MATHEMATIC CHARACTERIZATION OF DENTAL MORPHOLOGY

15-7-75

MATHEMATIC CHARACTERIZATION OF DENTAL MORPHOLOGY

A theoretical approach to identification in

Forensic Odontology

PAUL .W. DRUMMOND B.D.S. HONS.

Department of Oral Biology,
University of Adelaide,
Adelaide, South Australia.

January 1974.

CONTENTS

SUMMARY

Metric characters of the dentition and dental arches can serve to identify uniquely each member of a group of subjects. Methods have been developed to achieve this discrimination by using a precise mathematical procedure, based on a least squares technique, to minimize discrepancies between the metric characters of any two subjects. Each dental arch was described by the coordinates of reference points located within a cartesian system of orthogonal X and Y axes. The reference points, marked on all teeth except third molars, in both upper and lower arches were located so that dimensions of teeth and dental arches and the spatial relationships between morphological features of the dentition could be evaluated by the methods developed in the study.

Research material consisted of 100 dental casts obtained from students enrolled at the University of Adelaide Dental School. Each cast was marked with reference points and photographed in a standard manner so that images obtained on the film would be of uniform magnification. The negatives were used in conjunction with a semi-automatic digital recorder to derive values of the coordinates which were output direct onto punched computer cards.

The 100 casts were digitized on two separate occasions. The first set of coordinates, termed the first determination. was constituted as the master file - this would correspond to a file of known subjects in a real situation. A second set of data, the second determination, was recorded in the same format but located within different Cartesian axes - this file can represent a group of unidentified individuals. With the aid of a computer the mathematical techniques used in the study allowed an objective comparison between the values obtained for the unidentified subjects and those relating to the file of known subjects.

Identification of an unknown subject with the corresponding master file subject was determined from the value derived for the sums of squares of differences between sets of coordinates. This value was accepted as "The Index of Similarity", the minimum value of which indicated the closest agreement between an unknown subject and a subject on the master file.

Results of the study were conclusive even though 100 percent success was not achieved. The merit of the mathematical approach for identification purposes was clearly demonstrated. Molar and incisor segments of subjects' upper and lower casts were described by 26 subsets of reference points, each comprising a different number and combination. In turn all subsets were matched with master file subjects resulting in 1300 matchings for upper and lower casts respectively. Overall, successful identification was achieved for 95 percent of upper subjects and 92 percent for lower subjects.

Further research is indicated to examine the relationships between reference points, the accuracy of recording techniques and possible alternatives to the methods discussed in this study. A long term study to assess the reliability of data determined at one time and data recorded for the same subject on later occasions would be valuable. There is no doubt that the approach adopted in this investigation can make a valuable contribution to the methods used in forensic dental identification.

SIGNED STATEMENT

This project report is submitted in partial fulfilment of the requirements for the Degree of Master of Dental Surgery in The University of Adelaide.

This report contains no material which has been accepted for the award of any other degree or diploma in any University. To the best of my knowledge and belief, it contains no material previously published or written by another person except when due reference is made in the text of the report.

PAUL WILLIAM DRUMMOND

ACKNOWLEDGEMENTS

I record my sincere appreciation to Dr. T. Brown, Reader in Oral Anatomy, for his advice and supervision of this project and providing the necessary computer programmes.

I am grateful too, to Professor J.C. Thonard, Head of the Department of Oral Biology, for access to facilities of the department that aided the research project.

I am indebted to Mrs. M. Cummings for typing the report, Mrs. S.K. Pinkerton for valuable assistance with data processing and Mrs. I. Zaleski for the photography. Furthermore I record my gratitude to Dr. J. Scollin for allowing me the use of facilities of the Royal Adelaide Dental Hospital. Grateful appreciation is also extended to those students who so willingly participated in this study.

LIST OF TABLES

LIST OF FIGURES

PREFACE

The value of dental examinations in identification procedures has been recognized for a considerable time and many instances of this application have been recorded. However, it is only within the last few decades that the full potential of forensic dentistry as a branch of general forensic science has been acknowledged. In recent times, particularly, there has been a greater awareness of forensic dentistry or odontology as this science is sometimes termed. Forensic dentistry is closely related to the procedures of law and a very important aspect concerns handling of dental evidence and the proper presentation and evaluation of dental findings. The methods of forensic odontology have application in both civil and criminal cases and at times dental records and examinations may provide the only available evidence. A principal purpose of forensic odontology, however, is to assist in the identification of human remains.

