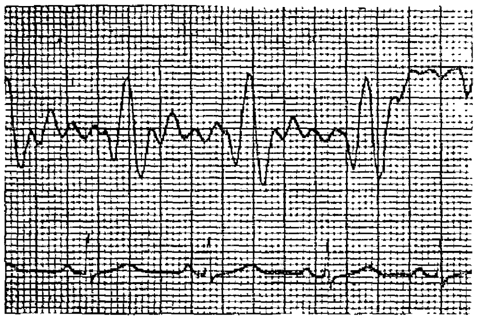
b. <u>Recording technique.</u>

Each subject lay on the bed of the instrument for at least 20 minutes in a warm and quiet room. Care was taken on every occasion that the subject's feet were pressed firmly

Figure 11.

The shift of the baseline of the ballistocardiogram by 10mm. when a force of 280 grammes is applied to the table.

This is the same illustration as Figure 6.



against the foorboard of the bed. The apparatus was then calibrated with the subject lying on the table. A force of 280 grammes was applied to the table and the controls were adjusted until it was seen that this force repeatedly deflected the baseline of the record by 1 cm. (Figure 11). Four such standardisations were carried out before and again after recording of the ballistocardiogram. If these were satisfactory the record was accepted but if not the apparatus was readjusted and further tracings were obtained. Lead 1 or lead 2 of the electrocardiogram was recorded simultaneously so that electrical and mechanical events might be correlated in time. When a satisfactory ballistocardiogram had been recorded the blood pressure and a standard 12-lead electrocardiogram were taken.

c. Smoking tests.

Ballistocardiograms were recorded in the way described above. The subject then smoked a standard cigarette in five to eight minutes while lying on the ballistocardiograph table. Immediately after the end of smoking the subject was again carefully positioned on the table with feet firmly placed against the footboard. The initial recording procedure was then repeated.

Summary.

The persons studied were apparently healthy normal subjects, patients with coronary artery disease and patients with diabetes mellitus, thyrotoxicosis or treated thyrotoxicosis. Because of the significant effect of age on the ballistocardiogram, only persons aged from 16 to 39 years were included in this investigation.

The apparatus was a table ballistocardiograph whose natural frequency was 14.5 cycles per second. The ballistocardiogram and electrocardiogram were recorded simultaneously, at least two hours after the previous meal or tobacco smoking. In some cases ballistocardiograms were taken before and after the smoking of a standard cigarette.

Chapter 10.

ASSESSMENT OF THE BALLISTOCARDIOGRAMS.

1. Qualitative Analysis.

a. General classification.

The contour of the ballistocardiogram was first inspected. Only regularly recurring abnormalities were considered significant. Sporadic departures from the normal pattern were regarded as artefacts and were disregarded. When there was doubt about the presence of abnormal complexes, the ballistocardiogram was regarded as being essentially normal in contour.

Henderson (1953) commented on certain difficulties in the classification of abnormal wave patterns. These difficulties undoubtedly exist but it is usually possible to devise a series of categories into which most abnormal wave contours can be placed.

Figure 12.

Diagrammatic representation of abnormal ballistocardiographic wave patterns. The abnormal patterns are shown in a solid line on the right of each diagram and in each case the normal pattern is also shown as a dotted line.

1. Normal pattern.
2. Early M pattern: prominent H wave and decreased J wave amplitude.
3. Late M pattern: deep notching of IJ segment to give a doubled J peak (J1 and J2).
4. Late downstroke pattern: HI and IJ segments are decreased in amplitude and the K wave is deepened.
5. Abnormal HI pattern: depth of I wave is decreased and amplitude of HI and IJ segments is decreased.

H
J
I
K
L
1.
2.
3.
J_1
J_2
4.
5.

b. <u>Abnormal ballistocardiographic patterns.</u>

In the present study, eight abnormal variants of the wave pattern were recognised. Some of these deviant contours have been described previously. The early M, late M and late downstroke patterns were first described by Starr et al. (1939) and the variant with short HI and IJ segments was first recognised by Henderson (1953). Truncation of the K wave, large late diastolic waves and the occurrence of completely bizarre patterns were noted by Pordy et al. (1951).

The aberrant ballistocardiographic patterns recognised in this study are shown schematically in Figures 12 and 13. In each case the normal pattern is also shown for comparison, first in a solid line and then in a broken line superimposed on the abnormal complex. The normal pattern is shown in Figure 12 as complex 1.

i. <u>Early M pattern.</u>

This is shown in Figure 12 as complex 2. It is characterised by an unduly tall or prominent H wave and usually also by a decrease in the amplitude of the J wave. Thus the height of the H wave approximates to, equals or occasionally exceeds that of the J wave. The HI and IJ segments are therefore almost equal in amplitude.

Figure 13.

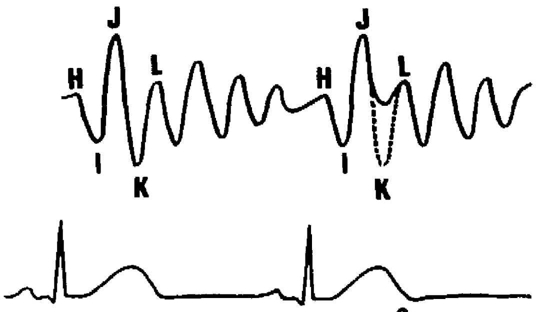
Diagrammatic representation of abnormal ballistocardiographic wave patterns. In each diagram the figure on the left shows the normal pattern and the figure on the right the abnormal pattern as a solid line with the normal pattern as a dotted line.

6. Short K pattern: depth of K wave is decreased.

7. Prominent L pattern: height of L wave equals or exceeds that of J wave.

8. Large diastolic wave pattern: a large headward deflection in late diastole.

9. Bizarre pattern: waves abnormal in contour and timing.



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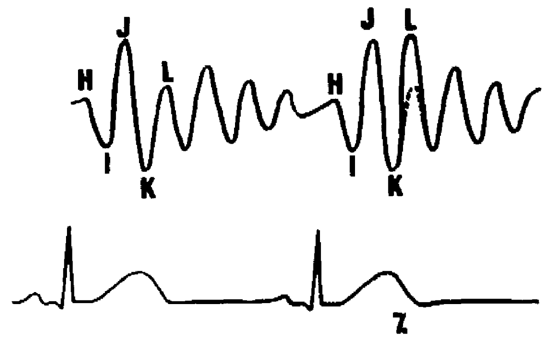

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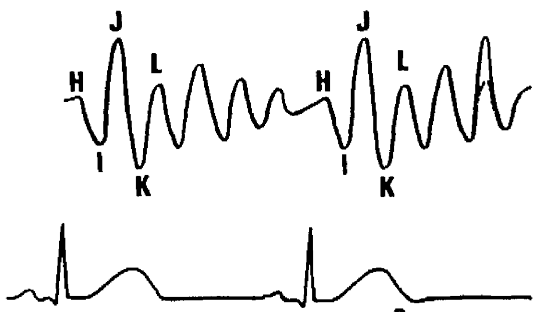

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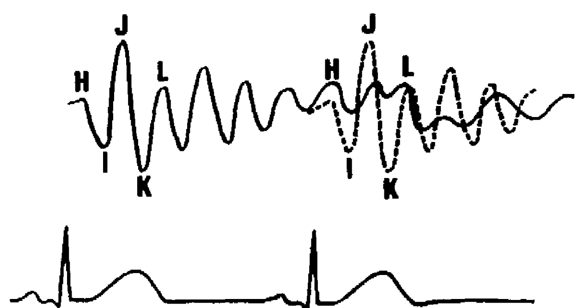


9.

ii. <u>Late M pattern</u>.

This pattern is illustrated as complex 3 in Figure 12. There is deep notching of the IJ segment to give a doubled J peak.

iii. <u>Late downstroke pattern</u>.

This pattern is shown in Figure 12, as complex 4. The HI and IJ segments are usually decreased in amplitude while the depth of the K wave is at least normal and often increased. Thus the JK segment is frequently increased in amplitude and becomes a prominent feature of the record.

iv. <u>Abnormal HI pattern</u>.

An example of the abnormal HI pattern is shown as complex 5 in Figure 12. The depth of the I wave is decreased. As a result the HI and the IJ segments are of less than usual amplitude but the normal height of the J wave peak is maintained. Occasionally the HI segment appears as a horizontal line and rarely this segment develops an upward instead of a downward slope.

v. <u>Short K pattern</u>.

This pattern is illustrated in Figure 13 as complex 6. There is appreciable shortening of the JK segment due to a decrease in the depth of the K wave. The J wave from which the segment descends is of normal height.

vi. Prominent L pattern.

This pattern is shown as complex 7 in Figure 13. The height of the L wave is increased and equals or exceeds that of the preceding J wave. Thus the KL segment equals or exceeds the JK segment in amplitude.

vii. Large diastolic wave pattern.

An example of this pattern is shown in Figure 13 as complex 8. There is a large headward deflection in late diastole. This wave is not described by any letter of the alphabet. Occasionally a deep footward deflection is seen in late diastole.

viii. Bizarre pattern.

An example of bizarre pattern is shown in Figure 13 as complex 9. There are alterations in several waves which may be abnormal in contour and timing. Occasionally the waves may be identifiable only by reference to a simultaneously recorded electrocardiogram. This is probably the most abnormal type of ballistocardiographic complex.

c. Classification of ballistocardiographic patterns.

i. Abnormal complexes.

On each occasion the ballistocardiogram was examined for the presence of these abnormal wave patterns. If the occurrence of abnormal contours was sufficiently consistent to make one consider the record definitely abnormal, the precise types of the deviant patterns were noted. Not infrequently several abnormal patterns were noted in a single record.

ii. Transitional complexes.

Complexes with contours that appeared transitional between the classical normal outline and one of the standard abnormal patterns described above were not uncommon. These were usually found in ballistocardiograms with both normal and clearly abnormal complexes, the latter occurring during expiration. Their presence did not influence the classification of abnormal records. Occasionally ballistocardiograms were found with a pattern that was normal except for regularly recurring transitional forms during expiration. It was considered that these were not definite abnormalities. Such ballistocardiograms were classified as equivocal records and were regarded as essentially normal in contour.

d. Grades of ballistocardiographic abnormality.

The degree of abnormality of the ballistocardiogram was determined essentially by the method of Brown et al. (1950).

This was modified in the way suggested in Chapter 6, that is provision was made for ballistocardiograms with abnormality of less than half the complexes. These grades are briefly described in Table 3. Grades 0 and 1 contained records with normal contour, while grades 2 to 4 contained increasingly abnormal ballistocardiograms. Equivocal ballistocardiograms were placed in grade 0 or grade 1, since they were regarded as essentially normal in form.

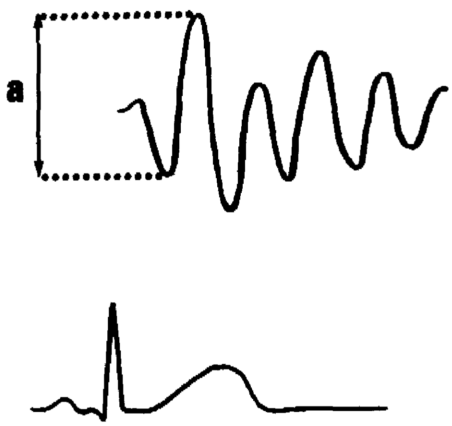
Grade	Description
0	Normal contour.
1	Normal contour with respiratory variation over 50 per cent.
2A	Less than half the complexes abnormal.
2B	More than half the complexes abnormal.
3	All complexes abnormal but well defined.
4	Totally abnormal complexes defined only by reference to electrocardiogram.

Table 3. Grades of severity of ballistocardiographic abnormality.

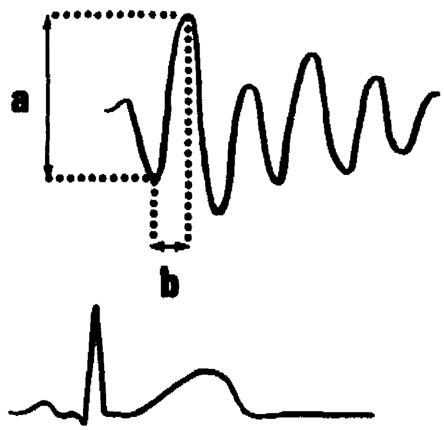
Figure 14.

The diagram on the left shows the method of measuring the amplitude of the IJ segment and the figure on the right shows measurement of the area of the theoretical triangle under the IJ segment of the ballistocardiogram.

This illustration is the same as Figure 7.



a = IJ Amplitude



$\frac{a \times b}{2}$ = IJ Area

2. <u>Quantitative Analysis</u>.

a. <u>Basic measurements</u>.

The upper edge of the tracing line was used as a "line of no thickness." Measurements of amplitude were made to the nearest 0.5 mm.. The duration of segments of the ballistocardiogram was measured in fractions of a second.

b. <u>Quantitative ballistocardiographic indices</u>.

In each ballistocardiogram, three typical large inspiratory complexes of consecutive respiratory cycles and the three corresponding small expiratory complexes were measured. From these results the mean values were calculated. Five indices were derived for each ballistocardiogram from these mean results. Certain facets of four of these indices were discussed in Chapter 6.

i. <u>Amplitude of the IJ segment</u>.

In three consecutive respiratory cycles, the IJ segments of typical large inspiratory and typical small expiratory complexes were measured to the nearest 0.5 mm. and the average value determined (Figure 14).

ii. <u>Area of the triangle under the IJ segment</u>.

This was calculated by multiplying the average IJ amplitude by the mean duration of the IJ segment and dividing

Figure 15.

The diagram illustrates the measurement of the "Ra" ratio of respiratory variation. The smaller figure on the left represents a typical expiratory complex and the larger figure on the right represents a typical inspiratory complex.

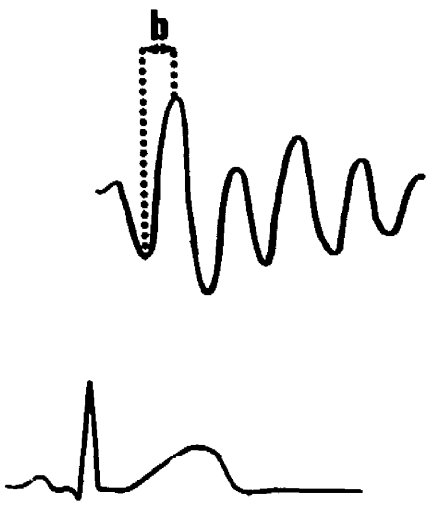
This illustration is the same as Figure 8.

$$\text{"Ra"} = \frac{ij}{IJ}$$

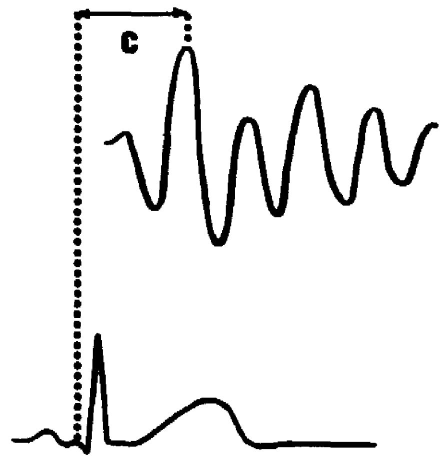
Figure 16.

The diagram on the left shows the method of measuring the duration of the IJ segment. The figure on the right shows measurement of the duration of the QJ interval.

This illustration is the same as Figure 9.



b= IJ Interval



c = QJ Interval

the result by 2. This value was expressed in mm. seconds (Figure 14).

iii. <u>Respiratory variation of the IJ segment</u>.

This ratio was obtained by expressing the mean amplitude of three small expiratory IJ segments from consecutive respiratory cycles as a decimal fraction of the mean amplitude of the three corresponding large inspiratory IJ segments, as shown in Figure 15, that is

$$\text{"Ra" ratio} = \frac{\text{Mean expiratory IJ amplitude}}{\text{Mean inspiratory IJ amplitude}}$$

This is the factor "Ra" described by Scarborough et al. (1953).

iv. <u>Duration of the IJ segment</u>.

The time interval between the tip of the I wave and the tip of the J wave was measured to the nearest 0.01 second in these six complexes and a mean value was calculated (Figure 16).

v. <u>Duration of the QJ interval</u>.

The duration of the time interval from the start of the Q wave (or R wave) in lead 1 or lead 2 of the electrocardiogram to the tip of the J wave in the ballistocardiogram was measured to the nearest 0.01 second in the six complexes and an average value was calculated (Figure 16).

c. Assessment of smoking test.

The essential feature of an abnormal or positive ballistocardiographic smoking test is that the record obtained after the smoking of a cigarette shows greater abnormality than the one taken before smoking (Henderson, 1953; Davis et al., 1953, 1956). This criterion applies whether the resting ballistocardiogram is normal or abnormal. Thus a positive test may be defined as one in which the ballistocardiogram becomes abnormal (or more abnormal if initially not normal) after the smoking of a cigarette. It may be difficult to be certain if increased abnormality has occurred when the resting ballistocardiogram is abnormal. The crucial point for decision is whether or not there has been a significant increase in the proportion of abnormal complexes in the record secured after smoking. In the present investigation the severity of the abnormality in the records taken before and after smoking was graded by the method of Brown et al. (1950) modified in the way described above. A test was considered positive if the degree of abnormality increased by one grade. An alteration from grade 2A to grade 2B was judged to constitute a positive response. A change from grade 0 to grade 1 was disregarded because no alteration in wave contour was involved, merely an increase in the amount of respiratory variation. It has been generally agreed (Henderson, 1953; Davis et al., 1953, 1956) that this constitutes an essentially negative test. These points are shown in Table 4.

Grade of resting ballistocardiogram	Grade of ballistocardiogram after smoking: Negative test	Grade of ballistocardiogram after smoking: Positive test
0	0 1	2A 2B 3 4
1	0 1	2A 2B 3 4
2A	0 1 2A	2B 3 4
2B	0 1 2A 2B	3 4
3	0 1 2A 2B 3	4
4	0 1 2A 2B 3 4	

Table 4. Grades of ballistic wave abnormality classified by modification of the method of Brown et al. (1950). Grades of resting ballistocardiograms and corresponding grades of records after smoking in positive and negative tests. Table allows for the theoretical possibility of ballistic wave improvement after smóking.

3. Use of Ballistocardiographic Indices.

The ballistocardiograms of the normal control subjects were examined in the way described above. The indices derived from these ballistocardiograms were used to provide normal standards by which the records obtained from the other groups could be assessed. The data from men and women were considered separately since the amplitude of men's ballistocardiograms is appreciably greater than that of women's.

The subjects in different age groups were also considered separately because advancing age affects some of the indices derived from ballistocardiograms. Thus subjects aged from 15 to 19 years, from 20 to 29 years and from 30 to 39 years were grouped in separate cohorts so that the records of persons of roughly equivalent age might be compared with one another. In this way ballistocardiograms of the various patients have been compared with those of their contemporaries in the normal control group, that is the comparative procedure of Scarborough et al. (1953) was followed.

Summary.

The ballistocardiograms were assessed by qualitative and quantitative methods.

They were judged to have normal, equivocal or abnormal contour. Eight categories of abnormal wave pattern were recognised.

Ballistocardiograms were considered abnormal when these aberrant complexes recurred regularly throughout the record. Several different abnormal patterns might be observed in a single ballistocardiogram. Equivocal ballistocardiograms were of two types. In one group, abnormal complexes were found intermittently and in the other transitional patterns were found to occur at regular intervals.

The degree of abnormality of ballistocardiograms was measured according to the proportion of abnormal complexes present in the record. Equivocal ballistocardiograms were placed in the normal grades.

Five quantitative indices were employed in the assessment of ballistocardiograms. These were the amplitude and area of the IJ segment, the degree of respiratory variation of the IJ segment and the duration of the IJ and QJ intervals. The methods of calculating thses indices are described.

Smoking tests were assessed on the degree of abnormality shown in the ballistocardiograms recorded before and after the smoking of a cigarette. An adverse change in the grade of abnormality of a ballistocardiogram after smoking constituted a positive test.

The ballistocardiograms of men and women were considered separately since men's records are usually of greater amplitude than women's. Age also affects the quantitative indices and the subjects were therefore divided into three age groups, 15 to 19 years, 20 to 29 years and 30 to 39 years, for assessment of their ballistocardiograms.

Chapter 11.

STATISTICAL METHODS.

1. Introduction.

The significance of the results was tested by statistical methods outlined by Bradford Hill (1959). The indices calculated were the mean, the standard deviation of the mean and the standard error of the difference between means. Differences between groups with dissimilar proportions of normal and abnormal results were assessed by Pearson's Chi-square test with Yates' modification for small numbers (Hill, 1959).

2. Qualitative Analysis.

Resting ballistocardiograms were graded as normal, equivocal or abnormal in contour. For the purpose of statistical analysis, only definitely and persistently abnormal records were classified as such. Normal and equivocal tracings were grouped together as essentially normal. There were thus two groups containing definitely abnormal and essentially normal records respectively.

The incidence of normal and abnormal records in the series of normal control subjects and in each group of patients was determined. Differences in the incidence of normal and abnormal records in the two groups being compared were assessed by means of the Chi-square test. When the factor of probability p was less than 0.05 the difference between the two groups was considered significant and when p was less than 0.01 it was held to be highly significant.

3. Quantitative Analysis.

a. Normal ranges.

In the case of four of the quantitative indices described in Chapter 10 the mean value was calculated. These indices were the IJ amplitude and area and the duration of the IJ and QJ intervals. Normal ranges for the present study were derived from the measurement of the ballistocardiograms of the normal subjects by calculation of the standard deviation of the mean of each index. The "normal range" for any index was then the range between its mean diminished by twice the standard deviation and the mean augmented by twice the standard deviation. This is the "normal range" which appears in the tables that follow in subsequent chapters. It is to be expected that if a series of ballistocardiograms is normal approximately 95 per cent of the results should fall within this "normal range."

b. Differences between means.

The significance of a difference between the mean values of an index measured in two groups of subjects was determined by calculation of the standard error of the difference between these mean values. If the difference observed between the mean values was more than twice the standard error of the difference between the means, it was regarded as significant and if more than three times the standard error it was considered highly significant.

4. The Assessment of Smoking Tests.

As in the case of the qualitative analysis of the resting ballistocardiograms, the smoking tests were graded as definitely abnormal or essentially normal, the latter group embracing the clearly normal and the equivocal tests. The incidence of abnormal tests was assessed in the two groups being compared and the probability that an observed difference was due to chance was calculated by the Chi-square test. When p was less than 0.05 the difference was held to be significant and when p was less than 0.01 it was considered highly significant.

Summary.

The significance of the results was tested by statistical methods.

Differences in the incidence of normal and abnormal ballistocardiograms in two groups of subjects being compared were assessed by means of Pearson's Chi-square test with Yates' modification.

The normal ranges of the quantitative ballistocardiographic indices were derived from the records of the normal control subjects by determination of the mean and the standard deviation of the mean of each index. The "normal range" was regarded as the range between the mean diminished by and augmented by twice the standard deviation.

Differences between mean values were assessed by calculating the standard error of the difference between these means.

Differences in the incidence of positive and negative smoking tests in two groups of subjects were assessed by the Chi-square test.

PART III

Chapters 12 to 15

THE CONTROL SERIES:

NORMAL SUBJECTS AND PATIENTS WITH CORONARY ARTERY DISEASE.

Chapter 12.

NORMAL CONTROL GROUP:

MATERIAL, METHOD AND RESULTS.

1. Subjects Studied.

There were 65 males aged from 16 to 39 years and 94 females aged from 16 to 39 years. These were apparently healthy persons drawn from hospital staff and medical students. As far as possible the presence of cardiovascular and endocrine disease was excluded from these subjects. The essential criteria for inclusion in the group were:

i. No history of rheumatic fever or chorea.

ii. No history of anginal or claudication pain.

iii. Clinically normal heart and peripheral pulses.

iv. Blood pressure less than 150/90.

v. No signs of cardiac failure.

vi. Normal electrocardiogram.

vii. No overt metabolic or endocrine abnormality.

The sex and age distribution of the subjects in this group are shown in Table 5.

Age (years)	Males	Females	Total
15-19	3	10	13
20-29	43	51	94
30-39	19	33	52
15-39	65	94	159

Table 5. Sex and age distribution of normal control subjects.

2. Recording of Ballistocardiograms.

a. Resting ballistocardiograms.

Each person refrained from food and tobacco for at least two hours before the ballistocardiogram was recorded. This was done after the subject had rested on the table for at least 20 minutes. Care was always taken that the subject's heels were placed firmly against the footboard. Once the ballistocardiogram was recorded the blood pressure and electrocardiogram were taken.

b. Ballistocardiogram after smoking.

Smoking tests were performed by 10 of the men aged from 19 to 37 years and 17 of the women aged from 21 to 39 years, all habitual smokers. Each smoked a standard cigarette in a period of five to eight minutes while lying on the ballistocardiograph. At the end of smoking the subject's heels were again placed against the footboard and the ballistocardiogram, blood pressure and electrocardiogram were recorded.

3. Assessment of Ballistocardiograms.

The wave contour of each ballistocardiogram was first inspected and the record was placed in the appropriate grade. Next, the IJ segments of typical large and typical small complexes from three consecutive respiratory cycles were measured and the five indices were calculated.

i. Amplitude of IJ segment.

ii. Area of triangle under IJ segment.

iii. Respiratory variation of IJ segment.

iv. Duration of IJ segment.

v. Duration of QJ interval.

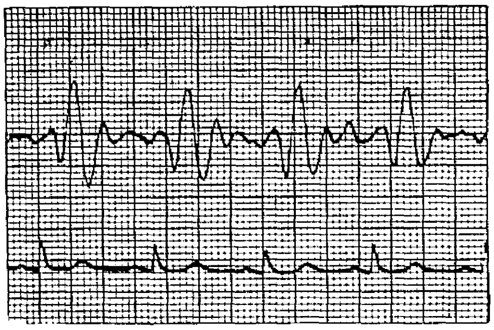
Normal standards for the ballistocardiograph used in this study were evolved from these indices. It has been generally recognised that each instrument yields absolute quantitative results that differ more or less from those of other ballisto-cardiographs of the same basic type. In each case appropriate normal standards may be derived from analysis of the ballisto-

Figure 17.

Ballistocardiograms of normal control women, aged 17, 23,23,29,29 and 35 years respectively.

All records are normal.

This is the same illustration as Figure 3.



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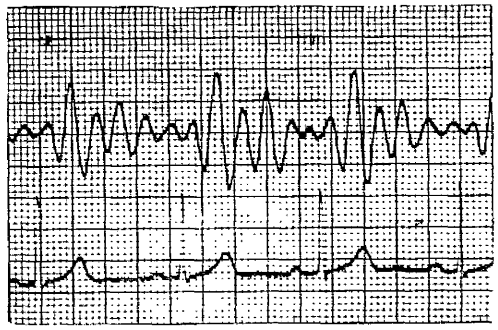

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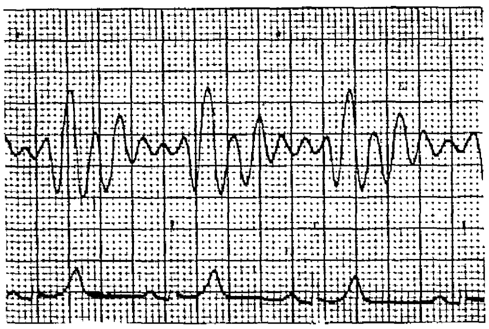

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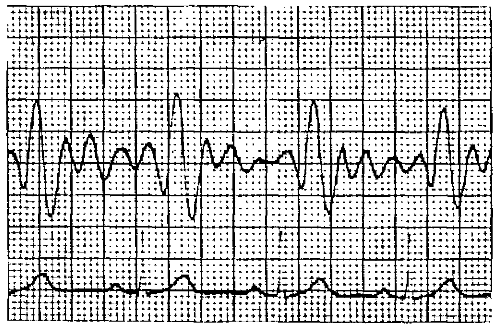

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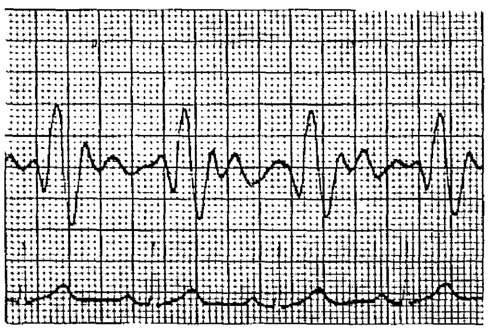

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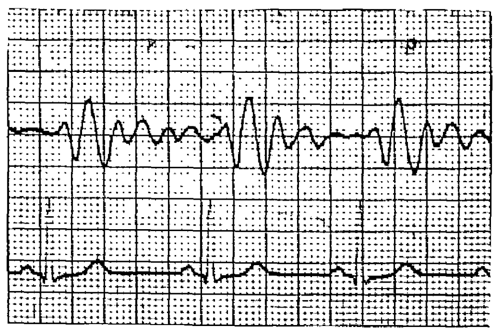


6.

cardiograms of normal subjects examined with the instrument.

4. Results.

a. Qualitative analysis.

All ballistocardiograms were entirely normal in form and were placed in grade 0. Figure 17 shows typical examples.

b. Quantitative analysis.

i. Amplitude of IJ segment.

The observed ranges and mean amplitudes of the IJ segment in the records of the normal subjects are shown in Table 6.

Sex and Age (years)	No.	Observed range (mm).	Mean (mm).	S.D. (mm).	Normal range (mm).
M15-19	3	18.1-23.6	21.3	2.75	15.8-26.8
M20-29	43	13.8-27.2	20.6	3.5	13.6-27.6
M30-39	19	12.5-20.0	16.9	1.95	13.0-20.8
F15-19	10	11.8-15.3	13.1	0.9	11.3-14.9
F20-29	51	7.9-15.9	13.2	1.85	9.5-16.9
F30-39	33	8.0-15.2	11.8	1.7	8.4-15.2

Table 6. Amplitude of IJ segment (mm). in normal subjects, with observed ranges, means, standard deviations (S.D.) and calculated normal ranges. M = males, F = females.

The calculated normal ranges were derived from the mean values augmented and decreased by two standard deviations. All but six results (3.8 per cent) were within the normal ranges.

ii. Area under IJ segment.

The observed ranges and mean values of the area under the IJ segment are shown in Table 7.

Sex and Age (years)	No.	Observed range (mm.sec.)	Mean (mm.sec.)	S.D.	Normal range (mm.sec.)
M15-19	3	.80-1.02	.90	.09	.72-1.08
M20-29	43	.59-1.22	.89	.165	.56-1.22
M30-39	19	.53- .85	.69	.085	.52- .86
F15-19	10	.53- .65	.59	.035	.52- .66
F20-29	51	.34- .71	.56	.09	.38- .74
F30-39	33	.27- .62	.48	.09	.30- .66

Table 7. Area under IJ segment (mm.sec.) in normal subjects, with observed ranges, means, standard deviations (S.D.) and calculated normal ranges. M = male, F = female.

The normal ranges were derived from the mean values decreased and augmented by two standard deviations. All but four results (2.5 per cent) fell within these normal limits.

iii. Respiratory variation of IJ segment.

The degree of respiratory variation was expressed as the "Ra" ratio. As the degree of respiratory variation increases the value of "Ra" becomes less. The ranges shown in Table 8 represent the observed scatter of results.

Sex and Age (years)	No.	Observed range ("Ra")	Mean ("Ra")
M15-19	3	.62-.81	.73
M20-29	43	.53-.92	.77
M30-39	19	.57-.82	.69
F15-19	10	.74-.88	.81
F20-29	51	.54-.91	.79
F30-39	33	.51-.86	.73

Table 8. "Ra" ratio in normal subjects, with observed ranges and mean values. M = male, F = female.

A value for "Ra" of 0.50 or more is generally accepted as normal. Thus the calculation of normal ranges from the mean and standard deviation was unnecessary in the case of this index. All results obtained from the records of the normal subjects were within the normal range.

iv. Duration of IJ segment.

The observed ranges and mean values of the duration of the IJ segment are shown in Table 9.

Sex and age (years)	No.	Observed range (sec.)	Mean (sec.)	S.D.	Normal range (sec.)
M15-19	3	.082-.088	.085	.003	.079-.091
M20-29	43	.080-.102	.089	.0055	.078-.100
M30-39	19	.071-.090	.082	.0055	.071-.093
F15-19	10	.085-.097	.090	.0035	.083-.097
F20-29	51	.075-.094	.085	.003	.079-.091
F30-39	33	.068-.092	.081	.007	.067-.095

Table 9. Duration of IJ segment (sec.) in normal subjects with observed ranges, means, standard deviations (S.D.) and calculated normal ranges. M = male, F = female.

The normal ranges were derived from the means augmented and decreased by twice the standard deviation. All but five results (3 per cent) fell within the normal range.

v. Duration of QJ interval.

The observed ranges and mean values of the QJ interval are shown in Table 10.

Sex and age (years)	No.	Observed range (sec.)	Mean (sec.)	S.D. (sec.)	Normal range (sec.)
M15-19	3	.235-.278	.262	.023	.216-.308
M20-29	43	.233-.295	.261	.013	.235-.287
M30-39	19	.228-.263	.246	.011	.224-.268
F15-19	10	.232-.277	.260	.014	.232-.288
F20-29	51	.230-.267	.249	.009	.231-.267
F30-39	33	.218-.262	.240	.011	.218-.262

Table 10. Duration of QJ interval (sec.) in normal subjects, with observed ranges, means, standard deviations (S.D.) and calculated normal ranges. M = male, F = female.

The normal ranges were calculated from the mean augmented and decreased by two standard deviations. All but three results (1.9 per cent) were in the normal range.

c. Smoking tests.

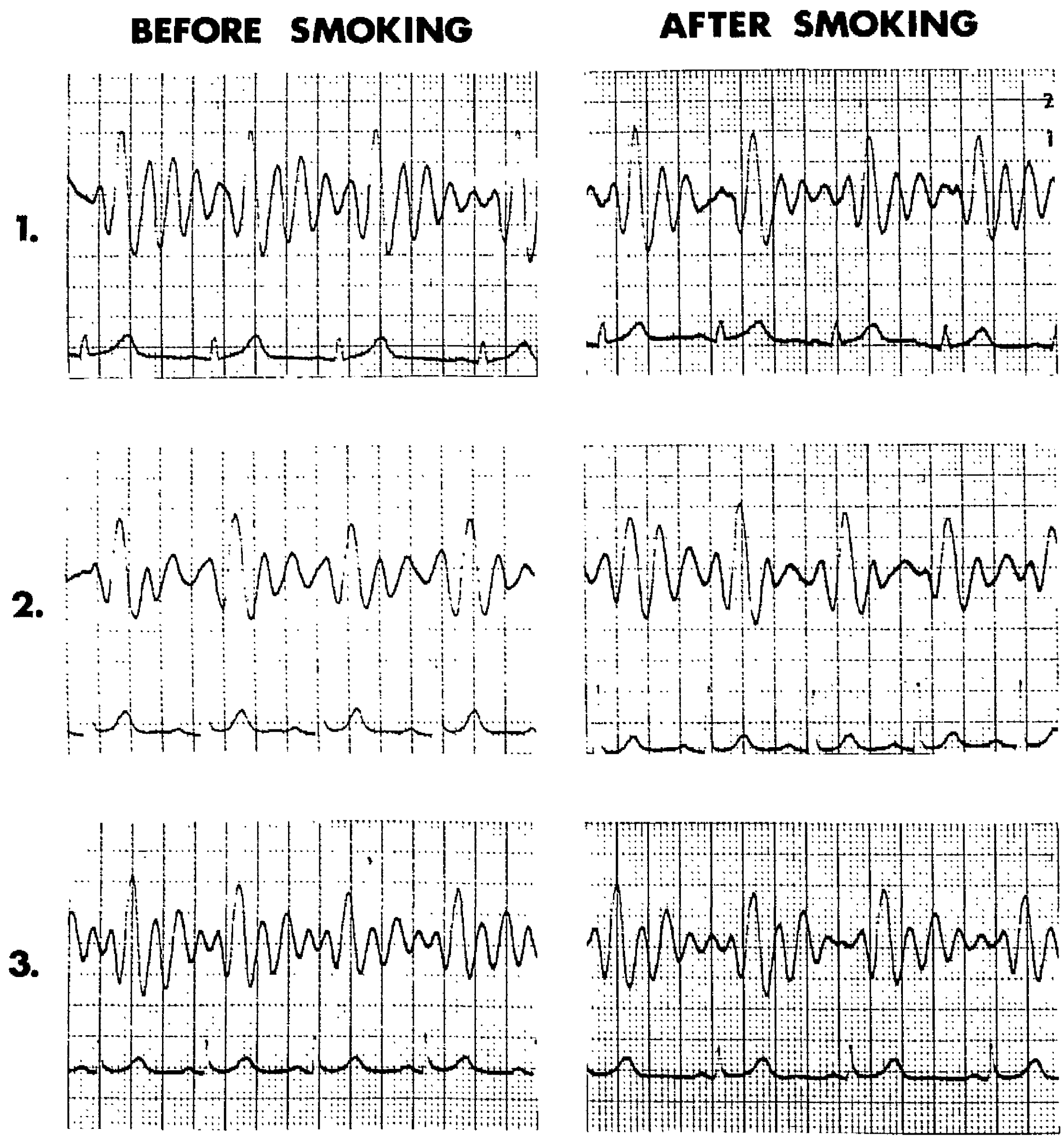
The results of the smoking tests performed by the normal

Figure 18.

Smoking tests in normal subjects.

1. Male, 25 years.
2. Female, 21 years.
3. Female, 25 years.

All ballistocardiograms were grade 0 before and after smoking and all three tests were negative.


BEFORE SMOKING
AFTER SMOKING
1.
2.
3.
2
1

subjects are summarised in Table 11. There were no positive or abnormal smoking tests. Figure 18 shows examples.

Result of test	Males	Females	Total
Negative	10	17	27
Positive	0	0	0

Table 11. Results of smoking tests in 27 normal subjects aged from 19 to 39 years.

These tests are detailed in the Appendix (Tables A and B).

Transient abnormalities of wave contour may occur in the ballistocardiogram just after the end of smoking. These short-lived deviations from normal form may be artefacts but it may be difficult to decide this point. In two normal subjects, a man aged 37 years and a woman aged 39 years, transient wave abnormalities were found. Thus these two records secured after smoking were classified as equivocal but placed in grade 0. These smoking tests were therefore regarded as essentially negative.

An increase in the amount of respiratory variation often occurs with smoking. This was found in eight of the 10 men and 11 of the 17 women. In the case of one man aged 21 years the degree of respiratory variation was increased so that the "Ra" ratio was less than 0.50 after smoking. The grade of the ballistocardiogram therefore changed from 0 to 1 but this did not constitute a positive smoking test because there was no change in wave contour.

Summary.

Ballistocardiograms taken at rest at least two hours after the previous meal and tobacco smoking from 65 males and 94 females, all apparently healthy and aged from 16 to 39 years, were analysed qualitatively and quantitatively.

All records had normal wave contour. The amplitude and duration of the IJ segment were related to sex and age. With an increase in age there was a decrease in the amplitude, area and duration of this segment and in the QJ interval, while the degree of respiratory variation was increased. The ballisto-cardiograms of men showed greater IJ amplitude and area and slightly longer IJ and QJ intervals than those of women but the degree of respiratory variation was the same in both sexes.

Normal standards were evolved from these results for the ballistocardiograph used in the present study.

Ballistocardiograms of 10 men and 17 women aged from 19 to

39 years were examined before and after the smoking of a standard cigarette. There were no positive smoking tests. In two cases there were transient abnormalities which rendered the records equivocal but the grade of abnormality was unchanged in each case and these tests were therefore negative. In one case the degree of respiratory variation increased beyond the normal limit but the contour of the record remained normal and this test was also considered negative.

Chapter 13.

NORMAL CONTROL GROUP: DISCUSSION OF RESULTS.

1. Qualitative Analysis.

The uniformly normal wave contour that was observed in this study is to be expected in a series of ballistocardiograms from a young and healthy population. Henderson (1953) found that the resting ballistocardiograms of 40 subjects aged between 20 and 40 years were all normal. Scarborough et al. (1953) examined the ballistocardiograms of 137 healthy persons aged from 20 to 39 years and found that all were normal except for one equivocal record. Davis et al (1956) found two equivocal ballistocardiograms in a series of 70 from normal subjects of this age group. All other records were entirely normal.

These three series were chosen for comparison because of the similar age groups studied and also because the ballistocardiographs employed were of high-frequency type similar to that used in the present study. If these series are combined they provide ballistocardiograms from 247 healthy subjects aged from 20 to 39 years. None of these subjects had definitely abnormal records. There were 244 normal ballistocardiograms and three equivocal records. This is in close agreement with the present result.

It may therefore be suggested that if a person aged under 40 years has a definitely abnormal ballistocardiogram this is an unexpected and probably significant finding.

2. Quantitative Analysis.

a. Amplitude of IJ segment.

The results of the present study confirmed previous reports that the IJ amplitude is influenced by sex and age.

i. Effect of sex on IJ amplitude.

From an analysis of 243 ballistocardiograms of normal persons Scarborough et al. (1953) deduced that the average IJ amplitude of women's ballistocardiograms was 67 per cent of that of men's. In those aged from 20 to 39 years the equivalent result was 64 per cent. Starr (1955) quoted the figure of 60 per cent for persons aged between 20 and 40 years. In the present study the mean amplitude of the women's ballistocardiograms was 65 per cent of that of the men's.

It has not been found that variation in body size accounts for this difference between the sexes. Starr (1955) suggested that it was due to women's hearts being weaker than men's, not because women are smaller but for some more subtle reason not clearly understood.

This relative lack of muscular strength in women compared with men is not confined to the heart. Astrand (1952) found that the potential muscular energy, as judged by the oxygen intake per unit of body weight, was appreciably less in women than in men, being about 70.6 per cent of that of the male in adult life. Further, when a less than maximal work load was performed, women's hearts beat more rapidly than men's (Metheny et al., 1942; Astrand, 1956). When these two factors are combined it is found that a given amount of physical work may require 50 per cent of a man's energy capacity but about 75 per cent of a woman's full potential energy (Astrand, 1956). The power of arm flexion and extension in women has been estimated to be about 75 to 80 per cent (Ufland, 1933) or 53 to 60 per cent (Hettinger, 1953) of that of men. Schochrin (1934) found that the relative figure for leg strength was 70 per cent. Hand and back strength in women was found to be 60 per cent of that of men by Reijs (1921) and Cullumbine et al. (1950) found that women could lift maximum loads of 60 per cent of those raised by men. These figures are in reasonably close agreement with the ballistocardiographic findings which suggest that women's hearts are about 60 to 65 per cent as strong as men's.

ii. Effect of age on IJ amplitude.

A decrease in the IJ amplitude as age advanced was observed in the present study. This was in agreement with the report of Scarborough et al. (1953). The relevant results of that study and the present one are compared in Table 12.

Sex and age (years)	Scarborough et al. (mm.)	Present study (mm.)
M20-29	21.9	20.6
M30-39	20.2	16.9
F20-29	13.8	13.2
F30-39	12.9	11.8

Table 12. Mean IJ amplitudes (mm.) in ballistocardiograms of normal males (M) and females (F). Results of Scarborough et al. (1953) compared with those of present study.

There are fairly consistent differences between the mean amplitudes found in each group but variations of this order are to be expected. Although the static calibration of the two ballistocardiographic beds was the same, differences such as variation in the weight of the platform and in the natural frequency of the apparatus inevitably affect the precise quantitative measurements of the records they yield. There were probably other unidentified factors.

The difference in the amplitude of men's and women's records has been attributed to a lesser degree of cardiac muscular power in women, whose potential muscular energy as judged by their oxygen intake per unit of body weight was about 70 per cent that of men (Astrand, 1952). In a similar way there is a decline in ballistocardiographic amplitude with increasing age, which may be related to the decrease in oxygen uptake that Robinson (1938) found to occur as age increased. Peak muscular strength occurs at an age of 20 to 30 years (Astrand, 1956) and this is the age at which maximum ballistocardiographic amplitude is usually found. Thus the decreasing amplitude of the ballistocardiogram probably reflects a lessening of the force of ventricular ejection as age increases.

b. Area under IJ segment.

As in the case of the IJ amplitude, variations in IJ area occurred with differences in sex and age. The mean IJ area value for the women was 64 per cent of that of the men. This figure is almost identical to the equivalent result for the IJ amplitude, namely 65 per cent. The decline in area value with age occurred separately in each sex. Starr (1955) published regression equations that would lead one to expect this result.

c. Respiratory variation of IJ segment.

There was no significant difference between the sexes in the degree of respiratory variation. There was, however, a tendency for the amount of variation to increase with age. These findings were in keeping with previous reports and agreed closely with the results of Scarborough et al. (1953).

d. Duration of IJ segment.

There was a general tendency for the duration of the IJ segment to lessen as age increased. This might be related to increased aortic rigidity in older persons and a consequently more rapid pulse wave. The exception was the small group of males aged from 15 to 19 years. Their number was too small for this to be significant. The difference between men and women was slight but was possibly related to body size and the length of the aorta.

e. Duration of QJ interval.

There was again a general tendency for the duration of the QJ interval to decrease as age advanced, possibly associated with greater vascular rigidity and increased velocity of the pulse wave. The difference between men and women was slight but was possibly related to body size and the length of the aorta.

3. Smoking Tests.

The uniformly negative smoking tests that were observed in this study are to be expected from a young and apparently healthy population. Henderson (1953) found no positive tests in 50 similar subjects. Davis et al. (1953) found that 27 of 28 normal subjects had normal tests. Kelly et al. (1954) examined 100 youths aged from 14 to 18 years and obtained normal records before and after smoking in every case. There were similar reports from Simon et al. (1954) and Thomas et al. (1956).

It may therefore be suggested that if a young person has a positive smoking test it is probably of some significance.

Summary.

The uniformly normal wave contour of the resting ballistocardiograms was in keeping with previous reports.

The observation that the amplitude of women's ballistocardiograms was less than that of men's was also consistent with earlier findings. Variations in body size do not account fully for the difference which may be related to a relative lack of muscular strength in women.

The effect of age in decreasing IJ amplitude was also in agreement with previous studies and may be related to a decline in the strength of the heart as age advances.

Sex and age had similar effects on the area under the IJ segment.

The decrease in the duration of the IJ and QJ segments as age advanced might be related to increased vascular rigidity and a consequently more rapid pulse wave in older subjects.

The uniformly negative smoking tests were essentially in keeping with the results of earlier studies. A positive smoking test in a young person is probably a significant finding.

Chapter 14.

PATIENTS WITH CORONARY ARTERY DISEASE: MATERIAL, METHOD AND RESULTS.

1. Subjects Studied.

a. Patients with myocardial infarction.

There were 18 men and two women aged from 27 to 39 years. All patients had been admitted to the hospital wards on account of myocardial infarction five or six weeks before the recording of the ballistocardiogram. The essential criteria for the diagnosis of myocardial infarction were:

i. History suggestive of cardiac pain, usually lasting more than half an hour, and frequently much longer.

ii. Characteristic electrocardiographic patterns : in 12 cases pathological Q waves and sequential changes in the STT segments and in eight cases sequential changes in the STT segments alone.

iii. Temporary increase in the erythrocyte sedimentation rate.

iv. In 15 cases, a short-lived increase in the serum transaminase levels.

b. <u>Patients with angina pectoris.</u>

There were four men and two women aged from 28 to 39 years with angina pectoris but no evidence of myocardial infarction. The diagnosis in each case was based on a classical history of chest pain related directly to exertion and sometimes provoked by emotion. In four cases the electrocardiogram taken at rest was normal and in two cases there were T wave abnormalities of ischaemic type.

c. <u>All patients with coronary artery disease.</u>

For the purpose of ballistocardiographic study Davis et al. (1956) combined these two groups of patients because their ballistocardiographic patterns did not differ appreciably. The same procedure was adopted in the present study. In addition to the diagnostic features mentioned above, the essential criteria for inclusion in the group were:

i. No history of rheumatic fever or chorea.

ii. No cardiac murmurs.

iii. Normal peripheral pulses.

iv. Blood pressure less than 150/90.

v. No signs of cardiac failure.

vi. No overt metabolic or endocrine abnormality.

The sex and age distribution of the patients are shown in Table 13.

Age (years)	Males	Females	Total
20-29	4	0	4
30-39	18	4	22
20-39	22	4	26

Table 13. Sex and age distribution of patients with coronary artery disease.

2. Recording of Ballistocardiograms.

a. Resting ballistocardiograms.

Each patient refrained from food and tobacco for at least two hours before the ballistocardiogram was taken. After the patient had lain for 20 minutes on the table, the record was secured and the blood pressure and electrocardiogram were then taken.

b. Ballistocardiograms after smoking.

Smoking tests were undertaken by 16 men aged from 28 to 39 years and three women aged from 33 to 39 years, all habitual smokers. A standard cigarette was smoked in a period of five to eight minutes. The patient was then repositioned on the table and the ballistocardiogram, blood pressure and electrocardiogram were taken once more.

3. <u>Assessment of the Ballistocardiogram</u>.

The wave contour of each ballistocardiogram was assessed and the record was classified as normal, equivocal or abnormal. The records were then graded from 0 to 4, in degrees of abnormality. The IJ segments of three typical large inspiratory and the corresponding three small expiratory complexes were measured and these indices were derived:

i. Amplitude of IJ segment.

ii. Area of triangle under IJ segment.

iii. Respiratory variation of IJ segment.

iv. Duration of IJ segment.

v. Duration of QJ interval.

4. <u>Results</u>.

a. <u>Qualitative analysis</u>.

Of the 26 resting ballistocardiograms, 10 were normal, four were equivocal and 12 were clearly abnormal in contour (Table 14).

Form of record	Males	Females	Total
Normal	8	2	10
Equivocal	4	0	4
Abnormal	10	2	12

Table 14. Distribution of normal, equivocal and abnormal ballistocardiograms of patients with coronary artery disease.

The incidence of abnormal ballistocardiograms in the patients with coronary disease was 46 per cent compared with none in those of the normal subjects. This difference was highly significant (p less than 0.001).

The grades of abnormality of the records are shown in Table 15.

Grades	Males	Females	Total
0	10	2	12
1	2	0	2
2A	6	1	7
2B	4	1	5
3 and 4	0	0	0

Table 15. Grades of abnormality of ballistocardiograms of patients with coronary artery disease.

All twelve records with abnormal wave contour were placed in grade 2, seven in grade 2A and five in grade 2B. One of the records from the men with normal contour and one record from the men with equivocal contour had a degree of respiratory variation greater than 50 per cent. These two records were thus placed in grade 1. The other three equivocal records were placed in grade 0. No records were sufficiently abnormal to be classified as grade 3 or grade 4.

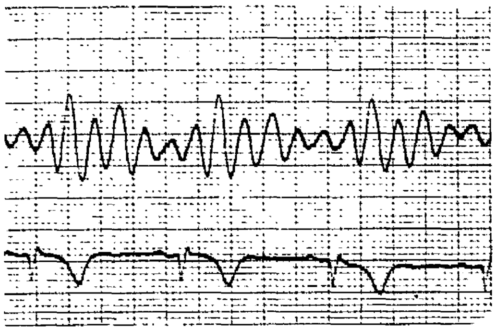
Type of abnormality	Males	Females	Total
1. Early M	7	1	8
2. Late M	3	1	4
3. Late downstroke	2	0	2
4. Abnormal HI	4	0	4
5. Short K	8	1	9
6. Prominent L	2	0	2
7. Large diastolic waves	3	0	3
8. Bizarre complexes	4	1	5

Table 16. Categories and distribution of abnormal wave contour in the 12 abnormal resting ballistocardiograms of the patients with coronary artery disease.

Figure 19.

Ballistocardiograms of patients with coronary artery disease.

1. Male, 32 years: normal pattern.
2. Male, 38 years: 2nd complex from left shows prominent L pattern, 3rd shows short K pattern and 4th is a bizarre complex.
3. Male, 39 years: 1st complex shows early M pattern and the 2nd, 3rd and 4th show combined early and late M patterns.
4. Male, 38 years: all complexes show large diastolic waves in bizarre complexes.
5. Male, 39 years:1st complex shows late M pattern and 2nd complex shows early M pattern.
6. Male, 39 years: 2nd complex shows short K pattern and 3rd shows late downstroke pattern.



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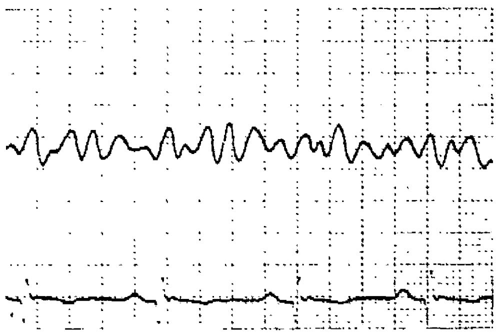

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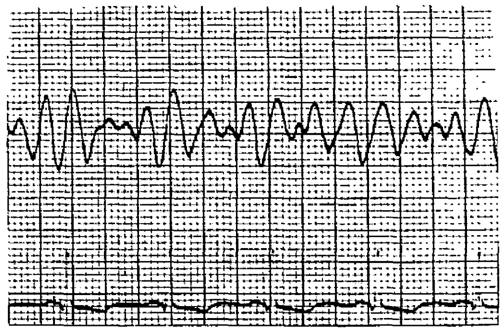

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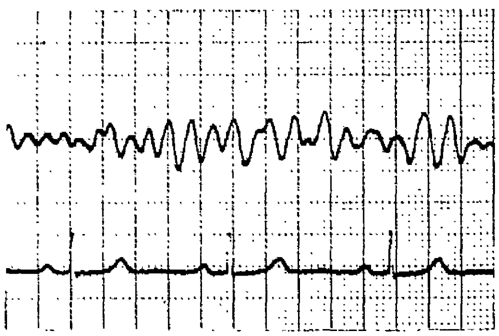

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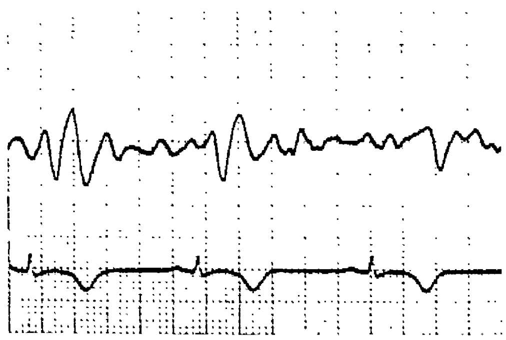

6.

Table 16 on the previous page summarised the variety of wave patterns that were observed in the twelve abnormal resting ballistocardiograms. Examples are shown in Figure 19. More than one type of wave abnormality might be present in a single ballistocardiogram.

b. Quantitative analysis.

i. Amplitude of IJ segment.

The amplitude results in the records of the patients with coronary artery disease are shown in Table 17.

Sex and age (years)	No.	Observed range (mm.)	Mean (mm.)	S.D. (mm.)	Normal range (mm.)
M20-29	4	9.0-15.4	13.1	2.8	13.6-27.6
M30-39	18	5.3-18.3	11.3	3.8	13.0-20.8
F30-39	4	2.8-14.3	9.0	4.7	8.4-15.2

Table 17. Amplitude of IJ segment (mm.) in patients with coronary artery disease, with ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison.

M = males, F = females.

There was a trend to low amplitude values in the records of the patients with coronary artery disease.

The statistical significance of the difference in the mean IJ amplitude between the group with coronary disease and the normal control group was tested only in the case of men aged from 30 to 39 years, becuase there were only four patients with coronary disease in each of the other two subgroups, namely men aged in their twenties and women in their thirties. The difference was highly significant (Table 18).

Coronary patients			Normal subjects			S.E.	Difference of means / S.E.
No.	Mean	S.D.	No.	Mean	S.D.		
18	11.3	3.8	19	16.9	1.95	1.61	3.48

Table 18. Significance of difference of mean IJ amplitude in men with coronary disease and normal men, aged 30 to 39 years. S.D. = Standard deviation. S.E. = Standard error of difference between means. Results in mm.

Ballistocardiograms with IJ amplitude of less than the normal range were obtained from 14 (54 per cent) of the patients with coronary artery disease. The difference between this group of records and those of equivalent normal subjects was highly significant (p less than 0.001.)

ii. Area under IJ segment.

The IJ area results are shown in Table 19.

Sex and age (years)	No.	Observed range (mm.sec.)	Mean (mm.sec.)	S.D. (mm.sec.)	Normal range (mm.sec.)
M20-29	4	.43-.67	.59	.105	.56-1.22
M30-39	18	.20-.75	.45	.18	.52- .86
F30-39	4	.10-.55	.34	.185	.30- .66

Table 19. Area under IJ segment (mm.sec.) in patients with coronary disease with ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison. M = males, F = females.

Table 20 compares the mean IJ area in the males aged from 30 to 39 years with the normal counterpart.

Coronary patients			Normal subjects			S.E.	Difference of means / S.E.
No.	Mean	S.D.	No.	Mean	S.D.		
18	.45	.18	19	.69	.085	.047	5.11

Table 20. Significance of difference of mean IJ area in men with coronary disease and normal men aged 30 to 39 years. S.D.= Standard deviation. S.E.= Standard error of difference between means. Results in mm.secs..

There was a trend to low IJ area values in the ballistocardiograms of the patients with coronary disease. The mean IJ area of the records of the patients with coronary disease aged from 30 to 39 years differed significantly from that of the equivalent normal subjects (Table 20). The other patients were not compared with their normal contemporaries because of the small numbers with coronary disease.

Fourteen of the patients with coronary disease had ballistocardiograms with IJ area of less than the normal range. The difference in the incidence of low IJ area results between this group of records and those of the normal subjects was highly significant (p less than 0.001).

iii. Respiratory variation of IJ segment.

This was expressed as the "Ra" ratio. The results are summarised in Table 21, which is shown overleaf.

The standard value of 0.50 or more was accepted as normal. Six of the men aged from 30 to 39 years had ballistocardiograms with abnormally large amounts of respiratory variation but the other 20 patients with coronary artery disease had normal "Ra" ratios. Thus 23 per cent of this group of patients had abnormal "Ra" ratios compared with none of the normal subjects. This difference was highly significant (p less than 0.001).

Sex and age (years)	No.	Observed range ("Ra")	Mean ("Ra")	Normal range ("Ra")
M20–29	4	.62–.87	.72	.50–1.00
M30–39	18	.17–.81	.57	.50–1.00
F30–39	4	.62–.83	.73	.50–1.00

Table 21. Degree of respiratory variation ("Ra" ratio) in patients with coronary disease with observed ranges, mean values and normal ranges for comparison. M = males, F = females.

iv. <u>Duration of IJ segment.</u>

The results are summarised in Table 22.

Sex and age (years)	No.	Observed range (sec.)	Mean (sec.)	S.D.	Normal range (sec.)
M20–29	4	.080–.095	.090	.007	.078–.100
M30–39	18	.068–.106	.081	.011	.071–.093
F30–39	4	.070–.077	.074	.0025	.067–.095

Table 22. Duration of IJ segment (sec.) in patients with coronary disease, with ranges, means, standard deviations (S.D.) and normal ranges for comparison. M = males, F = females.

There was no significant difference between the mean IJ interval in the ballistocardiograms of the men aged from 30 to 39 years with coronary disease and that of the equivalent normal men (Table 23).

Coronary patients			Normal subjects			S.E.	Difference of means / S.E.
No.	Mean	S.D.	No.	Mean	S.D.		
18	.081	.011	19	.082	.0055	.0029	0.34

Table 23. Significance of difference of mean duration of IJ segment in men with coronary disease and normal men aged 30 to 39 years. S.D. = Standard deviation. S.E. = Standard error of difference between means. Results in sec..

v. Duration of QJ interval.

The results are summarised in Table 24.