Forensic dentistry is a branch of the broader field of forensic science. In some European countries and more recently in the United States and Japan forensic dentistry is included as a special subject in the undergraduate dental curriculum. Students are made aware that at some stage in their future careers as practising dentists they will probably be called upon to assist in identification procedures using dental records or to make their patients' records available to others for the purposes of identification.

In an adult dentition of 32 teeth the chance of finding two identical dentitions has been calculated in the order of one in 10^{50}.* This probability is further reduced when we consider that during a lifetime the teeth are subject to morphological changes brought about by diseases and subsequent restoration by any of numerous methods and materials. The reliability of dental methods of identification is enhanced by the knowledge that teeth have a much higher degree of resistance to destruction than other body tissues used in the more traditional means of identification such as fingerprints.

The identification of unknown bodies falls primarily within the responsibility of local police and the general or forensic pathologist. If only skeletal structures remain, various specialists may be called upon to assist with identification - for example, anatomists, anthropologists, archaeologists or dentists can assist in certain circumstances. Identification procedures can be delayed if specialized examiners are not readily available or if the need for their services is overlooked. Bite marks on dead victims go unnoticed and people involved in violent assaults may receive medical treatment before they can be examined by a person with specialized dental training.

---

* KRAUS, B.S., JORDAN, R.E., ABRAMS, L. (1969). Dental Anatomy and Occlusion. Section 19, 293. (Williams and Wilkins)

In mass disasters problems can be encountered because of the lack of dental staff. Rescue squads are sometimes composed of people not fully aware of the vital information that may be gained from examining dental remains at the accident site. Other problems encountered are the compilation of accurate pre-flight passenger lists and the collection of dental records for these individuals if it becomes necessary. If foreign nationals are involved there may be further complications. Exhaustive time-consuming comparisons of ante and post-mortem records as well as exacting laboratory examinations are necessary to establish the identity of victims. The coordination of such a venture requires specially trained personnel and a high degree of efficiency and skill.

The study described here was undertaken as a preliminary assessment of a new method for dental identification based on some mathematical aspects of shape recognition. Conventional techniques of identification, relying on the examination and charting of dental structures and the subsequent comparison with previous records is time-consuming and, in many instances, it depends on the availability and completeness of previous records.

In recent years mathematical techniques concerned with the general recognition, quantification and comparison of analogous shapes have received much attention. Most of these methods are extremely complex and require computers for execution. However, a simpler technique, originally developed in comparative anatomy has been successfully applied by research workers in Adelaide on studies of facial growth.* The method relies on the matching of coordinates obtained from sets of analogous points selected to describe the shapes under study. The degree of matching, that is similarity, between similar but not identical shapes can be computed and the shapes ranked in order of similarity. The method is extremely discriminating, many times greater than the human visual mechanism. The extension of these methods to the recognition and matching of dental arch shapes is obvious.

For the purposes of this study, dental casts of 100 subjects were characterized so that teeth within each dental arch were identified by selected reference points from which recordings were made. However, conventional linear and angular dimensions were not obtained and each dental arch was described by the coordinates of the reference points located within a cartesian system of orthogonal X and Y axes. A semi-automatic X-Y recorder was used to obtain the coordinate readings from photographic negatives of the dental casts. The coordinates were directly recorded onto computer punched cards. Mathematical techniques were developed to compare the coordinate values obtained from test subjects with those relating to a file of known subjects using various combinations of teeth.

---

* SNEATH, P.H.A. (1967). Trend-surface analysis of transformation grids. J. Zool., Lond., 151, 65.

BROWN, T., BARRETT, M.J., CLARKE, H.T. (1970). Refinement of metric data from cephalograms and other records. Aust. Dent. J., 15, 482.

The study can be considered as the first phase of a continuing research programme. The findings have shown the discriminating power of the mathematical technique when used for the metric characterization of the dentition and dental arch. Dental casts were chosen for this study because they represented the most convenient type of record for testing the discriminatory powers of the matching technique. Quite obviously dental casts would not normally be available in a real situation involving many identifications, an air disaster for example. However, the methods described could be readily applied to a post-mortem fragment of dental arch with a set of impressions or wax bites made prior to travel.

The type of record appropriate for mass recordings will need to be standardized, speedily obtained, accurate, readily reproducible and able to be obtained pre and post-mortem by a semi-skilled operator. They should produce no discomfort to the subject being recorded, be acceptable as evidence in courts of law and not infringe personal rights. Authorities may in time recommend that some form of acceptable dental record be mandatory prior to air travel. A simple wax bite would appear at this stage to be a suitable pre-travel record.