Sex and age (years)	No.	Observed range (sec.)	Mean (sec.)	S.D. (sec.)	Normal range (sec.)
M20-29	4	.240-.272	.259	.014	.235-.287
M30-39	18	.225-.290	.254	.020	.224-.268
F30-39	4	.222-.247	.233	.011	.218-.262

Table 24. Duration of QJ interval (sec.) in patients with coronary disease, with ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison. M = males, F = females.

As in the case of the IJ interval, there was no significant difference in the mean QJ interval between the men aged from 30 to 39 years with coronary disease and their normal counterparts (Table 25).

Coronary patients			Normal subjects			S.E.	Difference of means
No.	Mean	S.D.	No.	Mean	S.D.		S.E.
18	.254	.020	19	.246	.011	.0053	1.51

Table 25. Significance of difference of mean QJ interval in men with coronary disease and normal men aged 30 to 39 years. S.D. = Standard deviation. S.E. = Standard error of difference between means. Results in sec..

c. Smoking tests.

The results are summarised in Table 26.

Result of test	Males	Females	Total
Negative	3	0	3
Positive	13	3	16

Table 26. Results of smoking tests in patients with coronary artery disease.

Figure 20.

Positive smoking tests in patients with coronary artery disease.

1. Male, 33 years: grade 0 with normal pattern before smoking and grade 2A with early M pattern after smoking.
2. Female, 39 years: grade 2B with early and late M patterns before smoking and grade 3 with the early M, late M and short K patterns after smoking.
3. Male, 39 years: grade 0 with normal pattern before smoking and grade 2B with early M pattern after smoking.

In some cases different abnormal patterns were present in other parts of the ballistocardiograms.

parts of the ballistocardiograms.

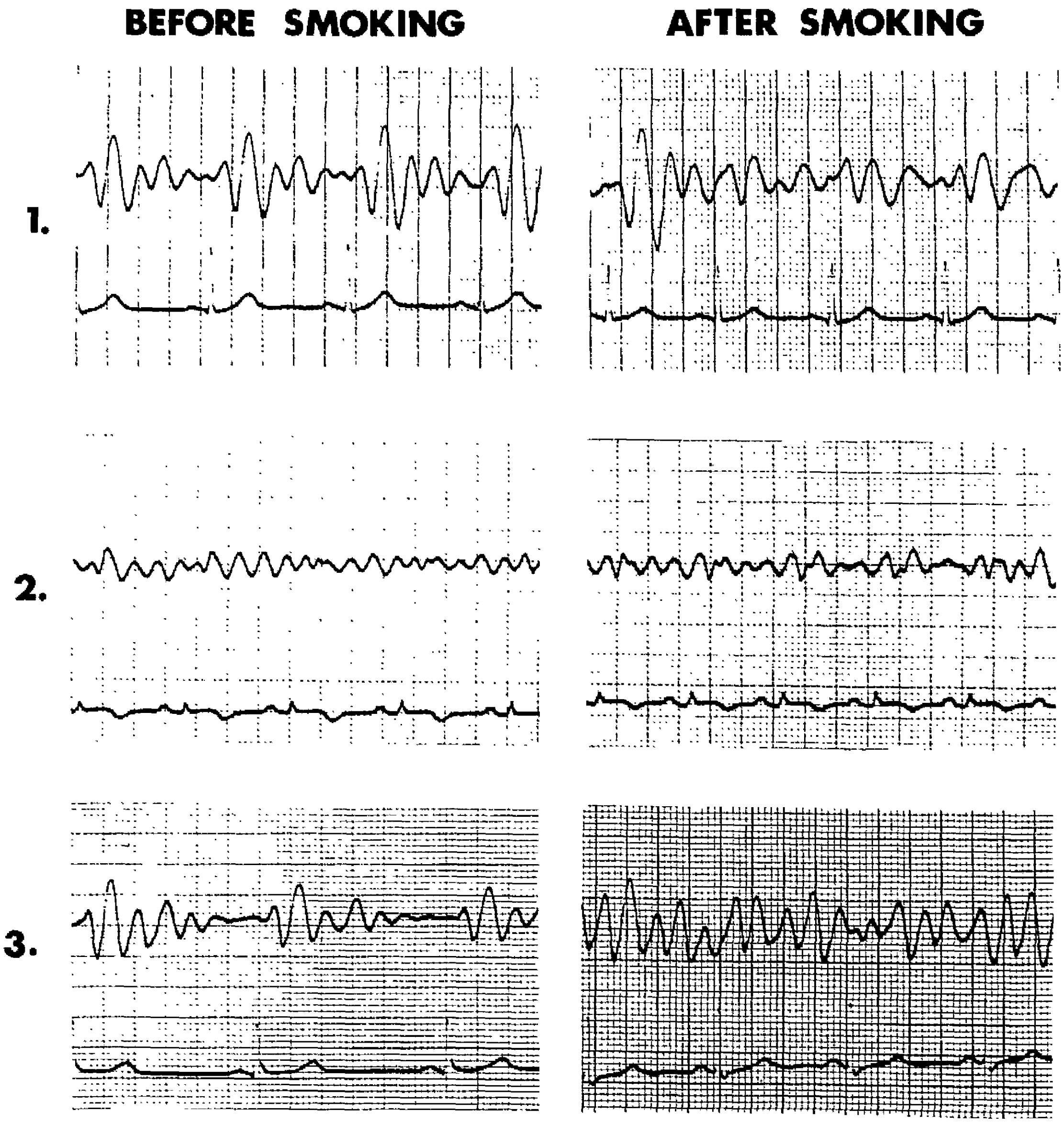
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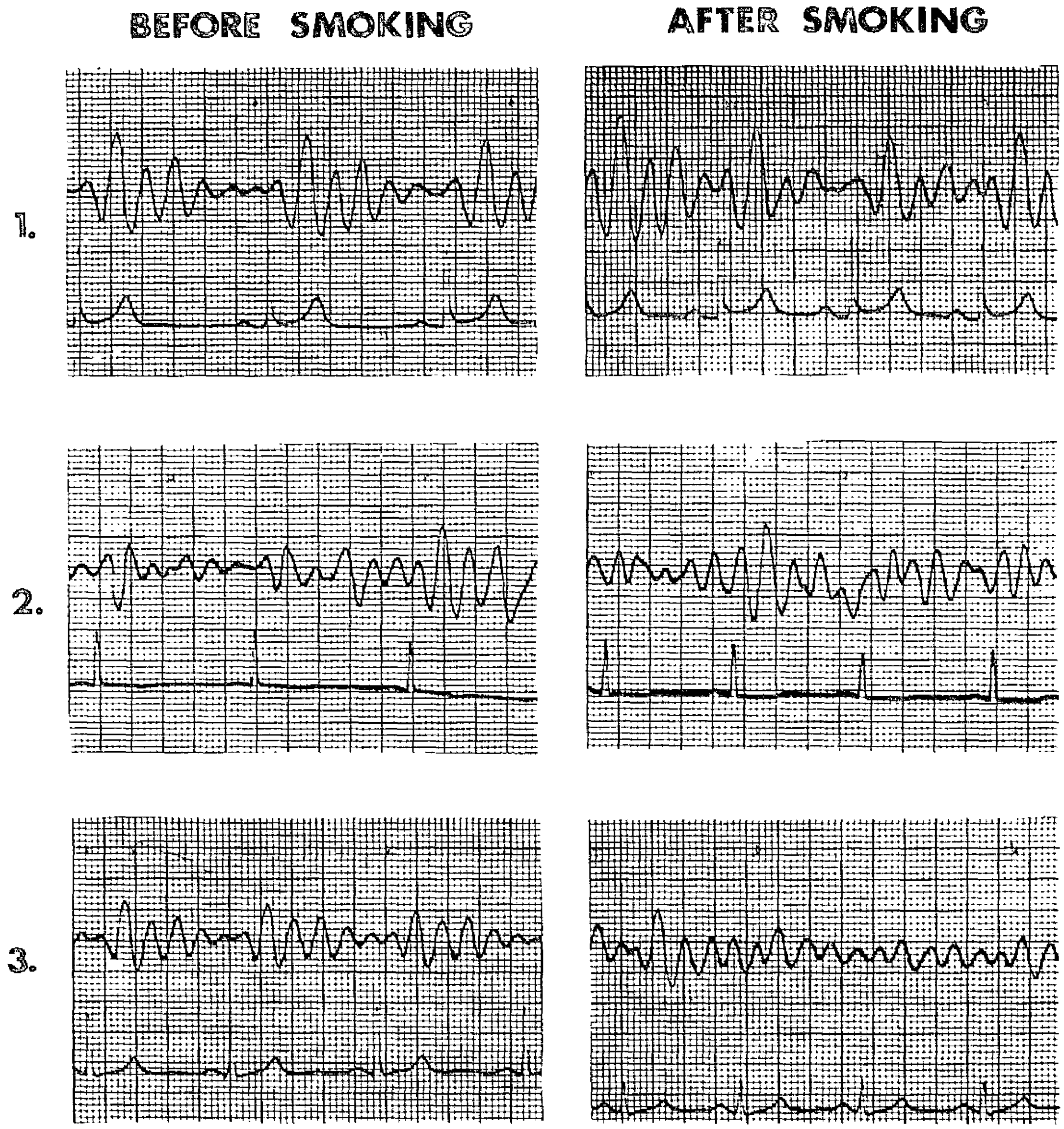
Figure 21.

Negative smoking tests in patients with coronary artery disease.

1. Male, 28 years: grade 0 with normal pattern before and after smoking.

2. Male, 38 years: grade 2B with short K pattern before smoking and grade 2B with early M and short K patterns after smoking.

3. Male, 39 years: grade 0 with normal pattern before smoking and grade 1 with normal pattern after smoking.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The grades of abnormality of the ballistocardiograms recorded before and after smoking are shown in Table 27.

Grade before smoking	Grade after smoking				
	0	1	2A	2B	3
0	1	1	6*	3*	0
1	0	0	2*	0	0
2A	0	0	0	2*	1*
2B	0	0	0	1	2*

Table 27. Grades of wave abnormality before and after smoking in patients with coronary artery disease. Positive tests *.

Figure 20 shows examples of positive smoking tests. The three negative smoking tests are shown in Figure 21.

Ten resting ballistocardiograms were entirely normal in contour. One showed an undue amount of respiratory variation. Thus nine records were placed in grade 0 and one in grade 1. Eight of these records developed grade 2A or 2B abnormalities after smoking. One showed transient wave defects after smoking. That record was considered equivocal but the grade of abnormality of the ballistocardiogram did not alter with smoking and the test was regarded as negative.

Three resting ballistocardiograms showed transient or variable abnormalities of wave contour. These records were considered equivocal but were regarded as normal for the purpose of grading. Two ballistocardiograms were placed in grade 0 and one in grade 1. These records developed grade 2A or 2B abnormalities after smoking.

Six resting ballistocardiograms were abnormal with grade 2A or 2B defects. The degree of abnormality increased in five but in one case the record showed abnormalities of grade 2B severity before and after smoking. This test was considered negative although the ballistocardiograms were quite abnormal before and after smoking.

There was much variety of wave pattern before and after smoking. The basic forms observed were the early M, late M, late downstroke, abnormal HI, short K, prominent L, abnormal late diastolic wave and bizarre patterns. Details of the wave contours are shown in Tables C and D of the Appendix.

There were 19 smoking tests, of which 16 were positive and three were negative. None of the normal subjects had a positive smoking tests. The difference in the incidence of positive tests in the two groups was highly significant (p less than 0.001).

Summary.

The ballistocardiograms of 22 men and four women aged from 28 to 39 years with recent myocardial infarction or angina pectoris were analysed. Ten records had normal wave contour, 12 had abnormal patterns of grade 2A or 2B severity while four records had short-lived abnormalities and were classified as equivocal.

The amplitude and area of the IJ segment were significantly less than in the records of equivalent normal subjects. There was unduly great respiratory variation in the ballistocardiograms of six men. The duration of the IJ segment and the QJ interval was normal.

The ballistocardiograms of 16 men and three women aged from 28 to 39 years were examined before and after the smoking of a cigarette. There were 16 positive and three negative smoking tests. The difference in the incidence of positive smoking tests in the patients with coronary artery disease, as compared with the normal subjects, was highly significant.

Chapter 15.

PATIENTS WITH CORONARY ARTERY DISEASE:

DISCUSSION OF RESULTS.

1. Qualitative Analysis.

a. Incidence of abnormal ballistocardiograms.

In this study the incidence of resting ballistocardiograms with evident abnormalities of wave contour was 46 per cent in the patients with coronary artery disease. This result is almost identical with that reported by Scarborough et al. (1952), namely 40 per cent. More detailed comparison of the two series reveals further similarities. This is shown in Table 28 overleaf.

A subsequent publication from the same department (Davis et al., 1956) suggested that the incidence of abnormal ballistocardiograms in young patients with ischaemic heart disease was much lower, namely 21 per cent. The reason for the reduction in the incidence of abnormal records was not made clear. Presumably the patients added to the series in the interval tended to have proportionately fewer abnormal ballistocardiograms and possibly they were less markedly affected by cardiac disease than those who were studied earlier.

Sex	Contour	Present Study	Scarborough et al.
Males	Normal	8	9
	Equivocal	4	5
	Abnormal	10	9
Females	Normal	2	1
	Equivocal	0	0
	Abnormal	2	1
Totals	Normal	10	10
	Equivocal	4	5
	Abnormal	12	10

Table 28. Incidence of normal, equivocal and abnormal resting ballistocardiograms in patients aged 20 to 39 years with coronary disease. Comparison of results of present study with those of Scarborough et al. (1952).

b. Grades of abnormality.

In the present investigation none of the resting ballistocardiograms showed abnormality of more than grade 2 severity. In most previous reports of the ballistocardiogram in ischaemic heart disease details of this nature were omitted. Thus comparison between these series and the present one was not possible. This form of classification of ballistocardiographic abnormality was devised by Brown et al. (1950) but comparison with their results is not valid because all but one of their patients were older than those included in the present study. Advancing age is one of the most important factors in the production of abnormal ballistic wave contour (Fulton et al., 1961). Since the patients in this investigation were relatively young the absence of severely affected ballistocardiograms is perhaps not surprising, even in the presence of ischaemic heart disease.

c. Abnormal wave contours.

The patterns of wave abnormality that were described in Chapter 10 were observed with varying frequency. The major forms outlined by Starr et al. (1939) were found but the late M and late downstroke patterns were noted relatively seldom. In contrast the early M pattern was seen in eight of 12 abnormal records and truncated K waves were even more frequent. Abnormalities of the HI and IJ segments, such as those described by Henderson (1953), were not uncommon. More than one type of abnormality might be found in a single ballistocardiogram.

These abnormal patterns have not been associated with a particular anatomical lesion. The ballistocardiogram reflects ventricular function rather than structure in most instances. Deviations from the normal pattern are a measure of abnormal ventricular ejection (Starr et al., 1950). In the present instance the hypoxic state of the myocardium might well be the primary factor in the production of abnormal wave patterns.

2. Quantitative Analysis.

a. Amplitude of IJ segment.

The ballistocardiograms of the patients with coronary disease had appreciably decreased mean IJ amplitude compared with those of the normal subjects. There have been few previous reports in which the IJ amplitude has been considered in connection with coronary artery disease. Brown et al. (1950) stated that patients with coronary disease who had severe abnormalities of wave contour also had ballistocardiograms with low amplitude but they gave no precise details of the relevant records in their study. Jacobs (1954) noted that some patients with coronary disease had IJ amplitudes much smaller than those of normal subjects of the same age. Rorvik (1963) observed a slight but consistent lowering of IJ amplitude in subjects with coronary disease. Thus the IJ amplitude of the records of patients with coronary disease tended to be less than that of apparently healthy persons of equivalent age. The results of the present study were in keeping with previous observations.

Starr and Wood (1961) showed that this figure had prognostic value. Even apparently healthy persons with ballistocardiograms of small amplitude later suffered cardiac deaths and disability, especially from coronary disease, in significantly greater numbers than those with initially large ballistocardiograms. It is possible that observation of the patients with coronary disease in the present study over a longer period might have revealed an association between low IJ amplitude and poor cardiac prognosis. More extended observation, however, was not undertaken and the matter remains conjectural.

b. <u>Area under IJ segment</u>.

The area results were similar in many ways to those of IJ amplitude. The mean values obtained from the patients with coronary disease were significantly lower than those of the equivalent normal subjects where comparison was valid. There have been no previous reports concerning the IJ area of the ballistocardiogram in coronary disease. Since the IJ area is related to the IJ amplitude and the duration of the IJ segment (which was found to be normal in this study), it is not surprising that the amplitude and area measurements showed the same trend. The significance of the two results is likely to be similar.

c. <u>Respiratory variation of IJ segment</u>.

Brown et al. (1950) studied ballistocardiograms from 26 patients with classical angina pectoris and suggested that an increase in the amount of respiratory variation was often the earliest sign of ballistocardiographic abnormality but marked respiratory variation occurs in older "normal" subjects as well as in patients with overt coronary disease. De Lalla and Brown (1949) suggested that in these subjects the pooling of blood in the peripheral or splanchnic circulation might decrease the pulmonary blood pool and consequently reduce the amount of blood available for filling the left ventricle, particularly during expiration. Scarborough et al. (1953) found that in normal subjects abdominal compression decreased the amount of respiratory variation but they were reluctant to assume that this necessarily reflected improved cardiovascular function.

In the present study only six of 26 patients with coronary disease had an abnormally great degree of respiratory variation. These patients were men in their thirties and their "Ra" ratios ranged from 0.17 to 0.48. The other 12 men in this age group had normal ratios but the average for the 18 patients was 0.57, compared with the value of 0.69 for the normal men of equivalent age. All men in their twenties and the women in their thirties had normal "Ra" ratios and the mean values for these groups did not differ appreciably from the mean values of the equivalent normal controls. The significance of the increased respiratory variation found in the men aged from 30 to 39 years is conjectural because to some extent it reflects abnormalities of ballistocardiographic wave form. Of the six men with undue respiratory variation only one had a ballistocardiogram of normal contour. The early M pattern is characterised by an increase in the amplitude of the H wave and a decrease in the J wave as described in Chapter 10. Thus the IJ segment is usually lessened in amplitude. Since the abnormal complexes occur mainly during expiration the presence of early M patterns at that point automatically increases the degree of respiratory variation. In this connection it is of interest that two other patients with low normal ratios "Ra" of 0.52 and 0.55 had early M patterns in expiration. Thus in the present study the abnormal degree of respiratory variation could be explained largely in terms of abnormal wave pattern.

The suggestion that increased respiratory variation is commonly found in the ballistocardiograms of patients with coronary disease (Brown et al., 1950) was not confirmed in this investigation. Different methods of estimating the amount of respiratory variation may partly account for the difference in results. The simple "Ra" ratio was employed in this study whereas Brown et al. (1950) used a more difficult and less satisfactory formula. The main reason for the different results probably lies in the age of the patients investigated. All patients in the present study were less than 40 years of age whereas only one of the 26 studied by Brown et al. (1950) was under 40 years of age. This is likely to be significant since age plays an important part in determining the degree of respiratory variation. It again emphasises the need to have control records from normal subjects of equivalent age in any study of ballistocardiograms.

iv. Duration of IJ segment.

No significant difference was found between the patients with coronary disease and the equivalent normal subjects in this respect. No previous reports have considered this ballistocardiographic measurement.

v. Duration of QJ interval.

There was again no significant difference between the mean results of the patients with coronary disease and the equivalent normal subjects. This was in keeping with the findings of Smith (1953).

3. Smoking Tests.

The incidence of abnormal resting ballistocardiograms was 46 per cent but 84 per cent of the smoking tests performed by the patients with coronary disease were positive. The smoking test thus differentiated this group from the normal subjects more sharply than did the resting ballistocardiograms.

The association between overt coronary artery disease and an increased incidence of positive smoking tests has been clearly recognised (Mandelbaum and Mandelbaum, 1952; Henderson, 1953; Davis et al., 1953, 1956). Kuo and Joyner (1955) found that 11 of 14 patients with clinical coronary disease had negative smoking tests but they emphasised that almost all of these patients had very abnormal resting ballistocardiograms. A marked circulatory change would be required to produce significant deterioration in the pattern of such abnormal records. In the present study one patient had ballistocardiograms with grade 2B abnormalities before and after smoking. This test was negative despite the occurrence of obviously abnormal patterns and was probably similar to those reported by Kuo and Joyner (1955).

In the present study the method of assessing the smoking tests, described in Chapter 10, was similar to that of Henderson (1953). For the purpose of comparison the results of Davis et al. (1956) were re-analysed according to Henderson's (1953) criteria. The method used in the present study was not applicable since details of the grades of abnormality of the ballistocardiograms were not given by Davis et al. (1956). It was found that 58 per cent of 24 patients aged from 20 to 39 years with coronary disease had positive smoking tests, compared with 84 per cent of 19 patients in the present study. The difference between the two groups was not statistically significant (p between 0.20 and 0.10) when the Chi-square test was used. This does not, however, exclude the possibility that the difference was a real one. Two factors might have contributed to this.

The patients examined by Davis et al. (1956) may not have had coronary disease of similar severity to the subjects in the present study. Secondly, the interval between myocardial infarction and ballistocardiographic examination was different. In the present investigation the patients were studied five or six weeks after acute myocardial infarction, whereas Davis et al. (1956) investigated their cases after a longer interval. Since ballistocardiographic abnormalities are most common five or six weeks after the acute incident (Kliorina, 1964) this is probably an important factor.

It is clear, however, from the major reported series that the ballistocardiograms of young patients with myocardial infarction or angina pectoris show abnormalities or increased abnormalities after smoking; these changes are not found in the records of apparently healthy persons of the same age (Henderson, 1953; Davis et al., 1953, 1956). It may be deduced that the effect of the coronary disease on the myocardium is essentially responsible for the abnormal ballistocardiographic patterns which reflect faulty ventricular ejection (Starr et al., 1950). These abnormal records contrast sharply with those obtained from the normal control group. They may be considered to provide a second and abnormal control series with which the records of patients suspected of having coronary artery disease may be compared.

<u>Summary</u>.

The incidence of abnormal resting ballistocardiograms was similar to that reported by Scarborough et al. (1952) but was greater than that given by Davis et al. (1956), due perhaps to a lesser degree of severity of the cardiac disease in the latters' patients.

The absence of severe ballistocardiographic wave abnormality in the present series might be attributed to the relative youth of the patients.

The decreased IJ amplitude might reflect an adverse cardiac prognosis but observation over a longer period, necessary to establish this point, was not undertaken in this study. The decreased IJ area was likely to have the same significance.

The previous observation that increased respiratory variation was a prominent feature of the ballistocardiograms of patients with coronary disease was not confirmed. This was probably related to age factors. In this study increased respiratory variation could largely be explained in terms of abnormal wave pattern.

The smoking test differentiated the patients with coronary disease from the normal subjects more clearly than did the resting ballistocardiograms. A higher incidence of positive tests was obtained than in previous reports. Differences in the severity of cardiac disease and in the interval between myocardial infarction and examination might be responsible but the increased yield of positive tests in this study could be due to chance.

These changes with smoking were not found in healthy young persons. The abnormal records from the patients with coronary disease form a contrasting series with which the ballistocardiograms of persons suspected of having ischaemic heart disease may be compared.

PART 1V

Chapters 16 to 19

THE BALLISTOCARDIOGRAM IN DIABETES MELLITUS.

Chapter 16.

DIABETES MELLITUS AND VASCULAR COMPLICATIONS.

1. Introduction.

The association between diabetes mellitus and vascular disease has long been recognised. This may affect the peripheral vessels and also the cerebral and coronary arteries. Vascular complications play an important part in the morbidity and mortality of diabetes. It is possible that they will ultimately develop despite satisfactory control of the metabolic disorder but it is generally accepted that good diabetic control probably lessens the risk of serious complications. The early detection of vascular abnormalities is thus important so that measures may be directed to achieving or continuing good diabetic control. Once serious lesions have developed, little can be done to alleviate them and the essential problem is therefore that of early detection preferably while the vascular disorder remains occult or latent.

2. Aetiology of Vascular Complications.

a. Duration of diabetes.

It has often been suggested that the duration of the clinical diabetic state is an important factor in determining the occurrence of vascular complications in patients with diabetes mellitus. A number of authors, including Dry and Hines (1941), Dolger (1947) and White (1956), have suggested that almost all diabetics develop overt vascular lesions provided that the diabetic state has been present for a sufficient length of time. On the other hand, Moore and Frew (1965) found no correlation between the duration of clinical diabetes and the severity of the angiopathy. It is not certain that the vascular lesions represent actual complications of diabetes (Le Compte, 1957). Dolger (1947) maintained that cardiovascular disease was not truly a complication of diabetes but rather an integral part of a basic disorder which also caused the metabolic upset. He suggested that vascular damage might precede the clinical discovery diabetes.

b. Genetic factors.

Le Compte (1957) postulated that genetic factors might determine the occurrence of both the vascular disorder and the metabolic upset. This view was supported by the findings of Lax and Feinberg (1959) who studied the arterial pulse wave of apparently normal children with a family history of diabetes. Abnormal pulse waves, similar to those found in the majority of subjects with overt diabetes, were observed in more of these children than in children without a family history of diabetes. Camerini-Davalos et al. (1963) used electron microscopy to examine skin from the ears of subjects thought likely to develop diabetes in the future, such as identical twins of known diabetics and children whose parents were both diabetic, and found changes in the dermal capillaries similar to those described in overt diabetics by Goldenberg et al. (1959). Conversely there are very few cases of the typical capillary lesions in diabetes due to a known cause such as pancreatitis or haemochromatosis (Le Compte, 1957; Galton, 1965).

3. Types of Vascular Lesions.

a. Capillary angiopathy.

The capillary vascular lesion is characteristic of diabetes mellitus (Megibow et al., 1953; Moore and Frew, 1965) and may be specific.

Starr (1930) observed a decreased circulation in the feet of diabetic subjects without demonstrable obstruction of the large arteries. Mendlowitz et al. (1953) demonstrated decreased blood flow in the toes of young diabetics who presented no overt clinical evidence of vascular disease. This was independent of the severity of the diabetes, the age of its onset or its duration. Peripheral vascular impairment was found also by Megibow et al. (1953) in young patients with diabetes. They suggested that the intrinsic or fundamental vascular derangement in diabetes mellitus was an occlusive lesion of the minute blood vessels. They postulated that the increased prevalence and accelerated development of arteriosclerosis in diabetes might be linked with increased intravascular tension as a result of the capillary lesions. Histological changes in the small vessels were demonstrated by Goldenberg et al. (1959) and by Moore and Frew (1965).

b. Arteriosclerosis.

Arteriosclerosis of a type indistinguishable from that found in non-diabetics is common (Bryfogle and Bradley, 1957; Alpert, 1957). The arteriosclerosis of diabetics and non-diabetics is histologically the same (Lisa et al., 1942) but its incidence in the diabetic population far exceeds expectation and its onset appears inevitable (White, 1941). Diabetes appears to accelerate the onset of arteriosclerosis (Bryfogle and Bradley, 1957; Cohen et al., 1963).

Lax et al. (1956) found that the major arterial pulse wave was consistently abnormal in diabetic patients of all ages. Subsequently Lax and Feinberg (1959) reported that 62 per cent of young diabetics, none of whom showed clinical evidence of vascular impairment, had abnormal arterial pulses, compared with 22 per cent of presumably healthy young adults. Simonson and Nakagawa (1960) observed that individuals with clinically evident coronary artery disease had more rapid pulse wave velocity than apparently healthy subjects and stressed the value of this measurement as an indicator of diffuse arteriosclerosis. Woolam et al. (1962) applied this method to diabetic patients and found that in the absence of clinically evident arteriosclerosis the pulse wave had greater velocity than that of healthy persons. They concluded that this technique could detect generalised arteriosclerosis before it was clinically demonstrable.

In most cases of diabetes mellitus overt and clinically evident arteriosclerosis does eventually develop. A high incidence of aortic involvement was reported by Liebow et al. (1955) and by Anderson et al. (1961). There is therefore considerable evidence to suggest that diabetic subjects (and persons likely to develop diabetes) are prone to develop vascular abnormalities and that these may be present for some time before they can be detected by the usual simple clinical methods.

4. Diabetes Mellitus and Coronary Artery Disease.

In diabetes mellitus the arteriosclerotic process is usually generalised. It involves not only the peripheral vessels but also the cerebral and coronary arteries. Coronary artery disease is clearly an important complication, for it is recorded as a cause of death in about 30 per cent of patients with juvenile diabetes (White, 1956).

As early as 1881, Vergely suggested that there was a definite association between angina pectoris and diabetes mellitus. More recent experimental studies have supported this view. Not only is there a tendency for the diabetic subject to develop coronary artery sclerosis (White, 1956) but there is also evidence that glucose tolerance may be impaired in an unduly high proportion of patients with myocardial infarction in the absence of clinical evidence of diabetes. Schrade et al. (1960) studied 74 patients, of whom 73 per cent had disturbed carbohydrate metabolism. Precisely the same incidence, namely 73 per cent of the patients studied immediately after myocardial infarction by Sowton (1962) had abnormal glucose tolerance and in 50 per cent the curve was frankly diabetic. Six months later, 43 per cent of the patients still had abnormal curves and in 10 per cent this was of diabetic type.

Nikkila et al. (1965) reported abnormal insulin production in response to a glucose load in 65 per cent of patients one month after myocardial infarction. Peters and Hales (1965) found that between six and eighteen months after myocardial infarction the plasma insulin level was increased when the fasting blood sugar level was normal. These patients did not have impaired glucose tolerance and Peters and Hales suggested that insulin resistance might be present. Vallance-Owen and Ashton (1963) showed that patients with recent myocardial infarction tended to have an albumin-attached insulin antagonist in the plasma. This insulin antagonist is found also in the plasma of diabetic subjects except for those with known causes of diabetes, such as haemochromatosis or pancreatitis (Vallance-Owen, 1962).

Keen et al. (1965) examined subjects who had been discovered to have symptomless glycosuria in a diabetes detection survey. Some patients had impaired glucose tolerance but were not frankly diabetic. There was a significantly increased prevalence of symptoms and electrocardiographic evidence of arterial disease.

Thus there seems to be a close and fundamental link between diabetes mellitus and coronary artery disease.

5. Detection of Occult Coronary Artery Disease.

a. Occurrence of occult coronary sclerosis.

A number of authors have reported that abnormalities of the peripheral vascular system may be detected experimentally in diabetics before the patients have any symptoms or other clinical evidence of vascular disease (Mendlowitz et al., 1953; Megibow et al., 1953; Lax and Feinberg, 1959; Woolam et al., 1962). Symptomless coronary artery sclerosis may exist in the non-diabetic population (Enos et al., 1953) and there is no essential difference between the arteriosclerosis of diabetic and non-diabetic subjects (Lisa et al., 1942) except for its accelerated onset (Bryfogle and Bradley, 1957; Cohen et al., 1963). Thus it seems likely that a proportion of diabetic patients without symptoms or electrocardiographic evidence of coronary artery disease may have a significant degree of coronary sclerosis.

b. Detection of occult coronary sclerosis.

The detection of occult coronary artery disease in diabetic patients may prove difficult although both direct and indirect methods of investigation may be employed.

Indirect approaches include the recording of electrocardiograms before and after stress procedures, such as standardised exercise or induced hypoxia. These tests are not entirely successful in detecting coronary insufficiency and are also not free from hazard. This is true particularly of induced hypoxia (Stewart and Carr, 1954; Wood, 1956).

More direct examination of the coronary arterial tree is possible by means of selective coronary angiography. This would seem to provide much more exact and conclusive evidence of coronary abnormalities. Hale and Jefferson (1963) recommended this method of investigation. For several reasons it is not entirely suitable for the investigation of possible coronary abnormalities in patients who have no apparent vascular disease. There are clear hazards, which include asystolic cardiac arrest. Emergency equipment must always be available for immediate attempts at cardiac resuscitation. Secondly, even fairly marked coronary disease, whose presence was verified at post mortem examination, might be difficult to detect by coronary angiography (Hale and Jefferson, 1963).

c. <u>Use of the ballistocardiogram</u>.

A number of studies concerning the ballistocardiograms of diabetic subjects have been published (Donoso et al., 1954; Rakel et al., 1958; Verdun di Cantogno et al., 1958; Oka and Savola, 1961; Poggi and Farroni, 1964). In a survey of the clinical applications of ballistocardiography, Fidler et al. (1958) gave details of the records of some patients with diabetes.

The importance of age in the production of ballistocardiographic abnormalities has been stressed repeatedly. It is only in subjects under 40 years of age that the occurrence of abnormal patterns may be considered significant. Beyond that age, it is not possible to attribute an abnormal pattern to factors other than age with any certainty. Oka and Savola (1961) and Poggi and Farroni (1964) examined diabetic patients under 40 years of age but all the other authors mentioned above included older cases. The emphasis that may be placed on the abnormal results that they reported is therefore uncertain.

Rakel et al. (1958), Oka and Savola (1961) and Poggi and Farroni (1964) considered that there was a relationship between ballistocardiographic abnormalities and the presence of overt vascular complications of diabetes. All series of patients included subjects with vascular complications that were evident.

This too might account for some of the abnormal ballistocardiograms that were observed by the authors whose reports were mentioned above. If, however, the presence of vascular abnormalities is certain and obvious, their detection by special investigative methods is unnecessary, although these techniques may provide additional and indeed valuable clinical information.

The ballistocardiogram will provide little useful information of this type in patients aged more than 40 years or in those who have patent vascular abnormalities. Its place might lie in the demonstration of occult coronary artery sclerosis in diabetic patients under 40 years of age. The prevalence of ballistocardiographic abnormalities in this group of patients has not hitherto been investigated. The diagnostic precision of the method may be strengthened by the recording of ballistocardiograms before and after the smoking of a cigarette. Davis et al. (1953) considered that the ballistocardiographic smoking test was a better means of detecting coronary artery disease than any other single indirect test.

The evidence suggesting that there is a fundamental link between diabetes mellitus and coronary artery disease has been considered above. Thus it would seem profitable to apply the ballistocardiographic method, reinforced by the smoking test, to this problem, namely the study of young diabetic patients without clinical evidence of coronary artery disease or other vascular abnormalities.

<u>Summary</u>.

The association between diabetes mellitus and vascular disease has long been recognised. It has often been suggested that the duration of the clinical diabetic state is an important factor in the production of vascular disorders but this is not certain. It has also been postulated that genetic factors determine a basic disorder which causes both the metabolic and vascular abnormalities. The occurrence of vascular defects in persons likely to develop diabetes would support this view.

The capillary vascular lesion is characteristic of diabetes mellitus and may be specific but arteriosclerosis of a type indistinguishable from that of non-diabetics is common. Diabetes seems to accelerate its onset. These features of the diabetic vascular abnormality have been confirmed by experimental studies.

There appears to be a fundamental link between diabetes and coronary artery disease, which is recorded as a cause of death in about one third of juvenile diabetics. Apparently non-diabetic patients with myocardial infarction may have impaired glucose tolerance or insulin antagonism.

It is likely that occult coronary artery sclerosis may exist in some diabetic subjects but it is difficult to detect at this early stage. Electrocardiography in conjunction with stress procedures and even selective coronary angiography might possibly be used in an attempt to demonstrate its presence but these methods have certain disadvantages.

Previous ballistocardiographic studies of diabetic patients have included older subjects and some with overt vascular complications. A more useful sphere of employment for the ballistocardiogram may lie in the attempted demonstration of occult coronary sclerosis in young diabetics, particularly if a stress procedure such as cigarette smoking is used.

Chapter 17.

DIABETIC PATIENTS:

MATERIAL, METHOD AND RESULTS.

1. Subjects Studied.

There were 19 men aged from 21 to 37 years and 18 women from 17 to 38 years. In each case the diagnosis of diabetes mellitus rested on typical symptoms such as thirst, polyuria and weight loss and on the finding of glycosuria and a diagnostic degree of hyperglycaemia, that is the fasting blood sugar level exceeded 120 mgm. per 100ml. or the random blood sugar level was greater than 200 mgm. per 100 ml.. The actual values considerably exceeded these levels in most instances. All patients received insulin in doses varying from 36 to 120 units daily. No patient had ketosis or hypoglycaemia at the time of the test. None was obese. The other essential criteria for inclusion in this group are shown overleaf.

i. No history of rheumatic fever or chorea.

ii. No history of angina or claudication pain.

iii. Clinically normal heart, peripheral pulses and optic fundi.

iv. Blood pressure less than 150/90.

v. Normal electrocardiogram.

vi. No albuminuria.

The sex and age distribution of these patients is shown in Table 29.

Age (years)	Males	Females	Total
15-19	0	3	3
20-29	11	9	20
30-39	8	6	14
15-39	19	18	37

Table 29. Sex and age distribution of patients with diabetes mellitus.

2. <u>Recording of Ballistocardiograms.</u>

a. <u>Resting ballistocardiograms.</u>

These were recorded in the standard manner at least two hours after the patient had taken food or smoked tobacco and after 20 minutes rest on the table. The blood pressure and electrocardiogram were taken after the ballistocardiogram had been recorded.

b. Ballistocardiograms after smoking.

Smoking tests were performed in the standard manner by 17 men aged from 21 to 36 years and 13 women aged from 18 to 38 years, all habitual smokers.

3. Assessment of Ballistocardiograms.

The wave contour of each record was inspected and the ballistocardiogram was graded from 0 to 4. The IJ segments of typical large inspiratory complexes and the corresponding small expiratory complexes from three consecutive respiratory cycles were measured and the five standard indices were calculated.

i. Amplitude of IJ segment.

ii. Area of triangle under IJ segment.

iii. Respiratory variation of IJ segment.

iv. Duration of IJ segment.

v. Duration of QJ interval.

4. Results.

a. Qualitative analysis.

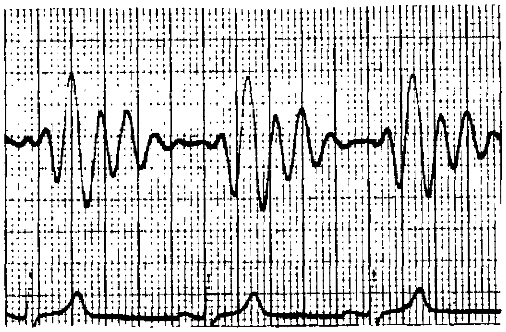
The wave pattern was normal in 32 resting ballistocardiograms,

Figure 22.

Ballistocardiograms of diabetic patients.

1. Male, 23 years.
2. Female, 19 years.
3. Male, 29 years.
4. Female, 19 years.
5. Male, 35 years.
6. Female, 31 years.

All ballistocardiograms are normal.



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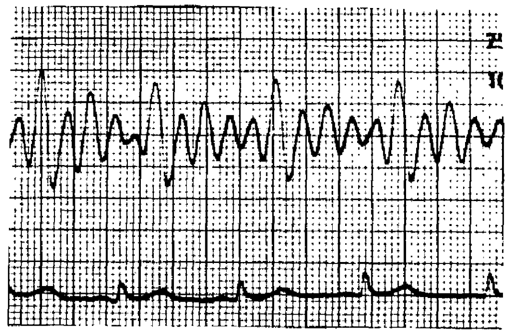

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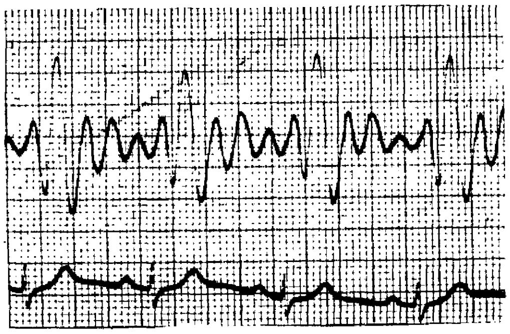

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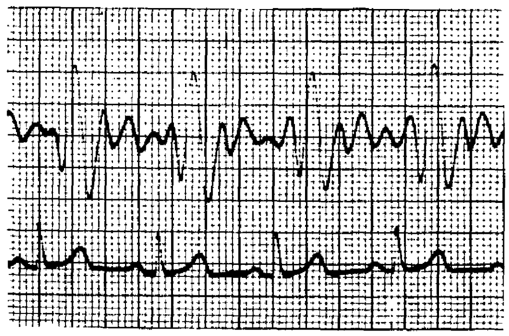

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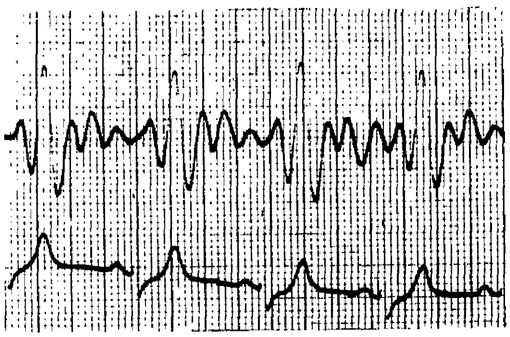

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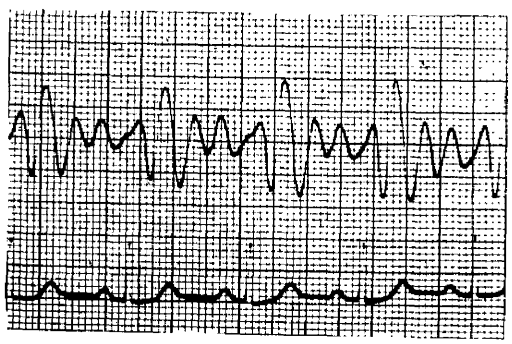


6.

those of 17 men and 15 women. All were placed in grade O.

Three records were considered equivocal and were placed in grade O. A man aged 24 years, a diabetic for 20 years, had a tracing with short K waves during some respiratory cycles. The same pattern occurred in the ballistocardiogram of a woman aged 33 years who had had diabetes for 21 years. Variable minor abnormalities were observed in the record of a woman aged 32 years with diabetes for four months.

Two records were definitely abnormal. A man of 36 years had a grade 2A ballistocardiogram with early M pattern and a woman aged 35 years had a grade 2A tracing with abnormal HI segments.

Thus two of the 37 diabetic patients had abnormal ballistocardiograms compared with none of the 159 normal subjects. The difference between the two groups just reaches the level of statistical significance (p between 0.05 and 0.02).

These results are summarised in Tables 30 and 31 overleaf.

Examples of ballistocardiograms of diabetic patients are shown in Figure 22.

Form of record	Males	Females	Total
Normal	17	15	32
Equivocal	1	2	3
Abnormal	1	1	2

Table 30. Distribution of normal, equivocal and abnormal ballistocardiograms of patients with diabetes mellitus.

Grades	Males	Females	Total
0	18	17	35
1	0	0	0
2A	1	1	2
2B	0	0	0
3 and 4	0	0	0

Table 31. Grades of abnormality of ballistocardiograms of patients with diabetes mellitus.

b. Quantitative analysis.

i. Amplitude of IJ segment.

The results are summarised in Table 32 which is shown overleaf.

Sex and age (years)	No.	Observed range (mm.)	Mean (mm.)	S.D. (mm.)	Normal range (mm.)
M20-29	11	14.1-23.8	19.6	3.61	13.6-27.6
M30-39	8	9.3-23.8	15.3	4.75	13.0-20.8
F15-19	3	9.0-16.8	12.7	3.91	11.3-14.9
F20-29	9	7.3-15.6	12.3	2.65	9.5-16.9
F30-39	6	7.5-15.5	11.4	3.17	8.4-15.2

Table 32. Amplitude of IJ segment (mm.) in diabetic patients showing ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison. M = males, F = females.

Table 33 tests the difference in mean IJ amplitude between the diabetic and normal subjects, aged 20 to 29 years.

Sex	Diabetic patients			Normal subjects			S.E.	Difference of means / S.E.
	No.	Mean	S.D.	No.	Mean	S.D.		
M	11	19.6	3.61	43	20.6	3.5	1.21	0.83
F	9	12.3	2.65	51	13.2	1.85	0.92	0.98

Table 33. Significance of difference of mean IJ amplitude in diabetic patients and normal subjects aged 20 to 29 years. S.D.= Standard deviation. S.E.= standard error of difference between means. M = males, F = females. Results in mm..

Because of the small number of diabetic patients only the records of those aged from 20 to 29 were compared with the normal control series. There was no significant difference in mean IJ amplitude in the two groups (Table 33 on the previous page).

Six diabetic patients had low amplitude records but three patients had ballistocardiograms with unduly large IJ amplitude.

ii. <u>Area under IJ segment.</u>

The results are summarised in Table 34.

Sex and age (years)	No.	Observed range (mm.sec.)	Mean (mm.sec.)	S.D.	Normal range (mm.sec.)
M20-29	11	.56-1.06	.81	.18	.56-1.22
M30-39	8	.36-1.01	.60	.21	.52- .86
F15-19	3	.39- .69	.54	.15	.52- .66
F20-29	9	.25- .62	.48	.13	.38- .74
F30-39	6	.29- .58	.43	.11	.30- .66

Table 34. Area under IJ segment (mm.sec.) in diabetic patients showing ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison. M = males, F = females.

Table 35 compares the mean IJ area in the diabetic patients aged from 20 to 29 years with the normal counterpart.

Sex	Diabetic patients			Normal subjects			S.E.	Difference of means / S.E.
	No.	Mean	S.D.	No.	Mean	S.D.		
M	11	.81	.18	43	.89	.165	.059	1.36
F	9	.48	.13	51	.56	.09	.045	1.78

Table 35. Significance of difference of mean IJ area in diabetic patients and normal subjects aged 20 to 29 years. S.D. = Standard deviation. S.E. = Standard error of difference between means. M = males, F = females. Results in mm.secs..

The mean IJ area of the ballistocardiograms of the diabetic patients did not differ significantly from that of the equivalent normal records. Only subjects aged from 20 to 29 years were compared because of the small number of patients

iii. Respiratory variation of IJ segment.

iii. Respiratory variation of IJ segment.

The degree of respiratory variation was expressed in terms of the "Ra" ratio, as previously described. A man aged 36 years who had a grade 2A ballistocardiogram with early M pattern had the "Ra" ratio of 0.48 but all other patients had

"Ra" ratios within the normal range, that is 0.50 or more. Thus one of the 37 diabetic patients had an abnormal ratio compared with none of the normal subjects. This difference was not significant (p between 0.50 and 0.30).

The results of the "Ra" ratio measurement are shown in Table 36.

Sex and age (years)	No.	Observed range ("Ra")	Mean ("Ra")	Normal range ("Ra")
M20-29	11	.64-.90	.81	.50-1.00
M30-39	8	.48-.87	.72	.50-1.00
F15-19	3	.77-.84	.80	.50-1.00
F20-29	9	.69-.91	.80	.50-1.00
F30-39	6	.61-.79	.70	.50-1.00

Table 36. Degree of respiratory variation ("Ra" ratio) in diabetic patients showing observed ranges, mean values and normal ranges for comparison. M = males, F = females.

iv. Duration of IJ segment.

The results are shown in Table 37 on the next page.

Sex and age (years)	No.	Observed range (sec.)	Mean (sec.)	S.D. (sec.)	Normal range (sec.)
M20-29	11	.073-.090	.082	.006	.078-.100
M30-39	8	.071-.085	.078	.004	.071-.093
F15-19	3	.082-.086	.084	.007	.083-.097
F20-29	9	.068-.086	.078	.006	.079-.091
F30-39	6	.070-.083	.076	.005	.067-.095

Table 37. Duration of IJ segment (sec.) in diabetic patients showing ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison. M = males, F = females.

Table 38 compares the mean IJ interval in the diabetic patients aged from 20 to 29 years with the normal counterpart.

Sex	Diabetic patients			Normal subjects			S.E.	$\frac{\text{Difference of means}}{\text{S.E.}}$
	No.	Mean	S.D.	No.	Mean	S.D.		
M	11	.082	.006	43	.089	.0055	.0020	3.5
F	9	.078	.006	51	.085	.003	.0019	3.68

Table 38. Significance of difference of mean duration of IJ segment in diabetic patients and normal subjects aged 20 to 29 years. S.D. = Standard deviation. S.E. Standard error of difference of means. M = males, F = females. Results in sec..

The difference was highly significant.

Nine of the diabetic patients had ballistocardiograms with IJ intervals of less than the normal range. The difference in the incidence of decreased IJ interval results between the diabetic group and the normal series was highly significant (p less than 0.001).

v. Duration of QJ interval.

Table 39 summarises the results.

Sex and age (years)	No.	Observed range (sec.)	Mean (sec.)	S.D. (sec.)	Normal range (sec.)
M20-29	11	.225-.277	.243	.014	.235-.267
M30-39	8	.218-.262	.240	.014	.224-.268
F15-19	3	.235-.248	.243	.007	.232-.288
F20-29	9	.223-.263	.240	.011	.231-.267
F30-39	6	.210-.250	.225	.014	.218-.262

Table 39. Duration of QJ interval (sec.) in diabetic patients, showing ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison. M = males, F = females.

Table 40 compares the mean QJ interval in the diabetic patients aged from 20 to 29 years with the normal counterpart.

Sex	Diabetic patients			Normal Subjects			S.E.	Difference of means / S.E.
	No.	Mean	S.D.	No.	Mean	S.D.		
M	11	.243	.014	43	.261	.013	.0047	3.80
F	9	.240	.011	51	.249	.009	.0040	2.25

Table 40. Significance of difference of mean QJ interval in diabetic patients and normal subjects aged 20 to 29 years. S.D. = Standard deviation. S.E. = Standard error of difference between means. M = males, F = females. Results in sec..

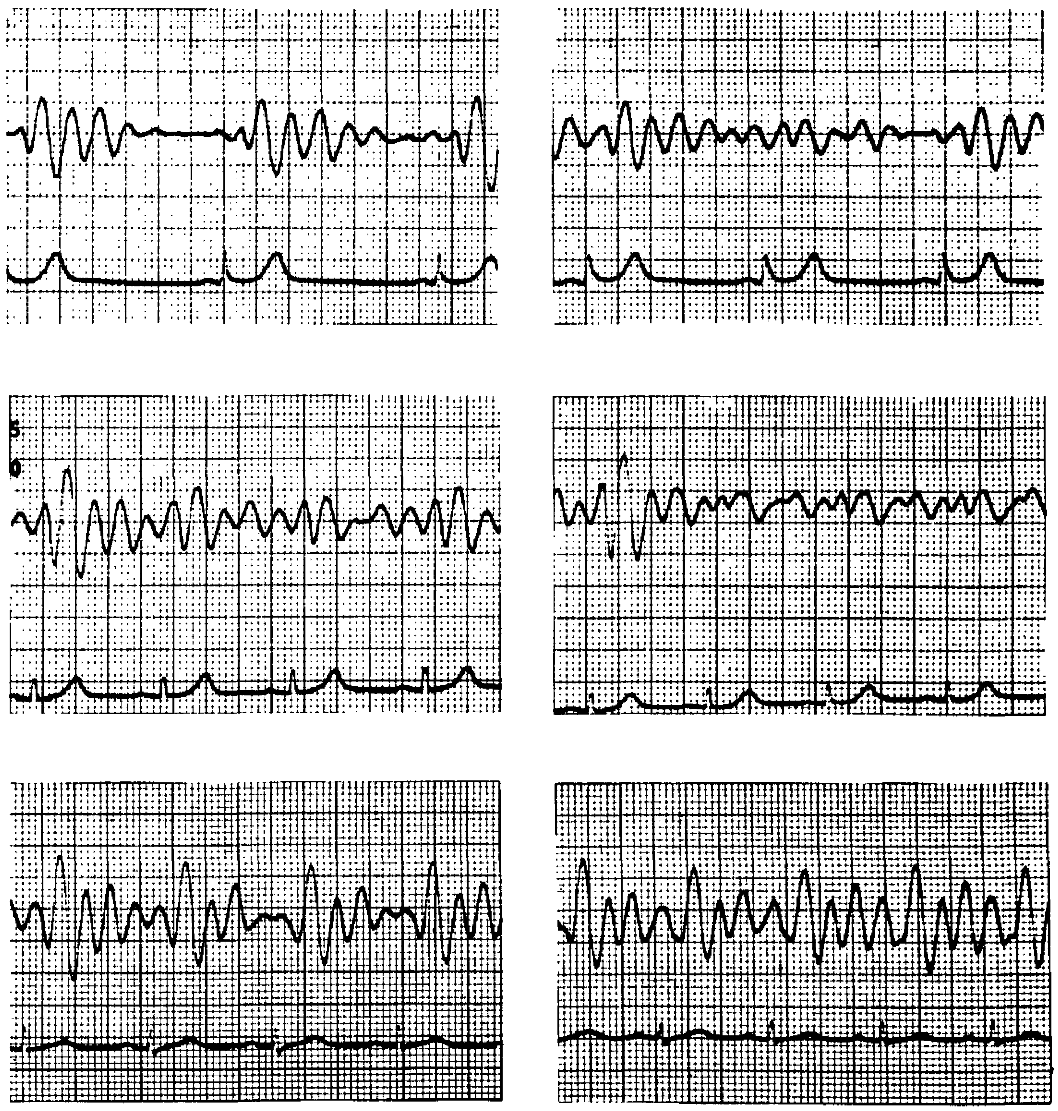
The mean duration of the QJ interval of the ballistocardiograms of the diabetic patients differed significantly from that of the equivalent normal subjects (Table 40). Eight diabetic patients had records with QJ intervals of less than the normal range. The difference between the ballistocardiograms of the diabetic patients and the normal subjects was highly significant in this respect (p less than 0.001).

Figure 23.

Positive smoking tests in diabetic patients.

1. Male, 34 years: grade 0 with normal pattern before smoking and grade 2A with early M pattern after smoking.
2. Male, 36 years: grade 2A with early M pattern before smoking and grade 2B with early M pattern after smoking.
3. Female, 18 years: grade 0 with normal pattern before smoking and grade 2B with abnormal HI pattern after smoking.

BEFORE SMOKING AFTER SMOKING



1.

2.

3.

Figure 24.

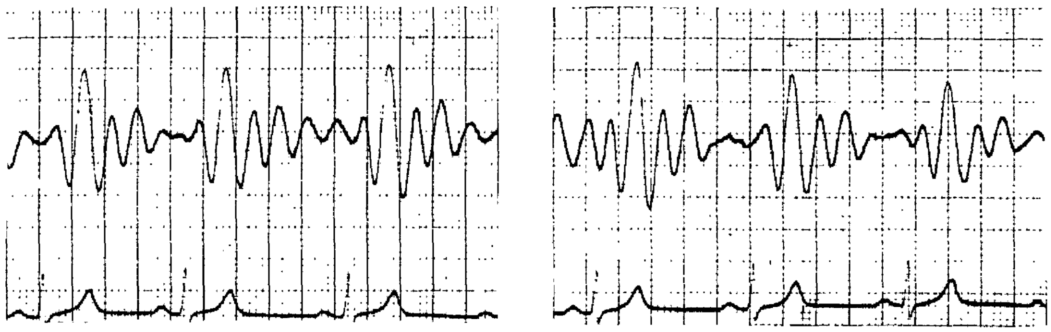
Negative smoking tests in diabetic patients.

1. Male, 23 years.
2. Female, 21 years.
3. Female, 21 years.

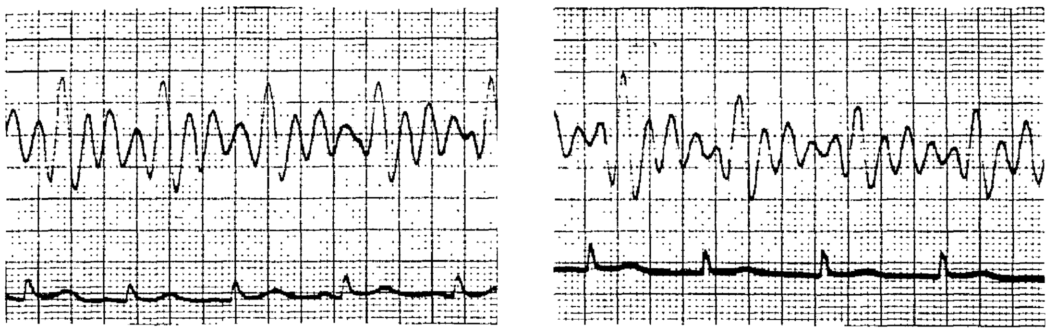
All ballistocardiograms were grade 0 with normal pattern before and after smoking.

BEFORE SMOKING | AFTER SMOKING

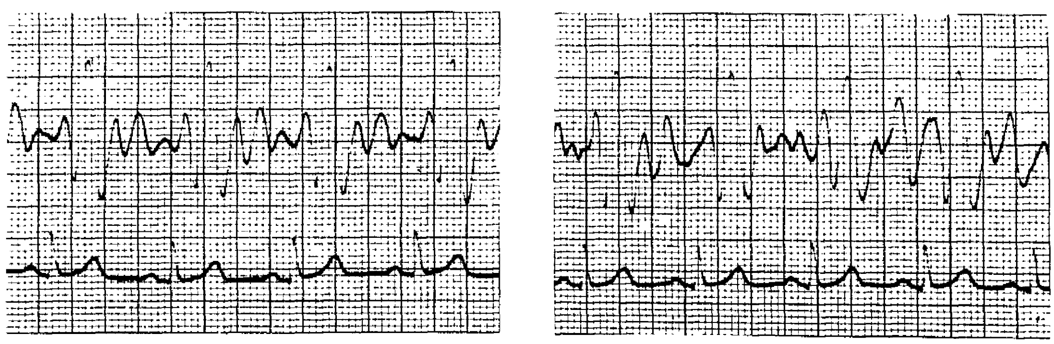
1.



2.



3.



c. Smoking tests.

The results of the smoking tests are shown in Table 41.

Result of test	Males	Females	Total
Negative	12	7	19
Positive	5	6	11

Table 41. Results of smoking tests in diabetic patients.

Figure 23 shows examples of positive smoking tests and Figure 24 shows negative tests.

The grades of abnormality of the ballistocardiograms recorded before and after smoking are shown in Table 42.

Grade before smoking	Grade after smoking.				
	0	1	2A	2B	3
0	18	1	9*	1*	0
1	0	0	0	0	0
2A	0	0	0	1*	0
2B	0	0	0	0	0

Table 42. Grades of wave abnormality before and after smoking in diabetic patients. Positive tests *.

Of the 30 resting ballistocardiograms, 29 were normal and equivocal and were placed in grade 0, while one showed grade 2A abnormalities.

The normal group consisted of 26 entirely normal records and three with transient or variable abnormalities of wave contour which were regarded as equivocal. Eight of the completely normal and two of the equivocal records became abnormal after smoking. In nine cases the abnormality was of grade 2A severity and in one case of grade 2B. Five other normal records developed transient wave defects after smoking. These ballistocardiograms were again considered equivocal but the grades of abnormality did not alter with smoking and the tests were regarded as negative. One equivocal record was unchanged by smoking : this also was a negative test.

The ballistocardiogram which initially showed grade 2A abnormality became more abnormal after smoking and was classified in grade 2B : the test was recorded as positive.

Details of the individual smoking tests are shown in Tables E and F of the Appendix. A variety of abnormal contours was observed after smoking. The basic forms observed were the early M, late M, late downstroke, abnormal HI and shortened K wave patterns.

There were 30 smoking tests, of which 11 were positive and

19 were negative. None of the normal subjects had a positive smoking test. The difference in the incidence of positive smoking tests in the two groups was highly significant (p between 0.01 and 0.001).

Summary.

The ballistocardiograms of 19 men and 18 women aged from 17 to 38 years with diabetes mellitus were analysed. Thirty-two records had normal wave contour, two had abnormal patterns of grade 2A severity while three records had short-lived abnormalities and were classified as equivocal.

The amplitude and area of the IJ segment were essentially normal. There was unduly great respiratory variation in the ballistocardiogram of one male patient. The duration of the IJ and QJ intervals was significantly less than in the records of equivalent normal subjects.