The methods used in this study have limited practical application but point the way for further applied research. Thus the study can be considered as an experimental approach to the problem of identification using dental arch shapes or portions of dental arches. The next logical extension would be to assess various types of ante-mortem records that could be used in practical applications. The criteria that these records would have to meet are listed above. The study, being a theoretical approach, has not been concerned with the legal aspects of forensic odontology. Obviously at a later stage the admissibility as evidence of analyses carried out by the methods described would have to be established.

UNIVERSITY OF ADELAIDE LIBRARY

LITERATURE REVIEW CHAPTER 1

Introduction

In forensic investigations, examinations of the dental structures are becoming increasingly important as valuable techniques in establishing identification.

Identification procedures using dental tissues have a great advantage over some of the more traditional methods of identification, fingerprinting for example, because teeth are less destructible than most other body tissues. Teeth, bone and restorative materials remain preserved long after soft tissues have been destroyed (TAYLOR 1963). Disasters involving large numbers of deaths are becoming more frequent with the vast increase in international traffic - air, land and maritime. Large numbers of passengers are transported at one time and the immensity and intensity of disasters, particularly aircraft crashes, make identification by traditional means such as facial and body features, fingerprints or personal effects difficult and in many instances impossible (GUSTAFSON 1963).

The importance of forensic dentistry in identification procedures is a consequence of both teeth and restorations being more resistant to fire and water than flesh, clothing or personal belongings. Every dental arch has morphological characters which identify it with one person only. In many cases records of individuals indicating teeth present and the types of restorative procedures carried out are kept by a dentist or a hospital. These records can be made available for identification purposes on request by the proper authorities.

Much of the work involved in forensic dentistry is objective and may be performed at the accident site or in a morgue. Nevertheless, accurate identification requires a highly trained specialist who needs both patience and considerable detailed knowledge (Table 1).

Techniques of forensic odontology have also been used in the field of criminology for many years. One of the first recorded cases was in 1477 (HUMBLE 1933). Humble also reported a case when a burglar was convicted in 1906 as a result of bitemarks he had left in a piece of cheese at the scene of the crime. Bitemarks left in food or other impressionable materials, including human flesh, have at times led to the conviction of criminals (FURNESS 1968, FURUHATA 1967, GUSTAFSON 1962, GUSTAFSON 1966, HARVEY 1966, TAYLOR 1963). There are many other references to instances when identification of dental remains, dentate arches or dental prostheses, have led to the conviction of suspects (GUSTAFSON 1963, RUDDIMAN 1969, TAYLOR 1963, FURUHATA 1967).

TABLE I

Skills Required In Forensic Odontology

A detailed knowledge of -

a. forensic medicine in relation to forensic odontology

b. identification by dental means

   (i) anatomical and racial traits

   (ii) restorative procedures

   (iii) recording methods

   (iv) defects related to habits

   (v) dental pathology

c. anthropology

d. general anatomy

e. estimation of age from

   (i) dental eruption times

   (ii) histological examination

   (iii) craniofacial radiographs

f. pathology of soft tissues

g. effects of trauma on teeth and jaws

h. identification of bite marks

i. photographic equipment and techniques

j. procedures of identification, mass disasters for example

k. law and ethics

l. legal procedures and evidence.

Resistance of Teeth and Dental Restorations

Victims of air crashes and other disasters may be mutilated to such an extent that identification from physical features by relatives or friends is impossible. Personal belongings such as watches, rings or passports are often destroyed or may be found adjacent to other bodies. Although fire may destroy recognizable features it has seldom been reported that a body has totally disappeared in a fire.

Teeth and dental restorations resist long exposure to soil and water as well as relatively high temperatures (GUSTAFSON 1966). There is evidence that when practically all other parts of the body have been changed to such a degree that they are no longer recognizable, teeth may be present without noticeable change. It is possible, however, for teeth to be destroyed in some instances. For example, anterior teeth suddenly exposed to heat may explode because of the sudden evaporation of water. If the exposure to heat is less intense and less rapid this situation does not occur despite burning of the dentine which may result in brown discolouration of the enamel.

Teeth are protected to some extent by the thick soft tissues of the cheeks and tongue. Anterior teeth are most frequently damaged but these may be protected in some cases by intrusion into the tongue. Therefore, changes in teeth and restorations generally occur when the protecting soft tissues are destroyed or when they are exposed directly to intense heat.

Some dental restorations undergo changes when exposed to heat. High temperatures will cause mercury to evaporate from silver amalgams; if gold restorations are present an amalgamation will occur causing the gold colour to change to a dull silver. In order to discriminate between restorations their surfaces must be scratched to expose the underlying material.