The ballistocardiograms of 17 men and 13 women aged from 18 to 38 years were examined before and after the smoking of a cigarette. There were 11 positive and 19 negative smoking tests. The difference in the incidence of positive tests in the diabetic patients compared with the normal subjects was highly significant.

Chapter 18.

DIABETIC PATIENTS:

DISCUSSION OF RESULTS.

1. Qualitative Analysis.

a. Comparison with previous reports.

Donoso et al. (1954) seem to have been the first to make a systematic study of the ballistocardiograms of diabetic patients. They analysed ballistocardiograms from 75 patients of whom 32 had definite evidence of coronary artery disease or hypertension. The remaining 43 were considered to be free from vascular complications. Most patients were middle-aged or elderly. Only six patients (9 per cent) were considered to have normal ballistocardiograms but in some cases the sole abnormality was an undue amount of respiratory variation without deformity of the wave contour. Thus the proportion of patients who had tracings with definite deformity of wave pattern was probably much less than 91 per cent. Fidler et al.

(1958) studied the ballistocardiograms of 30 patients with diabetes: a high proportion of the older patients had abnormal records. Rakel et al. (1958) found that 41 per cent of juvenile diabetics had abnormal ballistocardiograms: many patients had overt vascular complications or hypertension, while some were over 40 years of age. Verdun di Cantogno et al. (1958) found abnormal ballistocardiograms in 50 per cent of older diabetics.

The patients examined by Oka and Savola (1961) were all under 40 years of age. Abnormal wave patterns were reported in 20 cases (42 per cent) but increased respiratory variation without deformity of wave contour accounted for 11 of these cases (23 per cent). Thus only nine cases (19 per cent) had truly abnormal wave patterns. Abnormalities were more prevalent in association with hypertension and diabetic retinopathy. Poggi and Farroni (1964) also studied young diabetics aged from 14 to 35 years. Abnormal wave patterns occurred in five of 14 ballistocardiograms. In two of these five cases the electrocardiograms showed changes suggesting myocardial ischaemia and in a third case papilloedema of unknown aetiology was present.

Previous reports have thus suggested that there is a relatively high incidence of abnormal wave patterns in the resting ballistocardiograms of diabetic patients. This conflicts with the results of the present study in which only two abnormal ballistocardiograms were found in a series of thirty-seven. Several reasons for this difference may be suggested.

b. The effect of age.

Age is an important factor in the assessment of ballistocardiograms (Fulton et al., 1961). In several previous reports (Donoso et al., 1954; Fidler et al., 1958; Rakel et al., 1958; Verdun di Cantogno et al., 1958) there was a difference in age between the patients examined and the subjects of the present study. The report of Fidler et al., (1958) is of interest although the numbers involved are small. There was a high proportion of abnormal ballistocardiograms in the older age groups but all four patients who were less than 40 years of age had normal tracings. The fact that the patients in the present investigation were all under 40 years of age may at least partly explain the difference in results.

c. Cardiovascular complications.

A second factor is the presence of vascular complications. Both Oka and Savola (1961) and Poggi and Farroni (1964) felt that ballistocardiographic wave abnormality and vascular complications were associated. Rakel et al. (1958) considered that there was a connection between ballistocardiographic abnormalities and hypertension but not with other diabetic complications. Previous series have included patients with hypertension, coronary disease and other vascular complications. In the present study cases presenting these features were excluded as far as possible. Thus direct comparison of previously reported series with the present one is not strictly valid. Differences in results would seem almost inevitable.

d. Assessment of ballistocardiograms.

There was lack of uniformity in the assessment of ballistocardiograms. Although Donoso et al. (1954), Oka and Savola (1961) and Poggi and Farroni (1964) regarded a simple increase in the degree of respiratory variation as an abnormal wave pattern, they did not indicate how they assessed this index nor how much variation was considered normal. Thus, even if an increase in respiratory variation were accepted as an abnormal wave pattern, comparison with these series would be very difficult.

A simple increase in respiratory variation cannot, however, be accepted as an abnormal pattern, because the normal form of the ballistocardiographic waves is preserved. The classification of records with normal form but overmuch variation in the size of the complexes as abnormal in form is not universally accepted. An increase in the amount of respiratory variation was always recorded in the present study but ballistocardiograms of this type were included in the essentially normal group, unless there were abnormal wave patterns in addition.

Thus variation in the criteria for assessment of ballistocardiograms probably accounted for some of the apparent differences between this and previous studies.

e. Results of the present study.

In the present series the ballistocardiograms of two patients had clearly abnormal wave patterns. These aberrant forms were of types encountered in the records of young patients with ischaemic heart disease. The number of cases studied was too small for great significance to be attached to this result, although the level of statistical significance was attained. In this situation a stress test, such as the smoking of a cigarette, may accentuate or precipitate the emergence of ballistocardiographic abnormalities, which might help in differentiating patients with a cardiac abnormality from those with normal hearts. The results of the smoking tests are discussed in a later section of this chapter.

2. Quantitative Analysis.

a. Amplitude of IJ segment.

There have been few comments about the IJ amplitude in the ballistocardiograms of diabetics. Donoso et al. (1954) mentioned that they had found low amplitude in some records but gave no other details. Rakel et al. (1958) stated that all their records with normal contour also had normal amplitude but they added that twelve of their seventeen ballistocardiograms were abnormally small. Oka and Savola (1961) and Poggi and Farroni (1964) each found records with grade 3 abnormalities: presumably most of these records had low amplitude but no precise details were given. In the present study there was no significant difference in IJ amplitude in the ballistocardiograms of the diabetic patients as compared with the records of the normal subjects. As in the normal subjects the IJ amplitude showed a decline as age increased and men's records were larger than women's. The mean IJ amplitude of the ballistocardiograms of women aged from 20 to 29 years was 63 per cent of that of men's records. This result is very close to the equivalent figure for the normal subjects, namely 65 per cent.

b. Area under IJ segment.

The area measurement showed the same trend as the amplitude results. There was no significant difference between the diabetic and the normal subjects' results. The mean IJ area of the records of women aged from 20 to 29 years was 59 per cent of that of the equivalent men's records. This compares with the figure of 64 per cent for the normal subjects of the same age. The IJ area has not been discussed in previous reports.

c. Respiratory variation of IJ segment.

This subject has been discussed to some extent above. The true proportion of ballistocardiograms with increased respiratory variation is difficult to estimate from previous reports. Oka and Savola (1961) found an incidence of 23 per cent and Poggi and Farroni (1964) reported a figure of 36 per cent. These results may underestimate its occurrence because records of grade 2 abnormality, particularly those with early M pattern, frequently show this phenomenon. It is not clear if grade 2 records of this type have been included in the results quoted above. In the present study only one record of grade 2A abnormality and with early M pattern showed undue respiratory variation. There is thus once more a sharp difference in the results of this and previous investigations. Differences in age and in the incidence of vascular complications may perhaps account for this. There may, of course, be other factors.

d. Duration of IJ segment.

As in the ballistocardiograms of the normal subjects the duration of the IJ segment decreased as age advanced but there was appreciable shortening of the interval in the records of the diabetic patients, compared with those of the normal subjects. Increased rigidity and lack of elasticity of the vascular tree as a whole was invoked by Scarborough et al. (1953) to explain the decrease in the IJ interval with increasing age. Anderson et al. (1961) reported that the aorta was the site of athero-sclerosis in 72 per cent of diabetic subjects and a similarly high incidence was found by Liebow et al. (1955). Increased aortic rigidity might be the cause of the increased pulse wave velocity in diabetics reported by Woolam et al. (1962) and also of the decreased duration of the IJ segment found in the ballistocardiograms. Previous reports have not discussed this measurement.

e. Duration of QJ interval.

The results of the QJ interval measurement were similar in many ways to those of the IJ interval. The mean values obtained from the diabetic patients were significantly lower than those of the equivalent normal subjects, where comparison was valid. The relative decrease compared with normal values might be associated with undue ageing and rigidity of the vascular tree. The significance of the results was probably similar to that of the IJ interval measurements. The QJ interval has not been discussed in previous reports on the ballistocardiograms of diabetic subjects.

3. Smoking Tests.

Apparently symptomless but significant coronary artery sclerosis may exist in the non-diabetic population (Enos et al., 1953; Biorck, 1960) and it is likely that diabetics may have occult coronary artery sclerosis for some time before it becomes clinically manifest. It was shown by Henderson (1953) and Davis et al. (1953, 1956) that there was a fairly high incidence of positive smoking tests in young patients with ischaemic heart disease. In contrast, a positive test in a healthy young person was almost exceptional. In the present study none of the 27 apparently healthy subjects had positive smoking tests whereas 11 of the 30 diabetic patients yielded positive results. This was a highly significant difference. The abnormal patterns produced by smoking were similar to those found in the patients with coronary artery disease. There is thus a possibility that the same factors caused the positive smoking tests in most of the patients with coronary artery disease and in a significant proportion of the diabetic patients.

Lober (1953) has demonstrated that with advancing age there is a progressive increase in coronary artery sclerosis. Acceleration of this process seems likely in young diabetics for they are frequently recorded as dying from coronary disease (White, 1956). The arteriosclerotic process is the same in diabetics and non-diabetics but is more rapid in diabetics. An undue proportion of cases with occult coronary sclerosis might therefore be expected in the diabetic population. The essential problem is that of detection.

The present study does not provide conclusive evidence that the positive smoking tests are due to occult coronary artery disease but the results are suggestive. In general the evidence is reasonably in favour of a relationship to coronary sclerosis but the point at issue could be determined only by a prolonged study over a period of years. At present the ballistocardiographic smoking test seems a useful pointer, particularly because of the difficulty of demonstrating occult coronary disease in vivo in a simple and safe way, and it is tentatively suggested that the diabetic patients with positive smoking tests have occult coronary artery sclerosis.

<u>Summary</u>.

The incidence of abnormal resting ballistocardiograms recorded from diabetic subjects was lower than that mentioned in previous reports.

Several factors may have contributed to this difference: the unequal ages of the patients studied; the inclusion of patients with overt vascular complications in previous series and their exclusion from the present study; and differences in the criteria by which the ballistocardiograms were assessed.

The IJ amplitude and area results were similar to those found in the normal subjects and showed the same variations with sex and age.

The previous observation that increased respiratory variation was relatively common was not confirmed. Differences in age and in the incidence of vascular complications might account for the difference.

The decrease in the duration of the IJ and QJ intervals might be related to arteriosclerosis with rigidity of the aortic wall and an increase in pulse wave velocity.

There was a significant proportion of diabetic patients with positive smoking tests. The abnormalities found in the ballistocardiograms after smoking were essentially the same as those observed in the records of the patients with coronary artery disease. It is suggested that the diabetic patients with positive smoking tests may have occult coronary artery sclerosis.

Chapter 19.

DIABETIC PATIENTS:

CONCLUSIONS.

1. The wave pattern of the resting ballistocardiograms of young patients with apparently uncomplicated diabetes mellitus is usually normal. A small but significant proportion of these records show abnormalities but they are of only moderate severity.

2. Quantitative analysis of the resting ballistocardiograms reveals further significant abnormalities which suggest that the pulse wave velocity is increased in young diabetic patients, possibly due to generalised involvement of the major arterial tree by arteriosclerosis.

3. The use of a stress procedure, such as cigarette smoking, causes abnormalities of the wave pattern of the ballistocardiogram

in some diabetic patients. The resultant abnormalities are similar to those observed in the ballistocardiograms of young patients with clinical evidence of coronary artery disease. This emphasises the value of the smoking test in ballistocardiographic studies.

4. It is tentatively suggested that the abnormal patterns found in the ballistocardiograms of the young diabetic patients, particularly after cigarette smoking, may be taken as indirect evidence of occult coronary artery sclerosis.

5. Its presence is not readily demonstrable by standard clinical methods. Other direct and indirect methods of detecting coronary artery disease are not inevitably accurate in their results and may involve the patient in hazard.

6. Its detection seems important so that measures may be taken to achieve or reinforce good diabetic control in an attempt to minimise further vascular damage.

PART V.

Chapters 20 to 26

THE BALLISTOCARDIOGRAM IN THYROTOXICOSIS.

Chapter 20.

THYROTOXICOSIS AND HEART DISEASE.

1. Introduction.

The association of thyrotoxicosis and cardiac disorders is well recognised. Parry first recorded this in 1825. He was followed during the nineteenth century by Graves (1848) and Lockridge (1879). In the present century there have been numerous publications concerned with the effects of thyrotoxicosis on the cardiovascular system but the relationship between the metabolic and cardiac disorders has remained uncertain and has been the subject of controversy.

Some authors have suggested that thyrotoxicosis in itself causes heart disease, while others have maintained that various forms of independent heart disease, such as coronary sclerosis, hypertension and rheumatic heart disease, are always present as complicating or possibly dominating factors. The effect of thyrotoxicosis on the myocardium itself has also provoked disagreement. Some writers have reported specific myocardial lesions but others have either failed to find them or have proposed alternative explanations for their presence.

The cardiovascular effects of thyrotoxicosis include tachycardia, increased cardiac output and peripheral vasodilatation. There is also a tendency to atrial fibrillation and cardiac failure, whose occurrence may in many cases be due to the combined effects of hyperthyroidism and previously existing cardiac disease, such as coronary sclerosis, hypertension or valvular heart disease. In some instances, however, there is an apparent return to normal with abatement of thyrotoxicosis, which suggests that hormonal factors alone may be responsible for the cardiac arrhythmia or failure in a proportion of affected patients.

The precise cause of thyrocardiac disease has remained elusive but its clarification seems important because it is a prominent source of morbidity and occasionally mortality in what seems an eminently treatable disorder.

2. <u>Thyrotoxicosis as a Cause of Heart Disease.</u>

a. <u>A complication of pre-existing heart disease.</u>

Lahey and Hamilton (1924) held the opinion that in young persons with previously undamaged hearts there appeared to be no cardiac changes, no matter how intense the degree of hyperthyroidism. They commented that thyrotoxicosis seemed to pick out older patients, particularly those with already abnormal hearts, and produce profound cardiac effects that might dominate the clinical picture. Hurxthal (1928) considered that the excessive stimulus of hyperthyroidism revealed pre-existing cardiac weakness but suggested that there was little evidence that thyrotoxicosis injured previously healthy hearts, because of the paucity of cardiac complications in patients under 40 years of age. Ernstene (1938) stated that when thyrotoxicosis was complicated by cardiac failure with normal cardiac rhythm, independent heart disease was almost inevitably found.

b. <u>A specific cause of heart disease.</u>

Kepler and Barnes (1932) examined at post mortem 27 thyrotoxic patients who had had severe cardiac failure. In nine cases no clinical or pathological evidence of hypertension or intrinsic heart disease was found. In the other 18 cases either hypertension or intrinsic cardiac disease was present but in eight of these latter cases the authors considered that there was nothing to suggest that restoration to health would not have occurred had it been possible to control the hyperthyroidism. Magee and Smith (1935) found that 35 of 210 thyrotoxic subjects with atrial fibrillation showed no signs of hypertension or other pre-existing heart disease. They examined 62 cases with cardiac failure and in 29 of these patients hyperthyroidism was the only cause found for the failure. Likoff and Levine (1943) studied 409 patients with thyrotoxicosis and found 21 in whom there was no discernible cause for heart failure apart from hyperthyroidism. Griswold and Keating (1949) reported 54 cases of thyrotoxicosis with cardiac failure. In 18 there was no evidence of primary associated heart disease. Sandler and Wilson (1959) examined 150 patients of whom 64 had cardiac involvement in the absence of any clinical evidence of associated heart disease. Cardiac failure occurred in 21 cases and after treatment of hyperthyroidism it remained absent in 13 cases, five of whom required no further treatment with digitalis or diuretics. Further, post mortem examination of five of these patients without clinical signs of independent heart disease failed to reveal in four cases any other factor causing heart disease.

c. Histopathological studies.

There is some evidence, therefore, to suggest that thyrotoxicosis may affect the function of the heart adversely without necessarily altering its anatomical state but this too has been the subject of dispute. Fahr (1916) reported focal necrosis and interstitial myocarditis in five fatal cases of thyrotoxicosis. Similar findings in two cases were recorded by Hashimoto (1921). Wilson (1923) studied 18 cases and suggested that there was undue fatty change in the myocardium in thyrotoxicosis. Specific lesions have been mentioned also by Goodall and Rogers (1927) and Lewis (1932). Rake and McEachern (1932) studied 27 cases at post mortem examination. They found no relationship between the clinical symptoms and structural changes in the heart, which occurred also in many control cases. They deduced that hyperthyroidism by itself produced no specific lesions in the myocardium and suggested that too much emphasis had been laid on morphological changes with consequent neglect of important changes in myocardial metabolism and function. Weller et al. (1932) were essentially in agreement as a result of a study of 35 fatal cases. The heart was examined histologically in three patients from the series described by Sandler and Wilson (1959). These patients had died from cardiac failure but no specific myocardial lesions were found.

More recent opinion inclines to the view that thyrotoxicosis does not cause a specific histopathological lesion in the heart. Abnormalities such as perivascular infiltration, fatty degeneration and fibrosis probably represent non-specific reactions to prolonged overactivity of the heart (Somerville and Levine, 1950).

3. <u>Thyrotoxicosis and Coronary Insufficiency.</u>

a. <u>Angina pectoris and thyrotoxicosis.</u>

When coronary atherosclerosis complicates thyrotoxicosis, angina pectoris may be brought to light or aggravated to such an extent that it may dominate the clinical situation and lead to failure to diagnosis the underlying metabolic disorder. Treatment of thyrotoxicosis may relieve the anginal symptoms. Haines and Kepler (1930) studied 33 patients with angina pectoris and hyperthyroidism and reported improvement of the anginal pain in most cases after thyroidectomy. Lev and Hamburger (1932) described 9 cases, most of whom improved with abatement of hyperthyroidism. Similar favourable results were reported by Duchosal and Henny (1941). In 1950, Somerville and Levine published details of 24 patients and reported improvement in 13 of 15 patients after thyroidectomy and four out of five subjects after treatment with thiouracils. Sandler and Wilson (1959) found that 19 out of 21 thyrotoxic patients had a decrease in anginal symptoms after radioiodine therapy, ten patients being completely relieved of attacks and nine obtaining some degree of relief.

The relief from angina pectoris that went hand in hand with antithyroid treatment and its continued amelioration when the hyperthyroidism remained in control (Somerville and Levine, 1950) suggest that in such cases the coronary insufficiency was at least partly metabolically determined.

b. Angina pectoris without apparent coronary disease.

Somerville and Levine (1950) suggested that "coronary arteries with a relatively mild degree of arteriosclerosis, too slight to interfere with the blood supply of the heart in the euthyroid patient, may be unable to meet the demand of the increased metabolic rate of the heart in thyrotoxicosis, with its increased oxygen consumption, stroke volume and cardiac output." If the metabolic rate were reduced by treatment the degree of relative coronary insufficiency might be lessened with consequent reduction or disappearance of the anginal symptoms.

In support of their concept they cited the case of a thyrotoxic man of 31 years of age, who had angina pectoris. The pain disappeared immediately after subtotal thyroidectomy and did not recur in the subsequent 17 years. Throughout that period he could exercise without discomfort and his electrocardiogram was normal.

Duchosal and Henny (1941) described a 50 year old woman who had thyrotoxicosis and angina pectoris relieved by trinitrin. During hyperthyroidism, exercise or emotion provoked pain and electrocardiographic abnormalities resembling those of acute posterior myocardial infarction. Lugol's iodine abolished the attacks. Thyroid artery ligation was performed but she died six hours after the operation. Post mortem examination showed normal coronary arteries and no myocardial infarction.

In such cases it seems likely that thyrotoxicosis has affected the heart to the point of causing ischaemic cardiac pain in the absence of significant anatomical lesions of the coronary arteries. Post mortem examination in the case of the woman described by Duchosal and Henny (1941) revealed no coronary sclerosis and it is highly improbable that the man cited by Somerville and Levine (1950) had significant coronary artery disease, in view of his subsequent good health.

c. Effect of thyroxine on the myocardium.

The administration of thyroid hormone greatly enhances the oxygen consumption of the myocardium. The isolated atria of animals rendered hyperthyroid with thyroxine consume more oxygen per unit of weight than those of normal animals, as shown by Andrus (1932), McEachern (1932) and Goh and Dallam (1957).

Brewster et al. (1956) suggested that the haemodynamic and metabolic abnormalities of thyrotoxicosis were not the result of the isolated action of the thyroid hormones on the tissues of the body but were due to the physiological effects of the catecholamines augmented by the thyroid hormones, since total sympathetic block prevented these metabolic changes. Murray and Kelly (1959) suggested the use of an adrenalin infusion as a diagnostic aid in thyrotoxicosis because of this synergistic effect. The myocardial cells have a particular affinity for these amines which have the effects of increasing oxygen consumption and inducing local tissue hypoxia (Raab, 1953).

This experimental evidence is entirely compatible with the postulate of Somerville and Levine (1950) that there may be a metabolically determined form of coronary insufficiency in thyrotoxicosis.

4. Detection of Occult Coronary Insufficiency.

a. Occurrence of occult coronary insufficiency.

Apparently healthy persons may have a significant degree of coronary atherosclerosis in the absence of any cardiac symptoms (Enos et al., 1953). Similarly, it seems likely that some thyrotoxic patients without symptoms or electrocardiographic evidence of coronary insufficiency may have a significant degree of coronary insufficiency. It is improbable that the effects of a metabolically determined form of heart disease, which can provoke angina pectoris or cardiac failure in patients who do not have significant independent cardiac disease (Duchosal and Henny, 1941; Somerville and Levine, 1950), will be confined entirely to patients with overt clinical features. Thus the functional effects of hyperthyroidism on the myocardium may be expected to exist in a proportion of thyrotoxic patients who do not present any clinical or electrocardiographic abnormalities to suggest cardiac involvement.

b. <u>Detection of occult coronary insufficiency</u>.

The detection of an occult form of heart disease of this type is very difficult.

When the presence of coronary atherosclerosis is suspected, direct methods such as selective coronary angiography may be employed to demonstrate the abnormality. Quite apart from the possible disadvantages and the hazards of the method (Hale and Jefferson, 1963), coronary angiography is not a suitable means of investigating a form of coronary insufficiency which is considered to be due not to disease of the coronary arterial tree but to a metabolically determined myocardial abnormality.

Indirect methods of detecting coronary insufficiency include the recording of electrocardiograms before and after stress procedures, such as standardised exercise or induced hypoxia. These measures, however, are not completely successful in demonstrating coronary insufficiency. Further, they are not devoid of hazard. This applies particularly to induced hypoxia (Stewart and Carr, 1954; Wood, 1956).

Cardiac catheterisation has yielded valuable information on the altered haemodynamics of thyroid overactivity (Myers et al., 1950; Humerfelt et al., 1958). These studies did not, however, provide helpful evidence about the basic nature of thyrotoxic heart disease. In particular, they did not illuminate the problem of possible coronary insufficiency.

c. Use of the ballistocardiogram.

Several reports concerning the ballistocardiograms of thyrotoxic patients have been published (Gigli and del Bono, 1955; Alessio, 1956; Garello and Alcozer, 1956). Certain details of the records of patients with hyperthyroidism have been given in the course of more general articles by Starr and Mayock (1948), Mathers et al. (1950) and Fidler et al. (1958).

As mentioned in previous chapters, it is only in subjects under the age of 40 years that ballistocardiographic abnormalities may be considered significant. Beyond that age, abnormal patterns cannot be attributed with any certainty to factors other than ageing. Most of the patients examined by Gigli and del Bono (1955) and Alessio (1956) were less than 40 years of age and all of the cases studied by Garello and Alcozer (1956) were aged from 20 to 40 years. Although the proportion of patients with abnormal ballistocardiograms varied from one series to another, all these authors agreed that abnormal wave patterns were prevalent in the records of thyrotoxic patients.

These authors limited their studies to observation of the abnormal patterns. They indicated that some form of cardiac derangement was present but made no specific comment on the nature of the basic process responsible for the production of the defective wave contours. Alessio (1956), however, showed that they disappeared when the hyperthyroidism was controlled.

The patients cited by Starr and Mayock (1948), Mathers et al. (1950) and Fidler et al. (1958) were few in number and with one exception were over 40 years of age. The emphasis that may be placed on the abnormal contours of their records is therefore uncertain.

Thus previous reports regarding the ballistocardiogram in thyrotoxicosis have not shed much light on the essential nature of the cardiac abnormality.

Because the ballistocardiogram provides little useful information in patients in the older age groups it is most profitably employed in the investigation of cardiovascular problems in patients under 40 years of age. The diagnostic precision of the method may be intensified by the recording of ballistocardiograms before and after smoking. Davis et al. (1953) considered that the smoking test provided a better means of detecting coronary artery insufficiency than any other single indirect method.

The clinical and experimental evidence which suggests that there is a metabolically determined form of coronary insufficiency in thyrotoxicosis has been outlined above. If this form of heart disease is clearly and overtly present, its demonstration by special investigative methods is unnecessary.

On the other hand, the ballistocardiographic method, amplified by the smoking test, can be applied with profit to a specific problem, namely the investigation of possible coronary insufficiency in young patients without evidence of cardiac complications.

Summary.

The association between thyrotoxicosis and cardiac disorders has long been recognised. The precise cause of thyrotoxic heart disease has remained uncertain and controversial. Some authors have suggested that thyrotoxicosis itself causes heart disease while others have averred that it complicates pre-existing independent heart disease.

Earlier reports suggested that thyrotoxicosis could produce specific myocardial abnormalities but more recent histopathological studies were less conclusive. The abnormalities that were observed probably represent non-specific reactions to prolonged overactivity of the heart.

When coronary atherosclerosis complicates thyrotoxicosis, angina pectoris may dominate the clinical picture but treatment of hyperthyroidism frequently releves the cardiac pain. In a few reported cases angina seems to have occurred in the absence of significant coronary artery disease.

This suggests that there may be a metabolically determined form of coronary insufficiency in thyrotoxicosis.

It is likely that occult or latent coronary insufficiency may exist in some thyrotoxic patients but it is very difficult

to demonstrate. Electrocardiography in conjunction with stress procedures and cardiac catheterisation are standard methods of investigation but have not provided the answer and have certain disadvantages.

Previous ballistocardiographic studies of thyrotoxic patients revealed abnormalities but their significance was not fully assessed. Nevertheless the ballistocardiographic method, amplified by the smoking test, can be applied with profit to the specific problem of possible coronary insufficiency in young thyrotoxic patients.

Chapter 21.

THYROTOXIC PATIENTS: MATERIAL, METHOD AND RESULTS.

1. Subjects Studied.

There were 93 women aged from 16 to 39 years. All were thyrotoxic and none showed evidence of independent cardio-vascular disease.

a. Criteria for the diagnosis of thyrotoxicosis.

The diagnosis of thyrotoxicosis depends primarily on the finding of typical clinical features (Wayne, 1960). For this reason there was careful appraisal of the clinical features which were considered of diagnostic importance by Crooks et al. (1959). These were essentially the same clinical features as those occurring in the patients described by Somerville and Levine (1950) and considered of clinical importance by Wayne (1954).

The points in the history that received particular note were lassitude, dyspnoea, palpitation, heat intolerance, undue sweating, unwonted nervousness, excessive appetite and loss of weight. The clinical signs that were especially sought were the presence of a goitre and thyroid bruit, eye signs, fine tremor and hyperkinetic movements, peripheral vasodilatation (as evinced by warm and moist palms) and persistent tachycardia with a heart rate over 90 per minute. When the presence or absence of these clinical features had been determined a thyrotoxic diagnostic index was calculated in the way described by Crooks et al. (1959).

A score of 20 or more was accepted as presumptive evidence of thyrotoxicosis. All patients in the present study had scores in excess of 20 and in most it was more than 25. Further, in 52 cases the abatement of these clinical features during antithyroid treatment confirmed the initial diagnosis (Wayne, 1960).

In addition to the assessment of clinical features the diagnosis of thyrotoxicosis was supported by at least one of the following investigations.

i. Basal metabolic rate.

This was estimated in 43 cases. The procedure was carried out in the usual way with a spirometric apparatus and the result was calculated from the formula of Robertson and

Reid (1952). Values repeatedly over 20 per cent above standard were accepted as evidence of hyperthyroidism.

ii. Serum protein-bound iodine.

This was measured in 27 cases. The method used was a modification of that described by Bodansky et al. (1958). The normal range was 4 to 8 micrograms per 100 ml.. Values over 8 micrograms per 100ml. were regarded as evidence of hyperthyroidism.

iii. Radio-iodine studies of thyroid gland function.

These were undertaken in 43 cases. The method used was that outlined by Wayne (1954). A thyroid gland uptake of more than 45 per cent of the administered dose five hours after it was given, or a plasma protein-bound radio-activity of at least 0.4 per cent of the dose 48 hours after its ingestion, or both factors together, was accepted as evidence of thyrotoxicosis.

b. Other criteria.

The other essential criteria for inclusion in this group are shown below.

i. No history of rheumatic fever or chorea.

ii. No history of angina or claudication pain.

iii. Clinically normal heart and peripheral pulses.

iv. Blood pressure less than 150/90.

v. Normal electrocardiogram.

vi. No cardiac arrhythmia, since this in itself may produce ballistocardiographic abnormalities.

The age distribution of the thyrotoxic patients is shown in Table 43.

Age (years)	Number of patients
15-19	9
20-29	40
30-39	44
15-39	93

Table 43. Age distribution of patients with thyrotoxicosis.

2. Recording of Ballistocardiograms.

a. Resting ballistocardiograms.

These were recorded after the subject had refrained from food and smoking for at least two hours and had lain at rest on the table of the instrument for 20 minutes. The blood pressure and electrocardiogram were taken after the ballistocardiogram had been recorded.

b. <u>Effect of cigarette smoking.</u>

The smoking tests were performed in the standard manner by 26 thyrotoxic patients aged from 19 to 37 years, all habitual smokers.