On exposure to heat, anterior restorations such as silicates, acrylics or composite resins, may change colour or even disintegrate. Care is also needed to distinguish carious cavities and prepared cavities. The latter usually have smooth cavity margins whereas the former are irregular in outline due to the burning of non-calcified material. The well placed anterior restoration may be extremely difficult to detect because of a combination of factors including bad lighting or soiling by blood and debris. This situation necessitates the use of a stain which will either reveal the margin or be taken up by the filling material (MIDDA 1969).

Bodies which have been immersed in water for long periods may have teeth missing due to the disintegration of the periodontal ligament. When bodies have been buried with the teeth in contact with soil, the teeth may be preserved or decalcified depending on whether the soil was sandy or acidic.

Identification

The objective of identification procedures is to make a comparison between the dental characteristics recorded from an unknown body and corresponding records known to have existed for some missing person (KEISER-NIELSEN 1965).

The initial stages of any investigation involving one or more victims are crucial. The examiner must have the necessary experience and training in forensic odontology; at times it may be preferable to have two such examiners each performing their tasks of recording characteristics separately.

All details should be recorded as they are observed regardless of how trivial they seem at the time. This may be accomplished in one of three ways:

(a) written description by the examiners;

(b) drawing on a chart;

(c) drawing on a model made from the victim.

The accuracy of recording will be greatly influenced by the degree of mutilation and/or decomposition of the victims.

Adequate access to the mouth is essential and the teeth should be cleaned without damage or displacement of restorations.

In cases of drowning where victims may have been exposed to water for long periods of time, teeth may be loosened or at times lost as a result of breakdown of the periodontal ligament. The tooth loss takes place a certain time after exposure and may give some indication of the time of death.

Other factors relevant to the identification of victims may be observed by careful examination. For example, age, habits or social position may be assessed to provide additional valuable evidence. However, sex and general physical characteristics are difficult to assess from a dental examination alone.

Certain habits such as smoking or chewing tobacco, for example, are accompanied by discolouration of teeth and soft tissue. Long term habits such as bruxing, biting or chewing hard objects, tend to leave observable defects on tooth surfaces which are often characteristic of the habit.

Racial traits, if observable, may narrow the identification process to a select few missing persons or indicate a certain geographic extraction (KEISER-NIELSEN 1965). Keiser-Nielsen examined many bodies recovered from German prisoner of war camps in order to identify Danish citizens. Many of the bodies examined were believed to originate from Russia because of the heavy jaws and the perfect dentitions which were generally deep yellow in colour and showed marked attrition but relatively little caries.

Important evidence on the geographic origin of a victim is often provided by the examination of dental restorations present. However, the increasing number of people visiting and living in foreign countries limits the use of identification based on the matching of individual styles of dental work with specific nationalities.

Logically, a dental examination should reveal a set of facts which are unique to that particular dentition. Firstly, the different combinations of 32 teeth which may be present, absent, replaced or conserved are extremely large in number. Secondly, there is great variation with respect to form, arrangement of teeth, presence of retained roots and particular restorative materials used. However, although this evidence may be accurately recorded from a body, its effective utilization depends on the availability of reliable and accurate past records.

Importance of the Dental Record

There are always difficulties in recording the status of dental and oral tissues accurately and consistently. Ideally there should be a standard coding system which is universally acceptable and from which an accurate dental description can be obtained. Records of the teeth present, various restorations, types of material used, root remnants or unerupted teeth and the type of denture and retainers are invaluable in the identification process.

GUSTAFSON and JOHANSEN (1963) examined 775 children between the ages of 10 and 16 years. By visual examination and comparison of records they demonstrated clearly that exact, concise, complete records were required for effective identification. Of the children, 611 had fillings or a combination of fillings that were not present in any other child of the same sex. In 164 children the type and location of fillings were identical in at least two children.

It appeared that if observations were limited to sex, number of erupted teeth, type and location of fillings, then only 79 per cent of the children were positively identified. When greater detail of the restorative work was taken into account there were still 67 children with identical records. Further, when the colour and deposits on teeth as well as any hypoplastic lesions were also taken into account two children remained unidentified. These were distinguished by radiographs.

It is important to have a continuing record of current dental status and for this reason additional teeth extracted or filled need to be recorded. Entries into records must also be accurate. GUSTAFSON (1966) lists the common problems encountered with records - wrong designation of teeth, incorrect description of fillings, inconsistent abbreviations and the use of unusual recording systems. The success or failure of a forensic dental investigation depends on the availability of complete up-to-date records (TAYLOR 1963). Related to this is the requirement that records must be kept by practitioners for a certain period of time. Difficulties may arise when records are removed from a file after a patient has changed his dentist or died.

Methods of Identification

SASSOUNNI (1963) recommended dentofacial radiography for forensic purposes using landmarks located on both soft and hard tissues. He suggested two major types of human identification procedures:

(a) reconstructive method, where there are no previous records for comparison with data from a body. The basic aim, therefore, is to deduce the maximum amount of information from the remains;

(b) comparative method, where previous records are classified and kept in a central file to which given remains or recorded documents may be referred. Proof of identity is established by a match with central records.

Other workers have expressed the important uses of radiographs in identification. For example, the pantomograph developed by Paatero (1961) is a quick, cheap method of obtaining a complete dental record (GUSTAFSON 1966).

Reconstructive Method

Many ethnic groups have been studied and norms have been derived for morphological characters specific for age, sex and group. For example, by using cephalometric radiographs it is possible to compare derived values with published standards for the same group, sex and age.

Included in the information required to establish identity by the reconstructive method are age, sex and racial characteristics. There will be briefly discussed in turn.

Age Determination

This may be estimated with the aid of radiographs. Good estimates of age may be made until about the age of 15 years using eruption and calcification schedules such as those prepared by SCHOUR and MASSLER (1940), MOORREES and FANNING (1963) and more recently FANNING and BROWN (1971). Between the ages of 15-25 estimations of age by this method are not as accurate but the calcification and eruption of third molars may contribute helpful information. This type of estimation necessitates an observer experienced in this work.

Other methods involve complex histological techniques. After completion of tooth development normal and pathologic changes are visible in tooth structure and these may be used to determine age. GUSTAFSON (1966) examined six variables; attrition, periodontal disease, secondary dentin, cementum deposition, root resorption and root transparency.

The six variables were then each graded numerically, three points for each of the six criteria; the grades were then totalled. The value obtained was then interpolated onto a regression line, derived from an original study of many teeth, to obtain an estimation of age. Results showed that no single feature could be used alone otherwise the range of estimated age was too wide. The combination of factors provided an indication of time elapsed since the tooth first appeared in the mouth. Gustafson further recommended the use of anterior teeth because they are easier to assess by this procedure.

BANG and RAMM (1970) found that root transparency alone was a good estimate of age. Root dentine tends to become transparent during the third decade, commencing at the root tip and advancing coronally with age. The alteration is believed to be due to a reduction in diameter of the dentinal tubules caused by increasing intratubular calcification. GUSTAFSON (1966) has stated that although this particular variable is less influenced by pathological changes than other variables, the condition of the pulp and any inflammatory changes in the periodontal ligament may influence the degree of translucency. A third method discussed by TAYLOR (1963) is concerned with the correlation between age and the weight of mineral content of teeth estimated from their ash.

Further means of estimating age from radiographs are:

(1) the state of ossification and fusion of cranial and facial structures. Furthermore, radiographic cephalometry studies by BROADBENT (1937), BJÖRK (1947) and SASSOUNI (1959) have presented standards of facial size and proportions at

specified ages. They may serve as a basis for comparisons bearing in mind the range of normal variation in individuals;

(2) the paranasal, frontal and sphenoidal sinuses provide sharply defined outlines easily recorded on radiographs. There developmental stages may afford the possibility of age assessment. For example the maxillary sinus reaches its maximum size in the third decade, while later in life there is a tendency for it to assume a triangular shape;

(3) MÜLLER (1956), from studies of 2200 children, concluded that no two persons had the same pattern of nasal cavity as revealed by radiographs. This type of record he suggested could be used as a means of identification. However, these structures change their form during life and after disease, presenting a difficulty that Müller did not stress.

Sex Estimation

A combination of both dental and skeletal examination may permit the differentiation of sex (STEWART 1963 and MILES 1963). The formative stages of teeth, especially lower canines, show sex differences. For example if a root is two thirds complete, the mean age may be seven years by male standards but only six and a half years by female standards. Estimation of skeletal age may be made by examination of anteroposterior radiographs of the hand using derived standards for carpal and metacarpal development. Consideration of both dental and skeletal ages will give an indication of the sex of the individual being examined.

However, sex can be assessed with a high degree of accuracy from direct measurements of the ischium pubis index of the pelvic bone. Using radiographs of a group of people WASHBURN (1948) was able to correctly sex 90 per cent of Caucasoids and 83 per cent of Negroids.