3. <u>Assessment of Ballistocardiograms.</u>

The form of each ballistocardiogram was inspected and the record was graded from 0 to 4. The IJ segments of typical large inspiratory complexes from three consecutive respiratory cycles and the corresponding small expiratory complexes were measured and the five standard indices were calculated:

i. Amplitude of IJ segment.

ii. Area of triangle under IJ segment.

iii. Respiratory variation of IJ segment.

iv. Duration of IJ segment.

v. Duration of QJ interval.

4. <u>Results.</u>

a. <u>Qualitative analysis.</u>

The wave pattern was normal in 27 resting ballistocardiograms. Two of these records had an undue amount of respiratory variation and were classified as grade 1 but all of the other 25 normal records were classified in grade 0.

In 21 ballistocardiograms there were variable or short-lived defects of wave contour whose ultimate significance was in doubt. These records were considered to be equivocal but were classified as essentially normal. Eighteen ballistocardiograms of this group were placed in grade 0 and three in grade 1.

Definitely abnormal wave patterns of grades 2A, 2B or 3 occurred in 45 ballistocardiograms.

Thus 45 of the 93 thyrotoxic patients had abnormal ballistocardiograms compared with none of the normal subjects. The difference between the two groups was highly significant (p less than 0.001).

These results are summarised in Table 44 and in Table 45 which is shown on the next page.

Form of record	Number of patients
Normal	27
Equivocal	21
Abnormal	45

Table 44. Distribution of normal, equivocal and abnormal ballistocardiograms of patients with thyrotoxicosis.

Grades	Number of patients
0	43
1	5
2A	30
2B	11
3	4
4	0

Table 45. Grades of abnormality of ballistocardiograms of patients with thyrotoxicosis.

Table 46 summarises the wave patterns observed in the abnormal resting ballistocardiograms of the thyrotoxic patients.

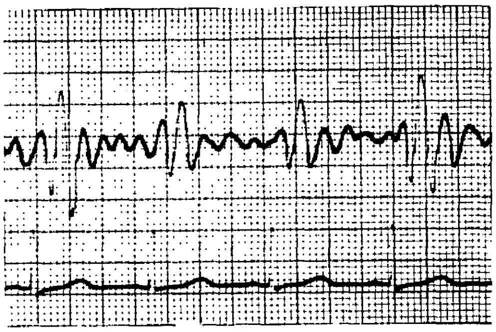
Type of Abnormality	Number of patients
1. Early M	26
2. Late M	13
3. Late downstroke	16
4. Abnormal HI	21
5. Short K	21
6. Prominent L	8
7. Large diastolic waves	4
8. Bizarre waves	6

Table 46. Categories and distribution of abnormal wave contour in the 45 abnormal resting ballistocardiograms of the thyrotoxic patients.

Figure 25.

Ballistocardiograms of thyrotoxic patients.

1. Female, 30 years: grade 0 with normal pattern.
2. Female, 22 years: grade 1 with normal pattern.
3. Female, 33 years: grade 0 with variable short K pattern. (Equivocal ballistocardiogram).
4. Female, 22 years: grade 2A with short K pattern.
5. Female, 37 years: grade 2A with early M pattern.
6. Female, 31 years: grade 3 with combined early and late M patterns in 1st, 2nd and 4th complexes and early M pattern in 3rd and fifth complexes.



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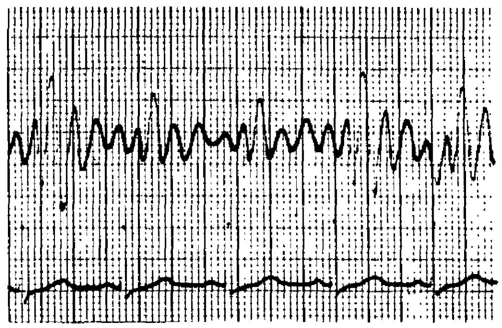

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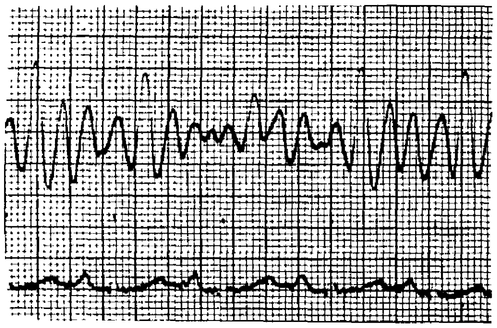

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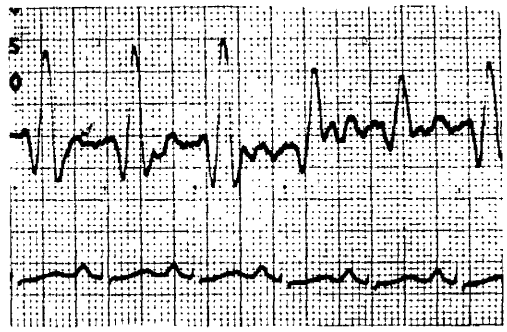

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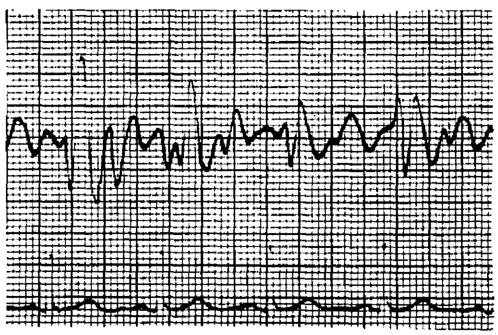

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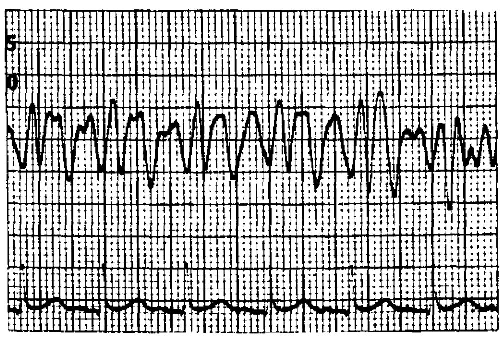


6.

There was a considerable variety of wave patterns in the 45 abnormal resting ballistocardiograms. More than one type of abnormal wave pattern might occur in a single record. Figure 25 shows examples of these deformed wave contours in addition to records with normal wave pattern.

There were transiently abnormal wave patterns in the equivocal records that were classified in grades 0 and 1. Table 47 shows the distribution of deviant contours in these ballistocardiograms. The early M, late M and late downstroke patterns were not found in the equivocal records.

Type of abnormality	Number of patients
4. Abnormal HI	9
5. Short K	16
6. Prominent L	2

Table 47. Categories and distribution of transiently abnormal wave patterns in the 21 equivocal resting ballisto-cardiograms of the thyrotoxic patients. The categories are numbered as in Table 46.

b. Quantitative Analysis.

i. Amplitude of IJ segment.

The IJ amplitude results are summarised in Table 48.

Age (years)	No.	Observed range (mm.)	Mean (mm.)	S.D. (mm.)	Normal range (mm.)
15-19	9	10.8-26.0	16.1	3.75	11.3-14.9
20-29	40	6.1-25.9	15.1	4.52	9.5-16.9
30-39	44	5.2-23.3	14.5	5.04	8.4-15.2

Table 48. Amplitude of IJ segment (mm.) in thyrotoxic females showing ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison.

Table 49 compares the mean IJ amplitude of the thyrotoxic and normal groups' ballistocardiograms.

Age	Thyrotoxic patients			Normal subjects			S.E.	Difference of means
(yrs.)	No.	Mean	S.D.	No.	Mean	S.D.		S.E.
15-19	9	16.1	3.75	10	13.1	0.9	1.70	1.77
20-29	40	15.1	4.52	51	13.2	1.85	0.76	2.50
30-39	44	14.5	5.04	33	11.8	1.7	0.64	4.22

Table 49. Significance of difference of mean IJ amplitude in thyrotoxic and normal females. S.D. = Standard deviation. S.E. = standard error of difference between means. Results in mm..

The mean amplitude of the IJ segment was consistently greater in the ballistocardiograms of the thyrotoxic patients than in those of the equivalent normal subjects.

The difference was statistically significant in the subjects aged from 20 to 39 years but not in those aged from 15 to 19 years. The difference in this latter group might, however, be a real one. The failure to demonstrate it at a statistically significant level could be due to the small number of subjects and the relatively wide scatter of the amplitude results of the thyrotoxic patients.

Both abnormally high and unduly low values of the IJ amplitude were found in each age group but the striking feature revealed by this analysis of the ballistocardiograms of the thyrotoxic patients was the high proportion (43 per cent) with increased amplitude of the IJ segment. The difference between the thyrotoxic and normal subjects in this respect was highly significant (p less than 0.001).

ii. Area under IJ segment.

Table 50 summarises the IJ area results.

Age (years)	No.	Observed range (mm.sec.)	Mean (mm.sec.)	S.D.	Normal range (mm.sec.)
15-19	9	.39-1.10	.64	.235	.52-.66
20-29	40	.16- .95	.55	.185	.38-.74
30-39	44	.16- .83	.55	.155	.30-.66

Table 50. Area under IJ segment (mm.sec.) in thyrotoxic females showing observed ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison.

Table 51 compares the mean IJ area of the thyrotoxic and normal subjects' ballistocardiograms.

Age	Thyrotoxic patients			Normal subjects			S.E.	Difference of means
(years)	No.	Mean	S.D.	No.	Mean	S.D.		S.E.
15-19	9	.64	.235	10	.59	.035	.079	0.63
20-29	40	.55	.185	51	.56	.09	.032	0.31
30-39	44	.55	.155	33	.48	.09	.028	2.50

Table 51. Significance of difference of mean IJ area in thyrotoxic and normal females. S.D.= Standard deviation. S.E. = Standard error of difference between means. Results in mm. sec..

As in the case of the IJ amplitude results, there was a wide scatter of IJ area measurements in the records of the thyrotoxic women. There was, however, a greater tendency for the thyrotoxic and normal subjects' results to overlap and the mean values were appreciably closer to one another in each age group. The difference between the mean values of the thyrotoxic and normal subjects was significant in the case of women aged from 30 to 39 years but not in younger subjects. Nevertheless the ballistocardiograms of 18 thyrotoxic women showed abnormally great IJ area compared with none of those of the normal women. The difference was highly significant (p less than 0.001).

iii. Respiratory variation of IJ segment.

As before this was expressed in terms of the "Ra" ratio. A value of less than 0.50 was regarded as abnormal.

Age (years)	No.	Observed range ("Ra")	Mean ("Ra")	Normal range ("Ra")
15-19	9	.46-.86	.55	.50-1.00
20-29	40	.30-.83	.57	.50-1.00
30-39	44	.16-.82	.54	.50-1.00

Table 51. Degree of respiratory variation ("Ra" ratio) in thyrotoxic patients, showing observed ranges, mean values and normal ranges for comparison.

The ratio was abnormal in the ballistocardiograms of 34 thyrotoxic patients but in none of the normal subjects' records. The difference was highly significant (p less than 0.001).

iv. Duration of IJ segment.

The results are shown in Table 52.

Age (years)	No.	Observed range (sec.)	Mean (sec.)	S.D. (sec.)	Normal range. (sec.)
15-19	9	.068-.090	.079	.008	.083-.097
20-29	40	.052-.090	.070	.008	.079-.091
30-39	44	.050-.105	.073	.0085	.067-.095

Table 52. Duration of IJ segment (sec.) in thyrotoxic patients with observed ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison.

Table 53 compares the mean IJ interval of the thyrotoxic and normal women's ballistocardiograms.

Age	Thyrotoxic patients			Normal subjects			S.E.	Difference of means
(years)	No.	Mean	S.D.	No.	Mean	S.D.		S.E.
15-19	9	.079	.008	10	.090	.0035	.0029	3.79
20-29	40	.070	.008	51	.085	.003	.0013	11.5
30-39	44	.073	.0085	33	.081	.007	.0018	4.44

Table 53. Significance of difference of mean duration of IJ segment in thyrotoxic and normal females. S.D.= Standard deviation. S.E.= Standard error of difference between means. Results in sec..

The mean duration of the IJ interval was consistently lower in the ballistocardiograms of the thyrotoxic patients than in those of the equivalent normal subjects. In each age group the difference was highly significant. Forty-six of the records of the thyrotoxic subjects had IJ intervals below the normal range. The difference between the thyrotoxic and the normal subjects was highly significant (p less than 0.001).

v. <u>Duration of QJ interval</u>.

The results are shown in Table 54.

Age (years)	No.	Observed range (sec.)	Mean (sec.)	S.D. (sec.)	Normal range (sec.)
15-19	9	.212-.232	.220	.0065	.232-.288
20-29	40	.187-.242	.216	.013	.231-.267
30-39	44	.180-.252	.211	.011	.218-.262

Table 54. Duration of QJ interval (sec.) in thyrotoxic patients, showing observed ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison.

Table 55 (shown on the next page) compares the mean QJ interval of the thyrotoxic and normal women's ballistocardiograms.

Age	Thyrotoxic patients			Normal subjects			S.E.	Difference of means
(yrs.)	No.	Mean	S.D.	No.	Mean	S.D.		S.E.
15-19	9	.220	.0065	10	.260	.014	.0049	8.2
20-29	40	.216	.013	51	.249	.009	.0024	13.75
30-39	44	.211	.011	33	.240	.011	.0025	11.6

Table 55. Significance of difference of mean QJ interval in thyrotoxic and normal females. S.D.= Standard deviation. S.E.= Standard error of difference between means. Results in sec..

Both the ranges and mean values of the QJ interval were lower in the thyrotoxic patients than in the normal subjects. In each age group the differences in the mean values were highly significant. QJ intervals below the normal range were observed in the ballistocardiograms of 77 thyrotoxic patients (83 per cent). Most of the other 16 ballistocardiograms in this group had QJ intervals low in the normal range. The difference between the thyrotoxic and normal women in this respect was highly significant (p less than 0.001).

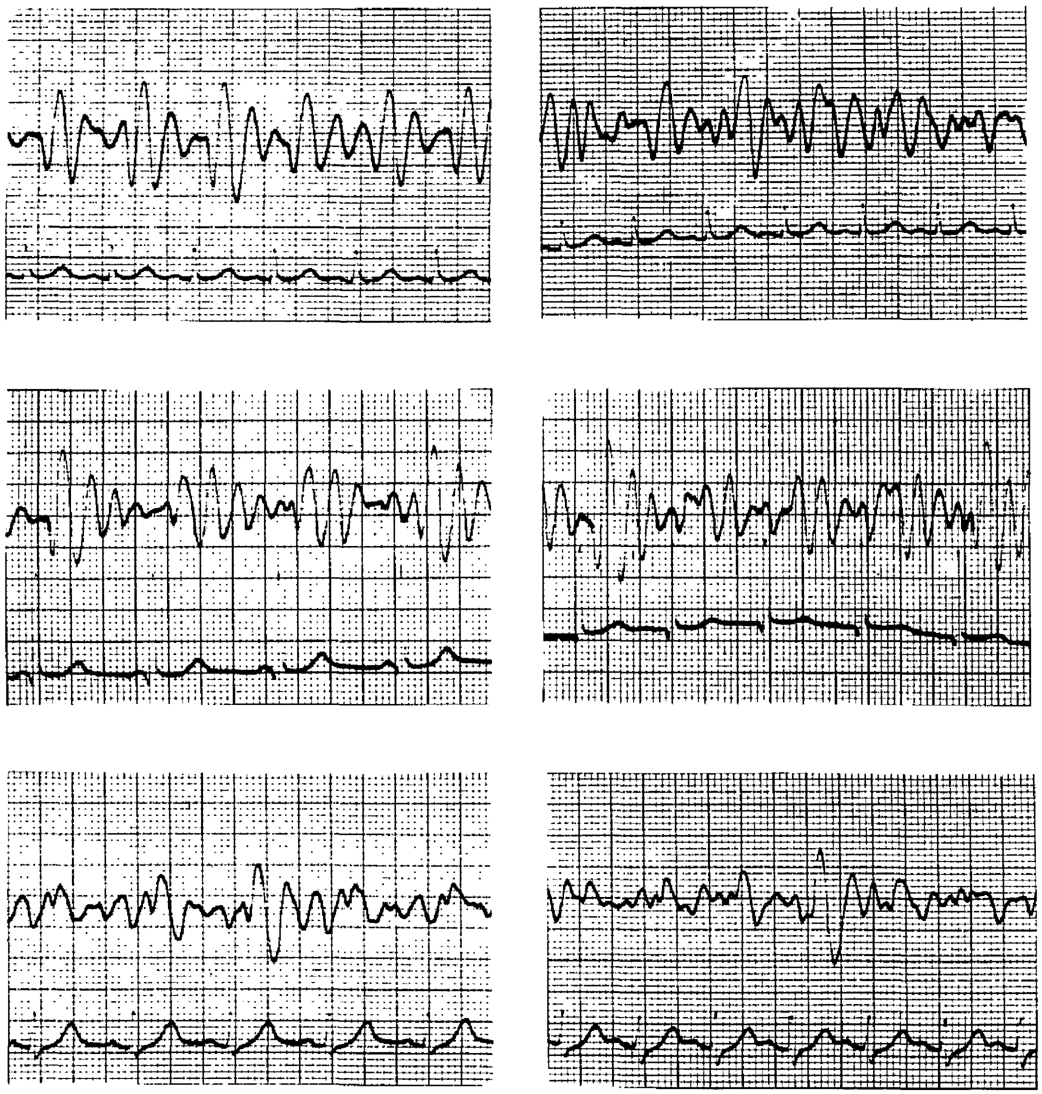
Figure 26.

Positive smoking tests in thyrotoxic patients.

1. Female, 22 years: grade 0 with normal pattern before smoking and grade 2A with late M and late downstroke patterns after smoking.
2. Female, 37 years: grade 0 with variable prominent L pattern (equivocal record) before smoking and grade 2B with late M pattern after smoking.
3. Female, 28 years: grade 2B with early M pattern before smoking and grade 3 with early M, late downstroke and abnormal HI patterns after smoking.

In some cases additional abnormal patterns were present in other parts of the ballistocardiograms.

BEFORE SMOKING **AFTER SMOKING**



1.

2.

3.

Figure. 27.

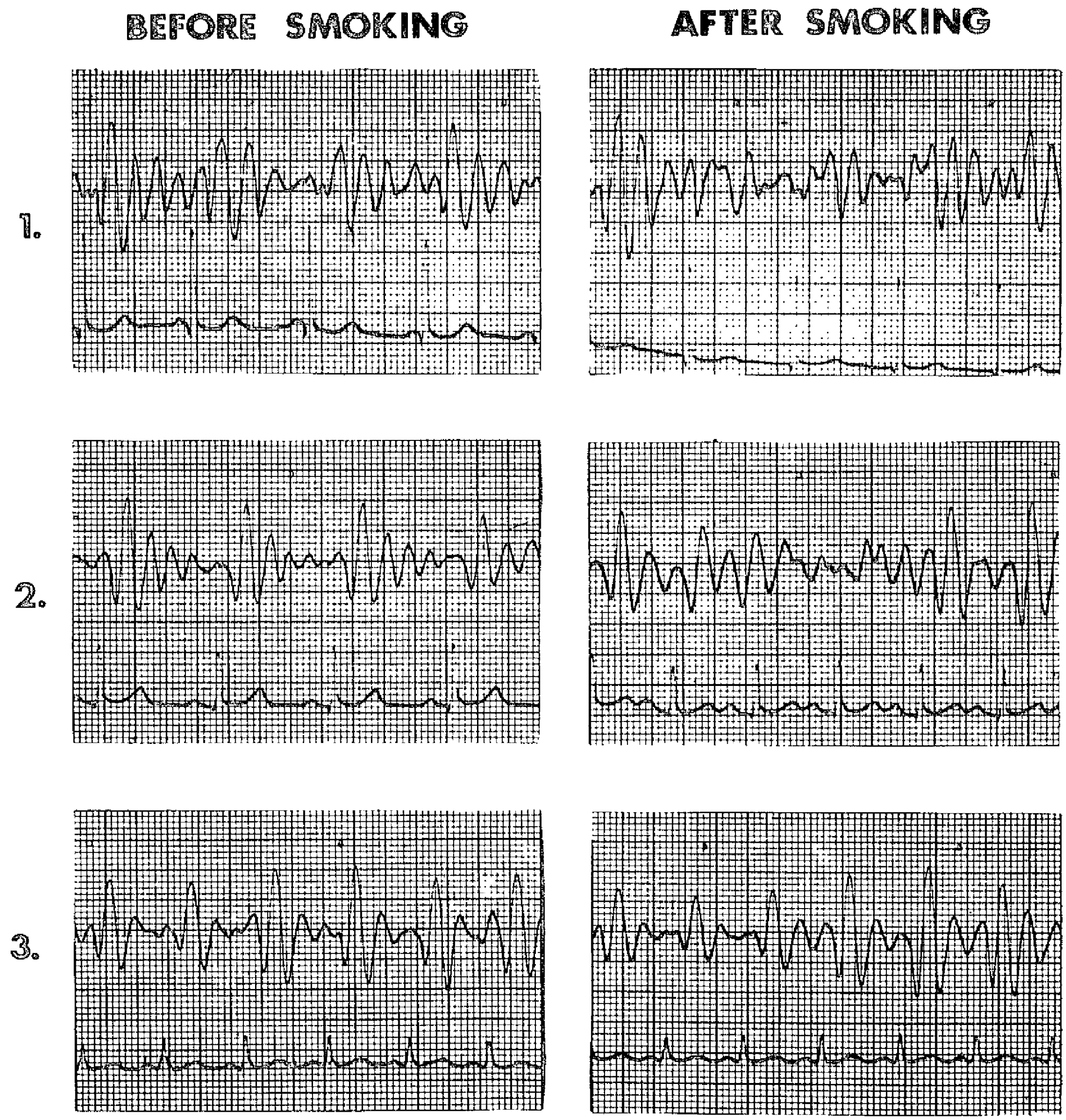
Smoking tests in thyrotoxic patients.

1. Female, 29 years: grade 0 with variable abnormal HI pattern (equivocal record) before smoking and grade 2B with late M and late downstroke patterns after smoking. Positive test.

2. Female, 22 years: grade 0 with normal pattern before smoking and grade 2A with early M and late M patterns after smoking. Positive test.

3. Female, 30 years: grade 0 with normal pattern before and after smoking. Negative test.

In some cases additional abnormal patterns were present in other parts of the ballistocardiograms.


BEFORE SMOKING
AFTER SMOKING
1.
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c. Smoking tests.

The results of the smoking tests are shown in Table 56.

Result of test	Number of patients
Negative	5
Positive	21

Table 56. Results of smoking tests in thyrotoxic patients.

Figures 26 and 27 show examples of smoking tests.

The grades of abnormality of the ballistocardiograms before and after smoking are shown in Table 57.

Grade before smoking	Grade after smoking				
	0	1	2A	2B	3
0	4	0	5*	4*	1*
1	0	0	0	0	0
2A	0	0	1	9*	0
2B	0	0	0	0	2*

Table 57. Grades of wave abnormality before and after smoking in thyrotoxic patients. Positive tests *.

Eight of the resting ballistocardiograms had normal wave form and of these five developed abnormalities of grade 2A, 2B or 3 after smoking but three remained normal. Six of the initial records were classified as equivocal but placed in grade 0. Five of these became abnormal (grades 2A or 2B) and one remained equivocal (grade 0). Thus ten of these fourteen tests were positive.

Twelve ballistocardiograms were abnormal in form before smoking. Ten had grade 2A and two had grade 2B abnormalities. One grade 2A record was not altered by smoking but all other grade 2A records developed grade 2B abnormalities after smoking. The two grade 2B records developed grade 3 abnormalities after smoking. There were therefore eleven positive tests in this group.

Thus there were 26 smoking tests, of which 21 were positive and five were negative. None of the normal subjects had a positive smoking test. The difference in the incidence of positive smoking tests in the two groups was highly significant (p less than 0.001).

There was considerably varied wave pattern before and after smoking. The basic forms observed were the early M, late M, late downstroke, abnormal HI, short K, prominent L, abnormal late diastolic wave and bizarre patterns. Details of the wave patterns are shown in the Appendix in Tables G and H.

Summary.

The ballistocardiograms of 93 female patients with thyrotoxicosis were analysed. Twenty-seven records had normal wave contour, 21 showed variable or short-lived wave defects and were regarded as equivocal and 45 ballistocardiograms showed abnormal patterns of grade 2A, 2B or 3 severity.

The mean IJ amplitude was greater than normal and a significant proportion of the ballistocardiograms had increased amplitude. In general, the mean IJ area was not increased but many individual ballistocardiograms had unduly great area values.

The degree of respiratory variation was abnormally great in 36.5 per cent of the ballistocardiograms.

The mean duration of the IJ segment was decreased and about half of the records had IJ intervals below the normal range. The mean duration of the QJ interval was decreased and most of the ballistocardiograms had short QJ intervals.

The ballistocardiograms of 26 patients were examined before and after the smoking of a cigarette. There were 21 positive and five negative smoking tests. The difference in the incidence of positive tests in the thyrotoxic patients compared with the normal subjects was highly significant.

Chapter 22.

EUTHYROID PATIENTS:
MATERIAL, METHOD AND RESULTS.

1. Subjects Studied.

There were 66 women aged from 16 to 39 years. All were euthyroid after treatment of thyrotoxicosis. In 52 cases the patients were drawn from the thyrotoxic group. A further 14 patients who were not previously studied but who were euthyroid after treatment of thyrotoxicosis were added (Table 58).

Age (years)	Thyrotoxic group	Euthyroid only	Total
15-19	7	1	8
20-29	18	3	21
30-39	27	10	37
15-39	52	14	66

Table 58. Age distribution of euthyroid patients, showing which subjects were drawn from the thyrotoxic group.

a. Criteria for attainment of the euthyroid state.

The clinical features of hyperthyroidism had disappeared or were so scanty that the thyrotoxic diagnostic index (Crooks et al., 1959) was less than 11. It should be emphasised, however, that an increase in the size of the goitre or an increase in the severity of the eye signs may occur as the thyrotoxic state regresses. On this account these two features alone were not regarded as suggesting the persistence of thyrotoxicosis.

In addition to the assessment of clinical features the attainment of the euthyroid state was confirmed by at least one of the following investigations.

i. Basal metabolic rate.

This was estimated in 38 cases. The standard procedure was followed. The results were calculated from the formula of Robertson and Reid (1952). A value of less than 15 per cent above standard was accepted as normal.

ii. Serum protein-bound iodine.

This was measured in 30 cases. The method used was a modification of that described by Bodansky et al. (1958). The normal range was taken to be from 4 to 8 micrograms per 100 ml..

iii. Radio-iodine studies of thyroid gland function.

These are of very limited value in the establishment of the euthyroid state after treatment of thyrotoxicosis. They were therefore not repeated.

b. Other criteria.

The other essential criteria for inclusion in this group were the same as those outlined in Chapter 21 for the thyrotoxic patients.

i. No history of rheumatic fever or chorea.

ii. No history of angina or claudication pain.

iii. Clinically normal heart and peripheral pulses.

iv. Blood pressure less than 150/90.

v. Normal electrocardiogram.

vi. No cardiac arrhythmia.

2. Recording of Ballistocardiograms.

a. Resting ballistocardiograms.

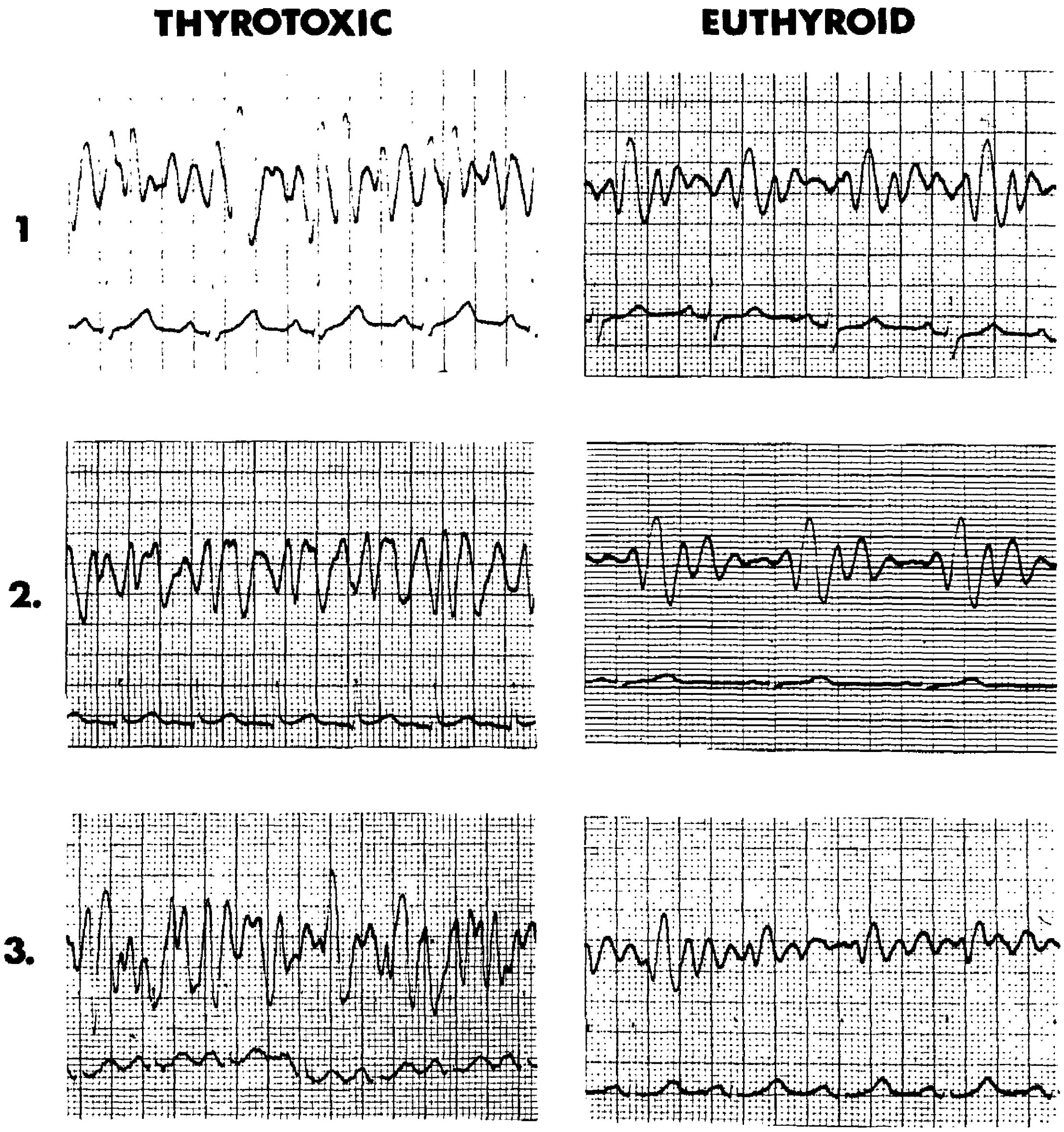
These were recorded after the patient had refrained from food and smoking for at least two hours and had lain at rest on the table for 20 minutes. The blood pressure and electrocardiograms were taken as usual after the recording of the ballistocardiogram.