Determination of Ethnic Groups

Many traits are best determined by direct examination of the crowns of teeth. Ethnic groups that are relatively homogeneous genetically are generally becoming less so because of migration and inter-racial marriages. DAHLBERG (1963) stated that racial variability in dental tissues is so well defined that features of the dentition are useful in identifying geographic or racial groups. For example, the size, number and location of cusps, occlusal and bony relationships, nature of pulp chambers and canals, and microscopic tooth surface characteristics are features common to all groups but the different degrees of expression and the frequency of occurrence assist in distinguishing one population from another. For example, a relatively small number of American whites have a marked form of shovel-shaped incisor whereas only a small percentage of American Indians do not have them. The cingulum area of some central Europeans is wide-based and prominent compared with the smooth rolled cingulum common to most Europeans.

The shape of certain teeth, in particular maxillary lateral incisors, can be subject to partial expression of a genetic character. For example, partial expression of genes determining lateral incisor form in Mongoloids results in a barrel shaped incisor while in Caucasians such expression may result in a peg shaped lateral incisor.

Because many dental features are genetically determined they may be useful in identifying members of a family. Moreover if individual characteristics are known they may help to identify one person in a group.

Comparative Methods

Two categories exist; cases where ante-mortem records exist but were not taken for purposes of identification; cases where the record was taken, coded and filed for the specific purpose of identification. Radiographs are frequently taken in dental or medical clinics at different times for a large number of the population. The usual procedure in the event of a death is to locate and compare ante-morten and post-mortem radiographs.

A good example of the contribution radiographs have in non-coded identification was seen in connection with the "Noronic" disaster (GUSTAFSON 1966). A ship in Toronto was gutted by fire and 107 of the 119 victims were burned beyond recognition. After body, facial and dental records were gathered and compared with records obtained from the victims, all but three were identifed.

If dentofacial radiographs are to be valid for identification they must include as much information as possible on one film. Panoramic films include all dental information as well as certain parts of the jaws. Furthermore, Sassouni stressed the importance of uniform records as an aid to identification. To record craniofacial structures accurately SASSOUNI (1963) recommended anteroposterior and lateral head films.

Some workers have insisted that the rugae patterns located on the palatal mucosa can be used for identification as they are believed to be unchanged throughout life (GUSTAFSON 1966 and SASSOUNI 1963). Classification systems have been constructed on the basis of size, form relationships and locations of the rugae elements. However the palate changes with age and the soft tissues will not withstand fire or prolonged exposure to the natural elements.

A new photographic technique described by Sassouni permits registration of soft tissues in three dimensions. The physioprint provides a means to project facial contours onto a flat surface, similar to maps created by a cartographer. From the "contour lines" measurements may be obtained to identify soft tissue features.

Bites

All persons express individuality in their dental bite and bite marks which are apparently similar exhibit differences which may be disclosed after careful examination by a dental expert (GUSTAFSON 1966 and FURUHATA 1967). Bite marks may be left in partially eaten foods, a variety of soft materials and in human flesh. Bite marks from the same individual will vary depending on the material being bitten. Bites left by sadists are usually well defined because they bite slowly and deliberately whereas the lunatic bites quickly and carelessly (GUSTAFSON 1966). Further, the character of a bite made by a person protecting himself from an assailant will be different to those already mentioned. Animals too, leave distinct marks.

Physical changes in foodstuffs after they have been bitten will vary according to type of food bitten and the length of time before their discovery. Bites left in cheese, butter, firm fruits, bread and other foods of similar consistency are reasonably distinct whereas bite marks in soft friable materials are poorly defined and usually not recognizable.

Insignificant bite marks can be made on human skin without breaking the continuity of the epithelial covering. The usual result is a bruising which makes the measurement of any tooth marks almost impossible. However, examination of the pathology may provide information relating to the time elapsed since the injury. The character of bite marks may be quite different depending on whether they are inflicted prior to or after death. Turgor of tissues lasts some hours after death so that during this time marks will be relatively sharp. However as the period of time after infliction of a wound increases bite marks become less distinct. Shrinkage also results because of loss of water from the tissues even after an area of tissue containing the bite has been removed and placed in a fixative. The removal of the bite and a surrounding area of tissue will probably lead to some deformation.

Impressions and photographs should be taken as soon as possible. All photographs should include a scale rule adjacent to the bite mark, a factor which will permit life size enlargements to be made. These can then be checked against models of the bite or, more importantly, the suspect.

Before an autopsy is performed there must be accurate detailed description of character, positions and dimensions of the bite as well as an assessment as to whether the bite is human or animal. Impressions of the bite mark are usually taken with rubber impression materials rather than plasters which are less accurate and suffer from edge fragility and dehydrating properties.

STRØM (1963) recommended a technique whereby a suspect was required to bite into a model made from a material with a similar consistency to human flesh. Photographs were then taken and compared with the originals. This method has obvious drawbacks, however.

Criminals have been frequently identified by marks left in food or human flesh. A case was recorded by TAYLOR (1963) in which two young women were savagely murdered after violent sexual attacks. The identities of the criminals were established by comparing tooth marks on the bodies with bites of the suspects.

Personnel Registration

Certain people, for example, members of the armed services, flying personnel of aircraft companies, those who are involved in dangerous occupations and those who travel widely form a group where personal records are usually kept in a precise manner (GUSTAFSON 1963 and 1966). In these instances records include photographs, dental chartings and personal identification. However, there is a need for a uniform system of recording that is compendious and easy to instigate.

In Denmark, 1947, a system was started where records were kept for all crew members of a national airline company (KEISER-NIELSON 1964). The registration included general anatomic description of personal effects such as watches or rings always worn, a complete fingerprint registration and a complete dental record coded on special charts. The latter included the type and extent of restorations and was reviewed from time to time.

GUSTAFSON (1966) has recommended photographic records of both upper and lower jaws as well as radiographic records.

Mass Disasters

The rapid advancement of our technology has led to the situation where all forms of transport are becoming larger, faster and supposedly, safer. However, with the advent of large airliners, for example, which may carry hundreds of passengers, the problems of identifying so many individuals in the event of a major catastrophe are immense. Other modes of transport, rail or maritime, may also result in much loss of life when serious accidents occur.

The increased speed of transport and the increased full capacity of large aircraft will result in greater mutilation of the human body when these machines crash. The resultant fire will be of greater intensity and will destroy personal effects as well as human features to a greater degree, thus increasing the problems of identification. Identification procedures involving the dentitions of victims now assume new importance because of their individuality and resistance to destruction.

Identification should be effected quickly and positively because of legal and social implications (KEISLER-NIELSEN 1964). Basic procedures and identification techniques must be precise, well tabulated and well organized.

Reports by GUSTAFSON (1966), FURNESS (1969), and KEISER-NIELSON (1963) stress the importance of establishing an organized team of experts which can be called into the disaster area at short notice.

The members should include experts from several fields including forensic dentistry as well as local authorities and police. The work of identification must not start under pressure or confusion which might result in the loss of valuable evidence vital to the identification of individuals. Experts at the site of a disaster must work unhampered so that all details may be observed. The authorities are therefore responsible for isolating the area and admitting only authorized personnel.

Identification procedures are commenced as soon as is possible after an accident. The area should be comprehensively photographed and sketches made of the location of wreckage, bodies and personal belongings. Dental data must be collected for each victim, recorded accurately and labelled for later use. Bodies must be removed to one central area where facilities permit accurate examination. The crash site should be examined for fragments of jaws, teeth or dental appliances.

Although radiographs of the victim's dentition should be taken, it is not always possible to have ready access to radiographic equipment. HENRICKSON (1962) developed a pen device to overcome this problem. A radioactive isotope of iodine on one end of the pen is covered by a retractable shield. The radiation emitted when the shield is opened is sufficient to expose a radiographic film.

For a satisfactory examination the jaws need to be open. After fire soft tissues become very hard and must be severed to obtain an intra-oral view. Leverage should not be applied to open a mouth for risk of damaging dental structures. Removal of the tongue by an incision at its base often improves visibility as does removal of lips and cheeks. These methods are not to be used unless permission is granted by the person in charge of the investigation.

In the case of air crashes a list of crew and passengers is immediately available. The crew may have had dental records taken by the company and these will be readily at hand. Dental records of passengers, however, will need to be collected from dentists by the proper authorities. It is essential that complete records are obtained including radiographs.

If the victims are of diverse nationality it is possible that difficulties will arise because of lack of standardization in recording systems and languages. Very often no dental records of any description will be available. There is an obvious advantage in establishing a universally accepted recording system and mandatory pre-travel records. This would reduce the need for gathering detailed records from dental practitioners.

ASHLEY (1970), investigating an air disaster involving primarily Asian nationals, stated that identification was carried out by estimating dental age. No radiographs were used. After available records had been used for identification, as far as possible, reconstructive methods, outlined previously, were used to assist in the identification of the remaining victims for whom no records were available.

Photography

Photographic records, besides being easy to obtain, provide other advantages such as clarity, accuracy, permanence and comprehensibility, regardless of language barriers (LUNZ 1968). Colour photographs of the mouth visually align shapes and sizes of teeth and restorations more clearly than a verbal description. Photographic records should include intra-oral photographs of the upper and lower arches, one with the teeth in occlusion and lips retracted as well as a full frontal facial view with the subject smiling.