Figure 28.

Ballistocardiograms of euthyroid patients.

In each case the ballistocardiogram of the same patient when thyrotoxic is shown for comparison.

1. Female, 27 years: grade 2B with early M pattern (thyrotoxic) and grade 0 with normal pattern (euthyroid).
2. Female, 31 years: grade 3 with early M and combined early and late M patterns (thyrotoxic) and grade 0 with normal pattern (euthyroid).
3. Female, 37 years: grade 3 with late M, late downstroke and abnormal HI patterns (thyrotoxic) and grade 0 with equivocal variable short K pattern (euthyroid).


THYROTOXIC
EUTHYROID
1
2.
3.

These results are summarised in Table 59 and Table 60.

Form of record	Number of patients
Normal	65
Equivocal	1
Abnormal	0

Table 59. Distribution of normal, equivocal and abnormal ballistocardiograms of euthyroid patients.

Grades	Number of patients
0	66
1	0
2A and 2B	0
3 and 4	0

Table 60. Grades of abnormality of ballistocardiograms of euthyroid patients.

Figure 28 shows examples of resting ballistocardiograms of euthyroid patients and also shows the records of the same patients when they were thyrotoxic.

b. Quantitative analysis.

i. Amplitude of IJ segment.

The results are summarised in Table 61.

Age (yrs.)	No.	Observed range (mm.)	Mean (mm.)	S.D. (mm.)	Normal range (mm.)
15-19	8	12.1-15.8	13.6	1.25	11.3-14.9
20-29	21	8.8-15.7	13.0	2.0	9.5-16.9
30-39	37	8.3-14.3	11.3	1.5	8.4-15.2

Table 61. Amplitude of IJ segment (mm.) in euthyroid patients, showing observed ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison.

Table 62 compares the mean IJ amplitude of the euthyroid and normal subjects' ballistocardiograms.

Age	Euthyroid patients			Normal subjects			S.E.	Difference of means / S.E.
(yrs.)	No.	Mean	S.D.	No.	Mean	S.D.		
15-19	8	13.6	1.25	10	13.1	0.9	0.53	0.94
20-29	21	13.0	2.0	51	13.2	1.85	0.51	0.39
30-39	37	11.3	1.5	33	11.8	1.7	0.39	1.28

Table 62. Significance of difference of mean IJ amplitude in euthyroid and normal females. S.D.= Standard deviation. S.E.= Standard error of difference between means. Results in mm..

The ranges and mean values of the IJ amplitude were essentially normal in the ballistocardiograms of the euthyroid subjects. The incidence of records with unduly great IJ amplitude did not differ significantly in the euthyroid and the normal series (p between 0.70 and 0.50).

ii. Area under IJ segment.

Table 63 summarises the results.

Age (yrs.)	No.	Observed range (mm.sec.)	Mean (mm.sec.)	S.D.	Normal range (mm.sec.)
15-19	8	.53-.74	.60	.07	.52-.66
20-29	21	.38-.67	.54	.085	.38-.74
30-39	37	.30-.64	.46	.075	.30-.66

Table 63. Area under IJ segment (mm.sec.) in euthyroid patients showing observed ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison.

Table 64 (overleaf) compares the mean IJ area of the euthyroid and normal subjects' ballistocardiograms.

The ranges and mean values of the IJ area were essentially the same in the ballistocardiograms of the euthyroid and the normal subjects. The incidence of records with unduly great IJ area did not differ significantly in the two series (p between 0.90 and 0.80).

Age (yrs.)	Euthyroid patients No.	Mean	S.D.	Normal subjects No.	Mean	S.D.	S.E.	Difference of means / S.E.
15-19	8	.60	.07	10	.59	.035	.026	0.38
20-29	21	.54	.085	51	.56	.09	.022	0.95
30-39	37	.46	.075	33	.48	.09	.020	1.00

Table 64. Significance of difference of mean IJ area in euthyroid and normal females. S.D.= standard deviation. S.E.= standard error of difference between means. Results in mm.sec..

iii. Respiratory variation of IJ segment.

This was expressed as the "Ra" ratio. The results are shown in Table 65.

Age (yrs.)	No.	Observed range ("Ra")	Mean ("Ra")	Normal range ("Ra")
15-19	8	.72-.83	.78	.50-1.00
20-29	21	.60-.94	.77	.50-1.00
30-39	37	.52-.94	.72	.50-1.00

Table 65. Degree of respiratory variation ("Ra" ratio) in euthyroid patients, showing observed ranges, mean values and normal ranges for comparison.

The ratio was normal in every ballistocardiogram.

iv. Duration of IJ segment.

The results are summarised in Table 66.

Age (yrs.)	No.	Observed range (sec.)	Mean (sec.)	S.D. (sec.)	Normal range (sec.)
15-19	8	.084-.094	.087	.0035	.083-.097
20-29	21	.070-.095	.083	.005	.079-.091
30-39	37	.067-.090	.080	.007	.067-.095

Table 66. Duration of IJ segment (sec.) in euthyroid patients, showing observed ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison.

Table 67 compares the mean IJ interval of the euthyroid and normal subjects' ballistocardiograms.

Age	Euthyroid patients			Normal subjects			S.E.	Difference of means / S.E.
(yrs.)	No.	Mean	S.D.	No.	Mean	S.D.		
15-19	8	.087	.0035	10	.090	.0035	.0016	1.83
20-29	21	.083	.005	51	.085	.003	.0012	1.63
30-39	37	.080	.007	33	.081	.007	.0016	0.61

Table 67. Significance of difference of mean IJ interval in euthyroid and normal females. S.D.= standard deviation. S.E.= standard error of difference between means. Results in sec..

The range and mean duration of the IJ segment were essentially the same in the ballistocardiograms of the euthyroid and the normal subjects. The incidence of records with unduly brief IJ intervals did not differ significantly in the two series (p between 0.50 and 0.30).

v. <u>Duration of QJ interval</u>.

The results are summarised in Table 68.

Age (yrs.)	No.	Observed range (sec.)	Mean (sec.)	S.D. (sec.)	Normal range (sec.)
15-19	8	.248-.272	.256	.009	.232-.288
20-29	21	.230-.275	.249	.013	.231-.267
30-39	37	.220-.272	.245	.013	.218-.262

Table 68. Duration of QJ interval (sec.) in euthyroid patients, with observed ranges, means, standard deviations (S.D.) and calculated normal ranges for comparison.

Table 69 compares the mean QJ interval of the euthyroid and normal women's ballistocardiograms.

Age (yrs.)	Euthyroid patients No.	Mean	S.D.	Normal subjects No.	Mean	S.D.	S.E.	Difference of means / S.E.
15-19	8	.256	.009	10	.260	.014	.0049	1.22
20-29	21	.249	.013	51	.249	.009	.0031	0
30-39	37	.245	.013	33	.240	.011	.0029	1.72

Table 69. Significance of difference of mean QJ interval in euthyroid and normal females. S.D.= standard deviation. S.E.= standard error of difference between means. Results in sec..

The range and mean duration of the QJ interval were basically the same in the ballistocardiograms of the euthyroid and the normal women. The incidence of records with QJ intervals below the normal range did not differ significantly in the two series (p between 0.80 and 0.70).

c. Smoking tests.

The results of the smoking tests are shown in Table 70.

Results of tests	Number of patients.
Negative	9
Positive	0

Table 70. Results of smoking tests in euthyroid patients.

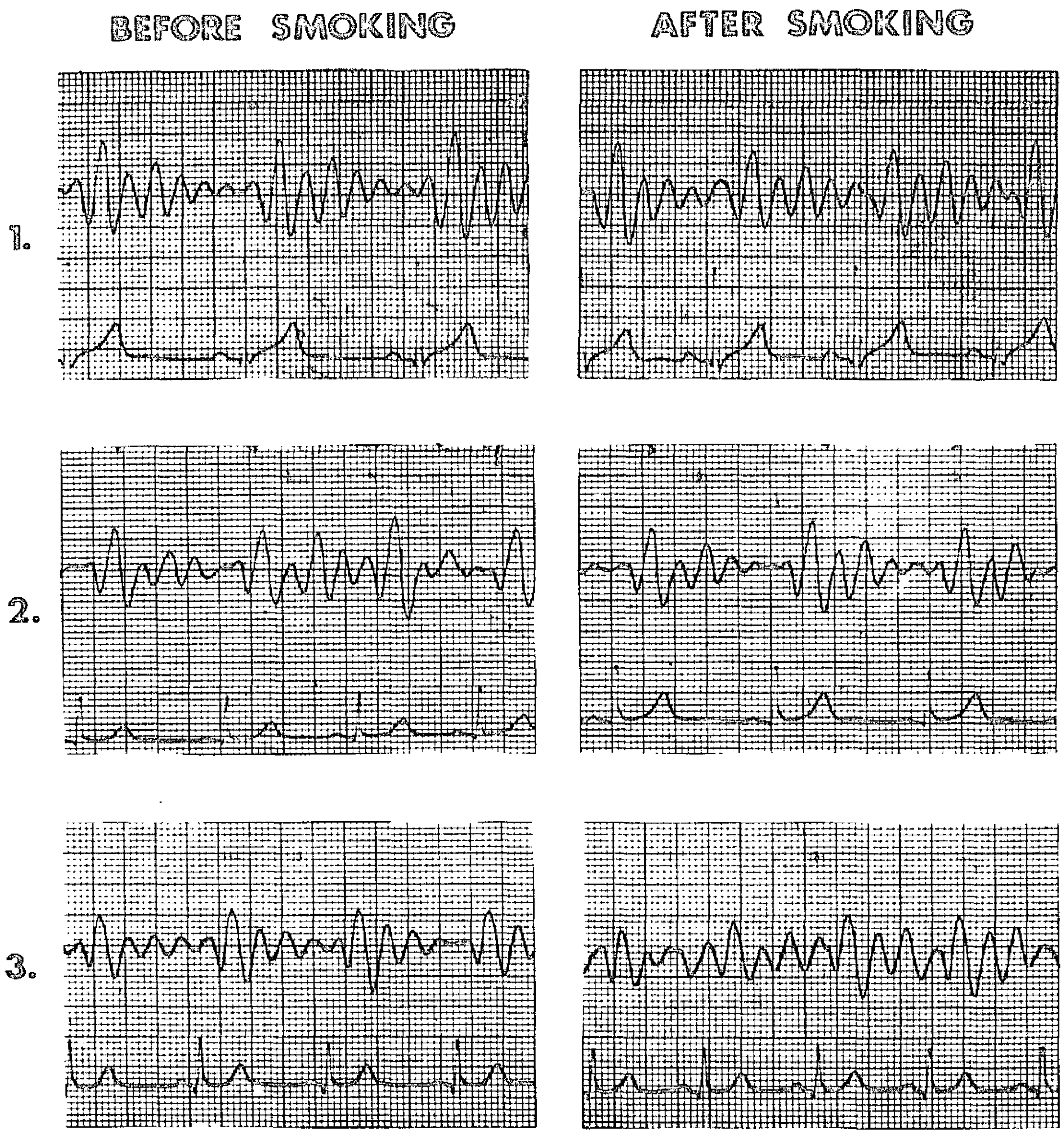
Figure 29 shows examples of smoking tests.

Figure 29.

Smoking tests in euthyroid patients.

1. Female, 20 years.
2. Female, 30 years.
3. Female, 38 years.

All ballistocardiograms were grade 0 with normal pattern before and after smoking and all three tests were negative.


BEFORE SMOKING
AFTER SMOKING
1.
2.
3.

All nine resting ballistocardiograms were normal in contour and were placed in grade 0. One ballistocardiogram developed an undue amount of respiratory variation with smoking and was classified as grade 1. This test was recorded as negative since a simple increase in respiratory variation does not constitute a positive smoking test. Another ballistocardiogram developed intermittent abnormality of the HI segment. This record was considered equivocal and classified as grade 0. This smoking test was recorded as normal. The remaining seven ballistocardiograms did not alter significantly with smoking and remained in grade 0.

Thus there were nine smoking tests, all of which were negative. The similarity of this result to that obtained in the normal subjects is evident.

Details of these smoking tests are given in Table J of the Appendix.

<u>Summary</u>.

The ballistocardiograms of 66 euthyroid female patients, aged from 16 to 39 years who had been treated for thyrotoxicosis were analysed.

The ballistocardiograms all had normal wave contour except for one record which showed variable wave defects. This ballistocardiogram was considered equivocal but was classified as essentially normal.

Quantitative analysis showed no difference between the ballistocardiograms of the euthyroid patients and equivalent normal subjects.

The ballistocardiograms of nine patients were examined before and after the smoking of a cigarette. All nine smoking tests were negative. This result was the same as that obtained in the normal subjects.

Chapter 23.

COMPARISON OF BALLISTOCARDIOGRAMS OF THYROTOXIC AND EUTHYROID PATIENTS.

1. Qualitative Analysis.

Tables 71 and 72 compare the classification and grading of the ballistocardiograms of the thyrotoxic and euthyroid patients.

Form of record	Thyrotoxic patients	Euthyroid patients
Normal	27	65
Equivocal	21	1
Abnormal	45	0

Table 71. Distribution of normal, equivocal and abnormal ballistocardiograms of thyrotoxic and euthyroid patients.

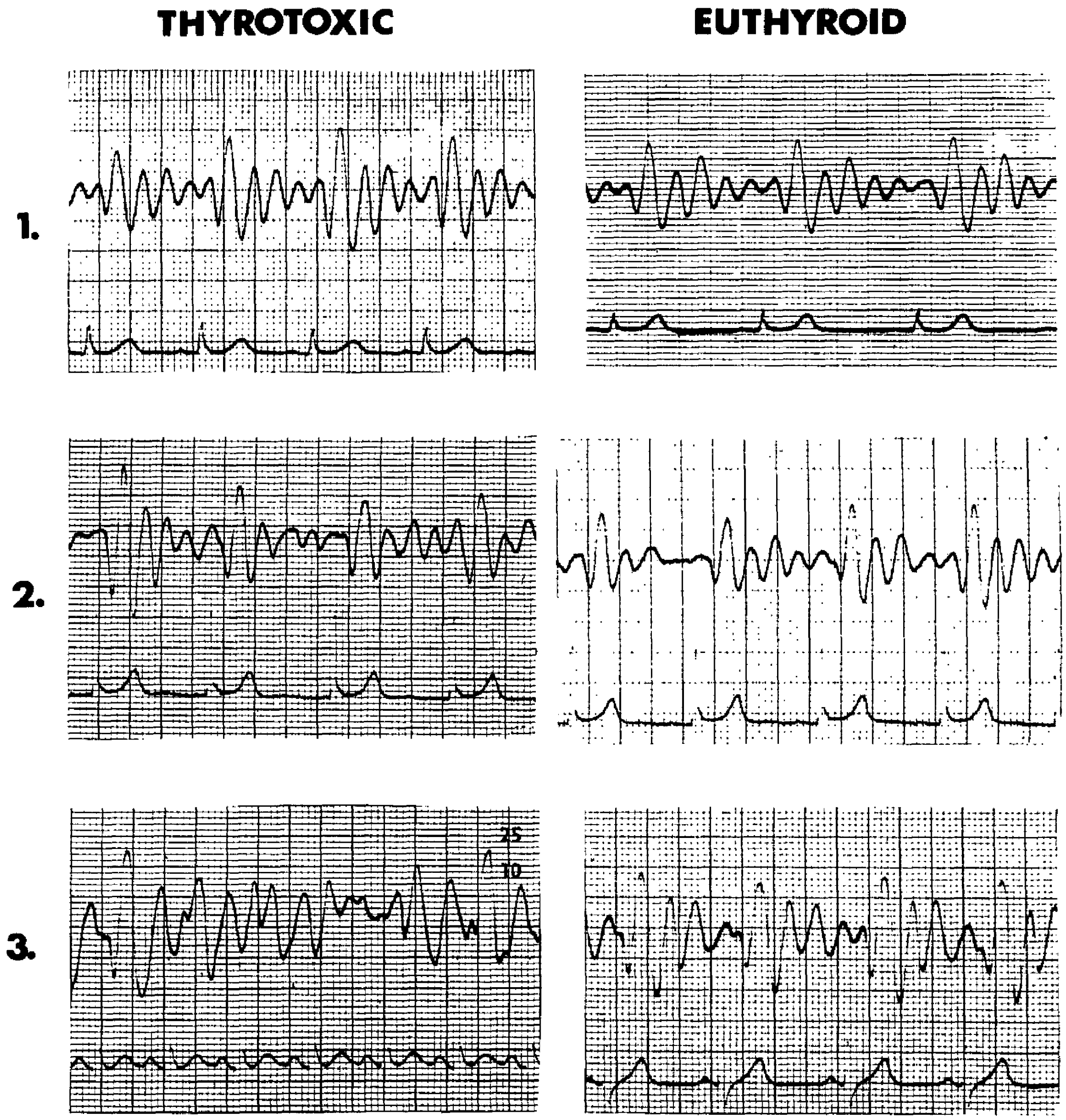
Grades	Thyrotoxic patients	Euthyroid patients
0	43	66
1	5	0
2A	30	0
2B	11	0
3	4	0

Table 72. Grades of abnormality of ballistocardiograms of thyrotoxic and euthyroid patients.

Figure 30.

Ballistocardiograms of patients when thyrotoxic and euthyroid.

1. Female, 34 years: grade 0 with normal pattern (thyrotoxic and euthyroid).
2. Female 33 years: grade 1 with normal pattern (thyrotoxic) and grade 0 with normal pattern (euthyroid).
3. Female, 16 years: grade 2B with early M, late M and abnormal HI patterns (thyrotoxic) and grade 0 with normal pattern (euthyroid).


THYROTOXIC
EUTHYROID
1.
2.
3.
25
10

The incidence of persistently abnormal records in the thyrotoxic patients was 48 per cent. None of the euthyroid patients had an abnormal ballistocardiogram. The difference was highly significant (p less than 0.001).

Examples of ballistocardiograms recorded during thyrotoxicosis and later in the euthyroid phase are shown in Figure 30.

2. Quantitative Analysis.

i. Amplitude of IJ segment.

Table 73 compares the IJ amplitude of the thyrotoxic and euthyroid patients.

Age (yrs.)	Thyrotoxic patients No.	Mean	S.D.	Euthyroid patients No.	Mean	S.D.	S.E.	Difference of mean / S.E.
15-19	9	16.1	3.75	8	13.6	1.25	1.74	1.44
20-29	40	15.1	4.52	21	13.0	2.0	0.84	2.50
30-39	44	14.5	5.04	37	11.3	1.5	0.62	5.16

Table 73. Significance of difference of mean IJ amplitude in thyrotoxic and euthyroid patients. S.D.= standard deviation. S.E. = standard error of difference between means. Results in mm.

The results of the thyrotoxic patients differed significantly from those of the euthyroid patients. The mean IJ amplitude was consistently greater in the records of the thyrotoxic patients. The difference was highly significant in the case of the subjects aged from 20 to 39 years (p less than 0.001). The failure to demonstrate a similar difference in the patients aged from 15 to 19 years was perhaps due to the small number of subjects studied and the wide scatter of the amplitude results of the thyrotoxic patients.

ii. <u>Area under IJ segment.</u>

Table 74 compares the IJ area results of the thyrotoxic and euthyroid patients.

Age (yrs.)	Thyrotoxic patients No.	Mean	S.D.	Euthyroid patients No.	Mean	S.D.	S.E.	Difference of means / S.E.
15-19	9	.64	.235	8	.60	.07	.082	0.49
20-29	40	.55	.185	21	.54	.085	.034	0.29
30-39	44	.55	.155	37	.46	.075	.027	3.40

Table 74. Significance of difference of mean IJ area in thyrotoxic and euthyroid patients. S.D.= standard deviation. S.E.= standard error of difference between means. Results in mm. sec..

The difference in the mean IJ area values of the thyrotoxic and euthyroid patients was significant in the case of women aged from 30 to 39 years but not in younger subjects. The incidence of unduly large IJ area results in the thyrotoxic series was 19 per cent, compared with 1.5 per cent in the euthyroid group. This difference was highly significant (p between 0.01 and 0.001).

iii. Respiratory variation of IJ segment.

Table 75 compares the incidence of ballistocardiograms with normal and excessive degrees of respiratory variation in the thyrotoxic and euthyroid groups.

Respiratory variation	Thyrotoxic patients	Euthyroid patients
Normal	59	66
Increased	34	0

Table 75. Incidence of normal and abnormal degrees of respiratory variation in thyrotoxic and euthyroid patients.

The difference between the two series was highly significant (p less than 0.001).

iv. Duration of IJ segment.

Table 76 compares the IJ interval results of the thyrotoxic and euthyroid patients.

Age (yrs.)	Thyrotoxic patients No.	Mean	S.D.	Euthyroid patients No.	Mean	S.D.	S.E.	Difference of means / S.E.
15-19	9	.079	.008	8	.087	.0035	.0029	2.76
20-29	40	.070	.008	21	.083	.005	.0017	7.65
30-39	44	.073	.0085	37	.080	.007	.0017	4.12

Table 76. Significance of difference of mean duration of IJ segment in thyrotoxic and euthyroid patients. S.D.= standard deviation. S.E. = standard error of difference of means. Results in sec..

In each group the thyrotoxic patients had ballistocardiograms with significantly shorter IJ intervals than did the euthyroid subjects. The incidence of records with IJ intervals of less than the normal range was 49.5 per cent in the thyrotoxic series and 4.5 per cent in the euthyroid series. This difference was highly significant (p less than 0.001).

v. <u>Duration of the QJ interval</u>.

The results are compared in Table 77.

Age (yrs.)	Thyrotoxic patients No.	Mean	S.D.	Euthyroid patients No.	Mean	S.D.	S.E.	Difference of means / S.E.
15-19	9	.220	.0065	8	.256	.009	.0038	9.5
20-29	40	.216	.013	21	.249	.013	.0034	9.7
30-39	44	.211	.011	37	.245	.013	.0028	12.1

Table 77. Significance of difference of mean QJ interval in thyrotoxic and euthyroid patients. S.D.= standard deviation. S.E.= standard error of difference of means. Results in sec..

In each age group the thyrotoxic patients had ballistocardiograms with significantly shorter QJ intervals than did the euthyroid patients. In addition, the incidence of records with QJ interval results below the normal range differed significantly in the two groups (p less than 0.001). Unduly short QJ intervals were observed in 77 records of the thyrotoxic series and in two ballistocardiograms of the euthyroid patients.

3. Smoking tests.

The results of the smoking tests also showed a sharp contrast in the two groups of patients (Table 78).

Result of test	Thyrotoxic patients	Euthyroid patients
Negative	5	9
Positive	21	0

Table 78. Results of smoking tests in thyrotoxic and euthyroid patients.

The difference in the incidence of positive tests in the two series was highly significant (p less than 0.001).

Summary.

The ballistocardiograms of the 93 thyrotoxic patients and the 66 euthyroid patients were compared.

The records of 45 of the thyrotoxic patients had definitely abnormal wave contour. The ballistocardiograms of the thyrotoxic patients showed a tendency to unduly large IJ amplitude and area, excessive respiratory variation and decreased duration of the IJ and QJ intervals. Smoking tests were positive in 21 out of 26 cases. None of these abnormal features was observed in the records of the euthyroid patients.

The differences between the ballistocardiograms of the thyrotoxic and euthyroid patients were almost identical to those observed between the thyrotoxic and normal subjects' records. The differences were found to be statistically significant.

Chapter 24.

COMPARISON OF BALLISTOCARDIOGRAMS OF PATIENTS WITH THYROTOXICOSIS AND CORONARY ARTERY DISEASE.

1. Qualitative Analysis.

The basic classification of the ballistocardiograms of the patients with thyrotoxicosis and with coronary artery disease is shown in Table 79.

Form of record	Thyrotoxic patients	Coronary patients
Normal	27	10
Equivocal	21	4
Abnormal	45	12

Table 79. Distribution of normal, equivocal and abnormal ballistocardiograms of patients with thyrotoxicosis and coronary artery disease.

The incidence of definitely abnormal records was 48 per cent in the thyrotoxic series compared with 46 per cent in the group with coronary disease. There was no difference between these results (p greater than 0.9).

The grades of the ballistocardiograms were similar in the two groups (Table 80).

Grades	Thyrotoxic patients	Coronary patients
0	43	12
1	5	2
2A	30	7
2B	11	5
3	4	0

Table 80. Grades of abnormality of ballistocardiograms of patients with thyrotoxicosis and coronary artery disease.

The similarity of the abnormal patterns that were observed in the resting ballistocardiograms is shown in Table 81, which is shown on the next page.

Type of abnormality	Thyrotoxic patients	Coronary patients
1. Early M	26	8
2. Late M	13	4
3. Late downstroke	16	2
4. Abnormal HI	21	4
5. Short K	21	9
6. Prominent L	8	2
7. Large diastolic waves	4	3
8. Bizarre complexes	6	5

Table 81. Categories and distribution of abnormal wave contour in the abnormal resting ballistocardiograms of the patients with thyrotoxicosis and coronary artery disease.

Thus qualitative analysis revealed striking resemblances in the ballistocardiograms of the patients with thyrotoxicosis and those with ischaemic heart disease.

2. Quantitative Analysis.

Since the thyrotoxic patients were all women and the patients with coronary artery disease were predominantly males, it was not feasible to compare directly the mean values of the five standard quantitative indices. The incidence of the abnormality of each index that was frequently observed in the ballistocardiograms of the thyrotoxic patients, namely increased IJ amplitude and area, excessive respiratory variation and a decrease in the duration of the IJ and QJ intervals, was compared in the two groups. This procedure has also been employed in all the comparative analyses in the preceding chapters.

i. Amplitude of IJ segment.

Of the 93 thyrotoxic patients, 40 had records with IJ amplitude above the normal range. None of the patients with coronary disease had an unduly large ballistocardiogram. This difference was highly significant (p less than 0.001).

ii. Area under IJ segment.

Area values above the normal range were observed in 18 of the 93 ballistocardiograms of the thyrotoxic patients but in none of the records of the patients with coronary disease. The difference was significant (p between 0.05 and 0.02).

iii. Respiratory variation of IJ segment.

Respiratory variation exceeded 50 per cent, that is the "Ra" ratio was less than 0.50, in the ballistocardiograms of 34 thyrotoxic patients and six of the patients with ischaemic heart disease. There was no significant difference in this respect between the two series of records (p between 0.30 and 0.20).

Most of the undue variation in the ballistocardiograms of the patients with coronary disease could be explained in terms of abnormal wave contour, as was discussed in Chapter 15. The same was true of the thyrotoxic group.

Not only the early M but also the late downstroke and abnormal HI patterns are associated with a decrease in the amplitude of the IJ segment. These patterns were observed in 28 of the 34 ballistocardiograms. More than one of these abnormal patterns might be present in a single record. There were 17 instances of the early M, 14 of the late downstroke and 15 of the abnormal HI pattern in these 28 records. Four of the remaining six records were abnormal but the wave pattern that was observed, namely the shortened K pattern, does not intrinsically affect the IJ amplitude. The other two records were normal in contour and were placed in grade 1.

The incidence of ballistocardiograms in which excessive respiratory variation might be explained in terms of abnormal wave pattern was 83.3 per cent (five of six cases) in the group with coronary disease and 82.4 per cent (28 of 34 cases) in the thyrotoxic group. The difference was not statistically significant (p between 0.70 and 0.50).

iv. Duration of IJ segment.

This interval was below the normal range in 46 of the thyrotoxic patients' ballistocardiograms. Two of the patients with coronary disease had records with similarly decreased duration of the IJ segment. The difference was highly significant (p less than 0.001).

v. Duration of QJ interval.

The QJ interval was below the normal range of duration in 77 thyrotoxic patients' records. None of the ballistocardiograms of the patients with coronary artery disease showed this feature. The difference between the two series was highly significant (p less than 0.001).

3. Smoking tests.

Table 82 shows the results of the smoking tests in the patients with thyrotoxicosis and with coronary artery disease.

Result of test	Thyrotoxic patients	Coronary patients
Negative	5	3
Positive	21	16

Table 82. Results of smoking tests in patients with thyrotoxicosis and coronary artery disease.

There was no significant difference in the incidence of positive smoking tests in the two series of patients (p between 0.70 and 0.50).

There was also a close resemblance in the categories and distribution of abnormal wave contours in the ballistocardiograms of the two groups, before and after smoking (Table 83).

Type of abnormality	Thyrotoxic patients		Coronary patients	
	Before	After	Before	After
1. Early M	8	14	4	15
2. Late M	3	15	3	8
3. Late downstroke	5	17	1	7
4. Abnormal HI	5	7	1	6
5. Short K	4	8	5	8
6. Prominent L	0	0	0	0
7. Large diastolic	1	1	1	1
8. Bizarre complex	0	10	1	5

Table 83. Categories and distribution of abnormal wave contour in the abnormal ballistocardiograms of the patients with thyrotoxicosis and coronary artery disease, before and after smoking.

<u>Summary.</u>

In several ways the ballistocardiograms of the thyrotoxic patients closely resembled the records of the patients with known coronary artery disease. The incidence of wave abnormality and the precise patterns of wave contour were similar in the two groups. A high incidence of increased abnormality after smoking was found in both groups. A further common feature was the proportion of ballistocardiograms that showed increased respiratory variation.

The records of the thyrotoxic patients, however, showed other abnormal features that were absent from the ballisto-cardiograms of the patients with coronary disease. The tendency to increased IJ amplitude and area and increased duration of the IJ and QJ intervals was peculiar to the records of the thyrotoxic patients and distinguished their ballisto-cardiograms from those of the patients with coronary disease.

Thus in general the ballistocardiograms of the thyrotoxic patients showed qualitative abnormalities that aligned them with the records obtained from the patients with ischaemic heart disease but the quantitative abnormalities were peculiar to the thyrotoxic records.

Chapter 25.

THE BALLISTOCARDIOGRAM IN THYROTOXICOSIS: DISCUSSION OF RESULTS.

1. Qualitative Analysis.

a. Comparison with previous reports.

Starr and Mayock (1948) seem to have been the first to record that the form of the ballistocardiogram might be abnormal in thyrotoxicosis and to recognise its return to normal with abatement of the metabolic upset. Mathers et al. (1950) published the records of three female patients aged from 41 to 45 years. When they were thyrotoxic their ballistocardiograms were abnormal in contour. In two cases there was reversion of the wave pattern towards normal with clinical improvement.

The first systematic study of the ballistocardiogram in thyrotoxicosis was that of Gigli and del Bono (1955). They examined fifty patients aged from 14 to 65 years. Of these

35 were under 40 years of age and are thus comparable with the patients in the present study. Five of the 35 ballistocardiograms were abnormal in form. In some instances the ballistocardiographic waves could not be clearly identified. The degree of abnormality was unrelated to the severity of the clinical features or the basal metabolic rate. Alessio (1956) studied 26 thyrotoxic females aged from 17 to 60 years. He claimed that ballistocardiographic wave abnormality, particularly the late M pattern, was common. Inspection of his published ballistocardiograms, however, reveals large L waves. This pattern does not conform to the generally accepted criteria of the late M pattern. Nevertheless, these ballistocardiograms were clearly abnormal and with treatment of thyrotoxicosis they became normal. Garello and Alcozer (1956) studied the ballistocardiograms of 54 thyrotoxic men and women. In 48 per cent there were abnormal complexes. The abnormal forms included the late M, late downstroke and chaotic patterns all observed in the present study. Fidler et al. (1958) reported that two of three thyrotoxic subjects they examined had distinctly abnormal ballistocardiograms.

There is thus general agreement that the ballistocardiograms of a significant proportion of thyrotoxic patients are abnormal in contour. Few of the previous reports specified the precise wave patterns of the abnormal ballistocardiograms but the tendency for the records to become less abnormal after treatment of the metabolic upset was observed (Starr and Mayock, 1948; Mathers et al., 1950; Alessio, 1956).

b. Abnormal wave contours.

When the patients were thyrotoxic definitely abnormal ballistocardiograms, graded 2A, 2B or 3 were found in 48 per cent of the cases. It has been shown that these ballistocardiograms closely resembled the records of the patients with coronary artery disease in the incidence of abnormal wave contours (46 per cent) and also in the distribution of specific wave patterns. In both groups a variety of deviant patterns might be observed in a single record. These included the early M, late M and late downstroke patterns which were associated by Starr et al. (1939) with significant cardiac disease. The similarity extended to some degree to the equivocal ballistocardiograms, none of which had abnormal patterns of these three types, in either series of patients.

Thus qualitative analysis revealed close resemblances in the results obtained from the two groups of patients. The similarities were such that a common cause for these abnormalities might be suggested. In the case of the patients with coronary artery disease the ballistocardiographic abnormalities probably reflect faulty ventricular contraction and ejection due essentially to myocardial hypoxia, as a result of coronary arterial narrowing or occlusion. Because of the reversibility, often rapid, of the abnormal patterns observed in the records of the thyrotoxic patients, it seems unlikely that an anatomical lesion of this type would be the source of myocardial hypoxia. A metabolically determined and significant increase in the oxygen demand of the myocardium might, however, be sufficient to create an imbalance between oxygen supply and demand. A form of "relative" myocardial hypoxia or ischaemia might then exist. This type of functional disorder might account for the essential likeness of the results of qualitative analysis of the ballistocardiograms of the patients with thyrotoxicosis and with coronary artery disease.

2. Quantitative Analysis.

i. Amplitude of IJ segment.

Starr and Jonas (1943) measured cardiac output from the ballistocardiograms of thyrotoxic patients and reported that it was increased. It may be deduced that these patients had ballistocardiograms with abnormally large amplitude. Mathers et al. (1950) described three patients who had large, deformed ballistocardiograms when they were thyrotoxic. Starr (1952) also found large complexes in the records of thyrotoxic subjects but added that their tracings might be of low amplitude. Ballistocardiograms of large amplitude were observed also by Gigli and del Bono (1955), Alessio (1956) and Fidler et al. (1958).

In contrast Garello and Alcozer (1956) stated that the ballistocardiograms of thyrotoxic patients aged from 20 to 40 years were of normal size. The disparity between their results and those of all other authors may have been due to the inadequate standardisation of their apparatus, which they themselves mentioned.

The results of the present study are therefore in general agreement with previously reported observations that, at least in young thyrotoxic patients, the ballistocardiogram tends to have increased IJ amplitude that reverts to normal with treatment of hyperthyroidism. The actual amplitude results showed a wide scatter and the observation made by Starr (1952) that some records were unduly small was confirmed. In three patients who were studied when thyrotoxic and also when euthyroid abnormally low amplitude was found in the thyrotoxic phase. The amplitude increased and became normal when the patients were euthyroid. Possibly these patients were more likely to develop overt cardiac complications of thyrotoxicosis had they not been treated. Starr and Wood (1961) considered that low amplitude of the ballistocardiogram carried an adverse cardiac prognosis. This remains a matter for speculation but in this way the ballistocardiogram may provide a pointer to the patients likely to develop thyrocardiac disease.

The augmented amplitude found in many records might reflect an increase in the force of ventricular ejection but lowered peripheral resistance could also play a part. This matter will be discussed in a subsequent section.

ii. Area under IJ segment.

The area results of the thyrotoxic patients did not parallel the amplitude results. This was probably because the area measurement is half the product of the amplitude and duration of the IJ segment. In most ballistocardiograms of the thyrotoxic patients, appreciably shortened IJ intervals were found. Thus the increase in amplitude was partly offset by the decrease in duration and the product was closer to the normal value.

The mean IJ area was increased in the records of the women aged from 30 to 39 years. It is likely that the same factors were responsible for the increase in both amplitude and area results. There was undoubtedly a trend to high area values in the records of the thyrotoxic patients and this was reflected in the unduly high proportion of ballistocardiograms with area results above the normal range. The significance of increased amplitude and area values was presumably similar.

The three patients who had ballistocardiograms of low amplitude once more had low IJ area results. The significance was probably again the same, that is the low IJ area might be a pointer to the likelihood that these patients would develop overt cardiac complications of thyrotoxicosis. This was, of course, conjectural because the patients were treated. When they became euthyroid their ballistocardiograms had normal IJ area.

iii. Respiratory variation of IJ segment.

There have been no previous comments on the degree of respiratory variation in the ballistocardiograms of thyrotoxic patients. In the present study there was an undue amount of respiratory variation in 34 of the thyrotoxic subjects' records. This feature was absent from the ballistocardiograms of the normal subjects and also from the records of the euthyroid patients, suggesting that the abnormality was associated with the thyrotoxic state.

It has been shown that there was no significant difference between the patients with thyrotoxicosis and those with coronary disease as regards the incidence of records with excessive respiratory variation. Further, in both groups a similar proportion of the records showing undue respiratory variation had abnormal wave patterns that in themselves might give rise to this phenomenon.

The increased amount of respiratory variation observed in many of these ballistocardiograms was, in one sense, an additional means of assessing the wave contour. The presence of excessive respiratory variation gave a reasonably accurate prediction of abnormal wave patterns during expiration. Regarded in this way, the calculation of respiratory variation became a facet of the qualitative analysis.

Thus the close correspondence of the results in the two series was not surprising, because the initial qualitative analysis had yielded very similar results and also because of the relationship between wave contour and the degree of respiratory variation that has been discussed.

Further, this association between ballistocardiographic form and respiratory variation suggests that in many instances the significance of the abnormality might be the same as that of the abnormal wave pattern, that is excessive respiratory variation might to some extent reflect faulty ventricular ejection.

iv. Duration of IJ segment.

a. Comparison with other groups of subjects.

The mean duration of the IJ segment was consistently decreased in the ballistocardiograms of the thyrotoxic patients compared with the equivalent normal subjects. The difference between the two groups was highly significant. There was a similar difference between the records of the thyrotoxic and euthyroid subjects, which suggested that the abnormality was associated with the thyrotoxic state.

The records of the thyrotoxic patients differed markedly also from those of the patients with coronary disease, whose ballistocardiograms had normal IJ intervals.

b. <u>Effect of tachycardia.</u>

The occurrence in thyrotoxicosis of a high cardiac output with tachycardia but a normal stroke volume has been demonstrated by cardiac catheterisation studies (Myers et al., 1950; Humerfelt et al., 1958). With a rise in heart rate there is a coincidental decrease in the duration of the cardiac cycle. Because of the possible effect this might have on the duration of the IJ segment the ballistocardiograms showing heart rates of less than 90 beats per minute were analysed separately. The mean IJ intervals were compared with those of the equivalent normal subjects. The heart rate of 90 per minute was chosen because this was the rate above which Crooks et al. (1959) considered tachycardia was present. All the thyrotoxic patients aged from 15 to 19 years had tachycardia. Only the relevant records of those aged from 20 to 39 years were re-examined.

Table 84 shows the comparison between the ballistocardiograms of the thyrotoxic patients with slower heart rates and the normal subjects, who had similar heart rates.

Age (yrs.)	Thyrotoxic patients No.	Mean	S.D.	Normal subjects No.	Mean	S.D.	S.E.	Difference of means / S.E.
20-29	10	.072	.004	51	.085	.003	.0013	10.0
30-39	16	.071	.0075	33	.081	.007	.0022	4.55

Table 84. Significance of difference of mean duration of IJ segment in thyrotoxic patients with heart rate less than 90 per minute and in normal subjects. S.D.= standard deviation. S.E.= standard error of difference between means. Results in sec..

In each age group the difference between the thyrotoxic and normal subjects was highly significant. The mean IJ interval was therefore decreased in the ballistocardiograms of the thyrotoxic patients in the absence of tachycardia. Thus tachycardia was not solely the cause, although it may have been partly responsible.

c. Other associated factors.

The shortened IJ interval probably reflected more rapid ventricular ejection and a probable increase in the pulse wave velocity. Two possible underlying reasons for this might be more forceful ventricular ejection and a lowered peripheral vascular resistance. Both factors might be operative. Other possible causes include an alteration in the duration of isometric ventricular contraction.

v. Duration of QJ interval.

a. Comparison with other groups of subjects.

In many ways the results of the QJ interval measurement were similar to those of the IJ interval. There was again a very significant difference between the ballistocardiograms of the thyrotoxic patients and those of both the euthyroid and the normal subjects which were essentially the same. The records of the patients with thyrotoxicosis and with coronary disease also differed markedly, the latter having normal QJ intervals in their ballistocardiograms.

The abolition of the abnormal interval measurement with abatement of thyrotoxicosis suggests that the endocrine abnormality was the cause of the decrease in the QJ interval.

b. Effect of tachycardia.

As in the case of the IJ interval, ballistocardiograms showing heart rates of less than 90 beats per minute were analysed separately and the mean duration of the QJ interval was compared with that of the equivalent normal subjects.

Table 85 shows the comparison.

Age (yrs.)	Thyrotoxic patients No.	Mean	S.D.	Normal subjects No.	Mean	S.D.	S.E.	Difference of means / S.E.
20-29	10	.220	.0065	51	.249	.009	.0024	12.1
30-39	16	.215	.0145	33	.240	.011	.0041	6.1

Table 85. Significance of difference of mean QJ interval in thyrotoxic patients with heart rate less than 90 per minute and in normal subjects. S.D.= standard deviation. S.E.= standard error of difference between means. Results in sec..

In both age groups there was a highly significant difference between the thyrotoxic and normal subjects' ballistocardiograms. The mean QJ interval was therefore decreased in the thyrotoxic patients' records in the absence of tachycardia. Thus rapid heart rate, which is common in thyrotoxicosis, was not the sole cause of the abnormality, although it may have had some effect.

c. Other associated factors.

The other factors giving rise to a decreased QJ interval were probably essentially the same as those involved in the shortening of the IJ interval. There was probably more rapid ventricular ejection with increased pulse wave velocity, brought about by increased force of ventricular contraction and lowered peripheral resistance among other factors. This will be discussed more extensively in a subsequent section of this chapter.

3. Smoking Tests.

The association between overt coronary artery disease and positive ballistocardiographic smoking tests has been clearly demonstrated by a number of authors, including Mandelbaum and Mandelbaum (1952), Henderson (1953), Davis et al. (1953, 1956) and Davis (1960A). In the present study similar observations were made in the patients with ischaemic heart disease. In this group there was a high yield of positive smoking tests. It has been shown also that the thyrotoxic patients in this study tended to have positive smoking tests. The incidence of positive tests did not differ significantly in this group of subjects and in the patients with clinical coronary disease. There was not only a close correspondence in the incidence of positive tests in these two groups of patients but also a striking similarity in the actual patterns observed in the ballistocardiograms. The resemblance of the two series of ballistocardiograms was such that a similar basic cause of the abnormalities seemed probable.

4. Significance of Ballistocardiographic Abnormalities.

a. Qualitative aspects.

In the case of the patients with clinical coronary artery disease the ballistocardiographic abnormalities, namely the aberrant wave patterns and the tendency to have undue respiratory variation, could be attributed to defective ventricular contraction and ejection as a result of myocardial hypoxia. The intensification of the abnormalities of contour by cigarette smoking might be caused by the adverse effects of nicotine on the ischaemic ventricles. The hypoxia can readily be explained on the basis of coronary arterial narrowing or occlusion, resulting in decreased blood supply and a consequent oxygen debt.

The disappearance of precisely the same abnormalities from the ballistocardiograms of the thyrotoxic patients when they became euthyroid suggests that these subjects might have had a reversible type of coronary insufficiency. A relatively stable anatomical lesion, such as coronary atherosclerosis, can hardly be invoked to explain abnormalities that were readily and often swiftly abolished by correction of the metabolic upset.

The theoretical possibility that these thyrotoxic patients had prolonged coronary arterial constriction also seems scarcely tenable, particularly in view of the widespread vasodilatation that is typical of hyperthyroidism (Andrus, 1953). The results of the smoking tests would also be difficult to explain on this basis because the smoking of a single cigarette tends to increase the coronary blood flow (Bargeron et al., 1957) and would therefore be likely to improve the wave pattern by counteracting coronary vasoconstriction. In practice, cigarette smoking increased the degree of ballistocardiographic abnormality.

The significantly enhanced demand for oxygen on the part of the myocardium during hyperthyroidism that has been demonstrated experimentally by Andrus (1932), McEachern (1932) and Goh and Dallam (1957) might well cause an imbalance between oxygen supply and requirement and create an oxygen debt, even when the coronary arteries were free from significant disease (Somerville and Levine, 1950). In these circumstances the disappearance of this relative myocardial ischaemia with attainment of the euthyroid state could reasonably be expected.

The results of the basic qualitative analysis and of the smoking tests of the thyrotoxic and euthyroid patients in this study were in harmony with this concept.

b. Quantitative aspects.

The similarities in wave pattern that existed in the ballistocardiograms of the thyrotoxic patients and the patients with coronary disease were evident. On the other hand, quantitative analysis showed that the records of the thyrotoxic patients differed in several ways not only from the ballistocardiograms of normal persons but also from those of the patients with coronary disease.

They tended to have increased IJ amplitude and area measurements and shortened IJ and QJ intervals. The combination of these four quantitative abnormalities seems specific for thyrotoxicosis and has not been reported in any other condition.

The increase in the amplitude of the IJ segment and its area might be related to an increase in the force of cardiac ejection (Starr et al., 1950). This could in turn be associated with augmented contractile power of the left ventricle. A decrease in peripheral vascular resistance might contribute to this.

Not all the ballistocardiograms were increased in size. Starr (1952) commented that "most cases of hyperthyroidism have ballistocardiograms that are abnormally large but normal in form but one also finds some cases with small distorted records and then it seems evident that thyroid heart disease has made its appearance and this can occur when other cardiac studies are still negative." All thyrotoxic patients with abnormal ballistocardiograms may have a form of thyroid heart disease, although those with small, distorted complexes in their records probably have more seriously affected hearts and may be more prone to develop overt cardiac complications.

While there was some variation in the results of the IJ amplitude and area, there was an almost uniform decrease in the duration of the IJ and QJ intervals to an average of about 85 per cent of the normal mean value. Tachycardia was not the sole cause of this decrease and it probably reflected a fundamental change in the function of the heart. These intervals are essentially expressions of the speed of ventricular contraction and ejection.

The function of other muscular tissue in the body, such as the skeletal muscles in the limbs, is affected by thyroid overactivity. Ramsay (1965) suggested that "in thyrotoxicosis there is almost always a reversible derangement of muscle function." He demonstrated this abnormality by electromyography and also showed that abnormal conduction of impulses in the nerves was not responsible.

Sherman et al. (1963) found that in thyrotoxicosis the mean duration of the ankle jerk was reduced to 76.3 per cent of normal. This agreed closely with the equivalent results reported by Young (1965) who found it reduced to 74.2 per cent of normal and Robson et al. (1965) who recorded a figure of 80 per cent. Probably the cardiac muscle is affected in common with other tissues by a fundamental metabolic change.

Raab (1953) and Brewster et al. (1956) suggested that the action of the thyroid hormones lay essentially in sensitisation of the tissues of the body to the effects of catecholamines. Raab et al. (1960) observed that adrenalin lessened the duration of isometric contraction of the left ventricle. More rapid contractility of ventricular muscle might account to some extent for the decrease in the IJ and QJ intervals which was independent of the existing heart rate. Swifter ventricular ejection, due essentially to these factors and possibly associated also with decreased peripheral vascular resistance, might go some way to explaining the increased amplitude and area of the IJ segment.

c. Combined qualitative and quantitative aspects.

The qualitative and quantitative abnormalities were probably interdependent. The effects of the thyroid hormones on the heart, mediated through the catecholamines, result in an increased energy expenditure, enhanced oxygen demand and local tissue hypoxia (McEachern, 1932; Raab, 1953; Goh and Dallam, 1957). The ballistocardiogram reflects both the functional effects of sensitation of the heart to the catecholamines, as shown by the quantitative abnormalities, and the resultant myocardial oxygen debt, as evinced by the resemblance of the qualitative abnormalities and the results of the smoking tests to those of the patients with coronary artery disease.

This form of myocardial ischaemia is metabolically determined and is therefore potentially reversible, as is confirmed by the return of the ballistocardiogram to normal with suppression of thyroid overactivity.

Myocardial ischaemia due to coronary atherosclerosis is a potent source of cardiac arrhythmias, including atrial fibrillation, and is a common cause of heart failure. It is possible that in thyrotoxicosis the basis for cardiac complications is to be found in relative coronary insufficiency.

It is suggested that the ballistocardiogram is able to detect an important form of heart disease in its latent or occult phase. It is also suggested that the nature of the abnormalities in the ballistocardiogram provides a clue to the fundamental cause of thyrocardiac disease. At present there seems to be no other satisfactory method of assessing this possibility in human subjects.

The detection of these abnormalities in the ballistocardiograms of apparently unaffected patients emphasises the importance of treating these patients expeditiously.

Further, the serious alterations that occurred in the ballistocardiograms of most patients after cigarette smoking suggests that cigarette smoking should be avoided during thyrotoxicosis.

Summary.

The thyrotoxic subjects frequently had ballistocardiograms with abnormal wave contour, as in previous reports.

Their ballistocardiograms closely resembled the records of the young patients with coronary artery disease in several ways. The proportion of abnormal records and the precise types of aberrant wave contour were similar. Both series showed excessive respiratory variation, largely related to wave contour. Most of the patients in each group had records that became more abnormal after smoking. Again the wave patterns were alike in the two series, both before and after smoking. These abnormalities disappeared when the patients became euthyroid. These findings were in keeping with the view that there is a metabolically determined form of coronary insufficiency in thyrotoxicosis.

The ballistocardiograms of the thyrotoxic patients also showed quantitative abnormalities which seemed peculiar to them. These abnormalities might reflect the functional effects of the thyroid hormones on the myocardium, mediated through the catecholamines. The resultant increased energy expenditure, enhanced oxygen demand and local tissue hypoxia might account for the apparent functional coronary insufficiency. These abnormalities also disappeared when the patients became euthyroid.

It is suggested that the ballistocardiogram is able to detect an important form of heart disease in its latent or occult phase and also that the nature of the abnormalities demonstrated provides a clue to the fundamental cause of thyroid heart disease.

Chapter 26.

THYROTOXIC PATIENTS:

CONCLUSIONS.

1. The wave pattern of the resting ballistocardiograms of young patients with thyrotoxicosis is frequently abnormal. The abnormalities are similar to those found in the records of patients of equivalent age who have clinical coronary artery disease.

2. Quantitative analysis of the resting ballistocardiograms reveals further significant abnormalities which suggest that cardiac contraction and ejection are more forceful and rapid than normal. This is possibly due to the effect of the thyroid hormones on the heart, mediated by the catecholamines.

3. The use of a stress procedure, such as cigarette smoking, causes increased abnormality of the wave pattern of the ballistocardiogram in most of the patients who are examined. The

abnormalities observed before and after smoking are almost identical to those found in the ballistocardiograms of young patients with clinical evidence of coronary artery disease.

4. When thyrotoxic patients are treated and become euthyroid their ballistocardiograms are normal in wave contour, even after smoking. Quantitative analysis also yields normal results.

5. It is tentatively suggested that the abnormal patterns observed in the ballistocardiograms of the young thyrotoxic patients, particularly after cigarette smoking, may be taken as indirect evidence of myocardial hypoxia.

6. It is also tentatively suggested that the quantitative abnormalities detected in these ballistocardiograms may reflect the effects of abnormal levels of circulating thyroid hormones, mediated through the catecholamines.

7. The fundamentally metabolic basis of these ballistocardiographic abnormalities is demonstrated by their disappearance when the patients become euthyroid.

8. The detection of this form of cardiac abnormality suggests that thyrotoxic patients should be treated expeditiously and should be advised to avoid cigarette smoking.

PART VI.

Acknowledgements, Communications, References and Appendix.

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Communications.

I have given preliminary communications on certain aspects of the present study to learned societies:

1. The Ballistocardiogram in Thyrotoxicosis (with Dr A.J.V. Cameron).
   At the 3rd European Congress of Cardiology, Rome, 1960.
2. Ballistocardiographic Smoking Tests in Young Patients with Diabetes Mellitus (with Dr A.J.V. Cameron).
   At the 2nd European Symposium for Ballistocardiography, Bonn, 1961.
3. Ballistocardiographic Smoking Tests in Thyrotoxicosis. At the First World Congress for Ballistocardiography and Cardiovascular Dynamics, Amsterdam, 1965.

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Appendix.

RESULTS OF INDIVIDUAL SMOKING TESTS.

The results of the individual smoking tests are shown in the Tables of this Appendix.

The abnormal patterns described in Chapter 10 have been identified by the following numbers :

1. Early M.
2. Late M.
3. Late downstroke.
4. Abnormal HI.
5. Short K.
6. Prominent L.
7. Abnormal late diastolic waves.
8. Bizarre contours.

Where the ballistocardiogram showed entirely normal contour this has been shown by a dash : - .

Where abnormalities were variable or transient, the ballistocardiogram was classified as equivocal. This is denoted by the asterisk * .

Age (years)	Before smoking Grade	Before smoking Patterns	After smoking Grade	After smoking Patterns
19	0	-	0	-
20	0	-	0	-
21	0	-	1	-
22	0	-	0	-
22	0	-	0	-
23	0	-	0	-
25	0	-	0	-
26	0	-	0	-
30	0	-	0	-
37	0	-	0	5*

Table A. Smoking tests in normal male subjects, showing age, grades of abnormality and wave patterns before and after smoking. Numerical code is given at start of Appendix. Equivocal ballistocardiogram * .

Age (years)	Before smoking Grades	Patterns	After smoking Grade	Patterns
21	0	-	0	-
22	0	-	0	-
23	0	-	0	-
23	0	-	0	-
23	0	-	0	-
23	0	-	0	-
24	0	-	0	-
25	0	-	0	-
26	0	-	0	-
27	0	-	0	-
27	0	-	0	-
28	0	-	0	-
33	0	-	0	-
34	0	-	0	-
35	0	-	0	-
35	0	-	0	-
39	0	-	0	4*

Table B. Smoking tests in normal female subjects, showing age, grades of abnormality and wave patterns before and after smoking. Numerical code is given at start of Appendix. Equivocal ballistocardiogram * .

Sex and Age (years)	Before smoking Grade	Patterns	After smoking Grade	Patterns
M28	0	-	2B	2,4
M28	0	-	2B	1,5
M33	0	-	2A	1,2,5
M33	0	-	2A	1,3
M33	2A	5,7	2B	1,5,7
M34	2A	1	2B	1,2,3,4,5
M36	2B	1,2,3,4,5	3	1,2,3,4,5,8
M38	0	-	2A	3
M38	0	5*	2A	1,3
M38	1	-	2A	1
M39	1	4*	2A	1,3,4
M39	0	5*	2B	1,2,8
M39	2A	5,8	3	1,2,4,8
F33	0	-	2A	1
F38	0	-	2A	1,5,8
F39	2B	1,2,5	3	1,2,3,4,5,8

Table C. Positive smoking tests in patients with coronary artery disease, showing sex and age, grades of abnormality and wave patterns before and after smoking. Numerical code is given at start of Appendix. Equivocal ballistocardiograms * . M= males, F = females.

Sex and Age (years)	Before smoking		After smoking	
	Grade	Patterns	Grade	Patterns
M28	0	-	0	4*
M38	2B	1,2,5	2B	1,2,5
M39	0	-	1	-

Table D. Negative smoking tests in patients with coronary artery disease, showing sex and age, grades of abnormality and wave patterns before and after smoking. Numerical code is given at start of Appendix. Equivocal ballistocardiogram * . M = Males.

Sex and Age (years)	Before smoking		After smoking	
	Grade	Patterns	Grade	Patterns
M21	0	-	2A	2,3
M24	0	5*	2A	1,2,5
M34	0	-	2A	1
M34	0	-	2A	1,5
M36	2A	1	2B	1,3
F18	0	-	2B	4
F28	0	-	2A	1,3
F31	0	-	2A	1
F33	0	5*	2A	5
F35	0	-	2A	4
F38	0	-	2A	3,4,5

Table E. Positive smoking tests in diabetic patients, showing sex and age, grades of abnormality and wave patterns before and after smoking. Numerical code is given at start of Appendix. Equivocal ballistocardiogram * . M = male, F = female.

Sex and Age (years)	Before smoking Grade	Before smoking Patterns	After smoking Grade	After smoking Patterns
M22	0	-	0	-
M22	0	-	0	5*
M23	0	-	0	-
M23	0	-	0	-
M27	0	-	0	-
M28	0	-	0	-
M28	0	-	0	-
M29	0	-	0	-
M29	0	-	1	2*
M34	0	-	0	-
M35	0	-	0	-
M35	0	-	0	-
F18	0	-	0	4*
F21	0	-	0	-
F21	0	-	0	-
F22	0	-	0	-
F24	0	-	0	1,4*
F28	0	-	0	3*
F32	0	4,5*	0	4,5*

Table F. Negative smoking tests in diabetic patients, showing sex and age, grades of abnormality and wave patterns before and after smoking. Equivocal ballistocardiogram * .

Sex and Age (years)	Before smoking Grade	Before smoking Patterns	After smoking Grade	After smoking Patterns
19	2A	1	2B	1
20	2A	3,4	2B	1,2,3,5,7
20	0	-	2A	1
22	0	-	2A	2,3
22	0	4,5*	2A	1,2,3
24	0	-	2B	1,2,3,4,7
24	2A	1,5	2B	2,5
26	0	4*	2B	1,2,3,5
26	2A	2,4	2B	2,3,4
28	2B	1,3,	3	1,3,4,7
28	2A	1,3,4	2B	1,3,4
28	0	-	2A	4,5,7
29	0	4*	2A	2,3,4
30	2A	1,2,5	2B	1,2,5,7
34	0	-	3	1,2,3,5,7
35	2A	3,6	2B	2,3,6,7
35	0	5*	2B	2,3,5,7
36	2B	1,2,4,5	3	1,2,3,5,7
36	2A	1	2B	1,3
37	0	4,6*	2B	2,3,7
37	2A	5	2B	1,2,3

Table G. Positive smoking tests in female patients with thyrotoxicosis, showing age, grades of abnormality and wave patterns before and after smoking. Equivocal ballistocardiogram * . Numerical code is given at start of Appendix.

Age (years)	Before smoking Grade	Patterns	After smoking Grade	Pattern
23	0	-	0	-
25	2A	1,3,4	2A	1,3,4
28	0	4*	0	4*
30	0	-	0	-
31	0	-	0	-

Table H. Negative smoking tests in female patients with thyrotoxicosis, showing age, grades of abnormality and wave patterns before and after smoking. Numerical code is given at start of Appendix. Equivocal ballistocardiogram * .

Age (years)	Before smoking		After smoking	
	Grade	Patterns	Grade	Patterns
19	0	-	0	-
20	0	-	0	4*
20	0	-	0	-
26	0	-	1	-
30	0	-	0	-
30	0	-	0	-
31	0	-	0	-
37	0	-	0	-
38	0	-	0	-

Table J. Smoking tests (all negative) in euthyroid female patients, showing age, grades of abnormality and wave patterns before and after smoking. Numerical code is given at start of the Appendix. Equivocal ballistocardiogram * .