Photographic records are low in cost, speedily obtained, are easily stored and, furthermore, camera equipment is versatile and can be used anywhere. Photographs supplemented by post-mortem examination reinforce the written dental chart and permit visual examination at a later stage without direct reference to the body.

JOHANSEN and LINDENSTAM (1961) briefly outlined the use of photography as a method of identification. CREER (1935) used a water-cooled 750 watt lamp as a light source and a Burton clinical camera. McINTOSH (1937), KALZIN and CARLIN (1943) and DYCE (1948) used Leica cameras and KORKHOUS (1953) used a miniature film camera. All these methods were limited to photography of the anterior teeth and surrounding tissues.

MORGAN and LISTER (1938) described a method of photographing the entire upper and lower jaws using large circular mirrors. However, because of the mirror shape, second and third molars, if present, were not included on the record. TAYLOR and SCHLACH (1951) described the use of rectangular metal mirrors which enabled inclusion of all teeth and avoided the troublesome double image obtained with ordinary mirrors. A further refinement in the form of the deposition of a metal onto a glass surface, has resulted in clearer photographic reproduction. The film currently available is far superior and the increased speed ratings of colour film enables their use in most situations. Photographic equipment is more versatile too, especially flash units, which may be exposed hundreds of times from a battery operated power unit.

Suggested Recording Methods

The value of dental evidence for identification depends firstly on the acquisition of dental records from victims and secondly on the adequacy and accuracy of the dental records obtained. A standard method of charting and recording of the dentition must meet the requirements of the dental profession generally.

Many recording systems for dentate patients are in use throughout the world (FRYKHOLM and LYSELL 1962, and FURNESS 1969).

1. Zsigmondy's System 1861

This system is widespread throughout the world, Europe, Americas, Australia and Japan. It is also referred to as "Palmer's Notation" (Palmer 1891).

The central incisor of each segment is assigned the number 1 and the numbers then run in a distal direction to 8, the third molar. Segments are described by ┘, └, ┐, ┌, the upper right and left maxillary arch and the lower right and left mandibular arch respectively.

R	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	L
	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	

Deciduous teeth may be designated by, Roman numerals, letters a - e, Capital A - E or letters d or m beside the number of the tooth.

2. In another system the angle signs and arabic numerals 1 - 8 used in Zsigmondy's system are retained but in reverse order. A similar situation exists for the deciduous teeth.

3. A Dutch system uses the letters I, C, P, M to indicate incisor, canines, premolars and molars:

I1, I2, C, P1, P2, M1, M2, M3.

Deciduous teeth are designated by a small d preceding lower case letters.

4. The Haderup System

Haderup (1887, 1891) created a system whereby teeth are numbered 1 - 8 as in the Zsigmondy system, but plus and minus signs are used to indicate upper or lower arch respectively. Right and left sides of the arches are indicated by placement of the signs on the corresponding side of the tooth number.

	8+	7+	6+	5+	4+	3+	2+	1+	+1	+2	+3	+4	+5	+6	+7	+8	
R																	L
	8-	7-	6-	5-	4-	3-	2-	1-	-1	-2	-3	-4	-5	-6	-7	-8	

Deciduous teeth designation may be preceded by an O or use of Roman numerals. The system is used particularly in Scandinavian countries.

5. Other systems have different notation for each segment. The following are common in America:

(a) The army system

	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	
R																	L
	16	15	14	13	12	11	10	9	9	10	11	12	13	14	15	16	

(b) The navy system

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
R																	L
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	

(c) The universal system

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
R																	L
	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	

(d) The Bosworth system

	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	
R																	L
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H	

Deciduous teeth may retain Arabic numerals with a distinguishing letter placed adjacent or Roman numerals or capital letters.

The registration of surfaces may be designated by:

(1)	m,	mesial
	o, c,	occlusal or central
	b, v, f, bg	buccal, vestibular, facial, buccal and gingival
	d,	distal

l, li, p, lg	lingual, palatal, lingual and gingival
i,	incisal

(2) In Scandinavian Countries / In U.S.A.

In Scandinavian Countries	In U.S.A.
1 - occlusal	1 - mesial
2 - mesial	2 - distal
3 - facial	3 - facial
4 - distal	4 - lingual
5 - lingual	5 - occlusal

(3) The location of the surface may also be given by signs such as lines or dots. A system found in the United Kingdom.

(4) In America, England and several other countries, the surfaces are sometimes classified according to Black's classification.

I - occlusal pits and fissures

II - proximal surfaces of premolars and molars

III - proximal surfaces of anteriors

IV - proximoincisal

V - gingival

(5) The use of schematic or anatomic diagrams of restorations is widely used.

Haderup's system has certain advantages when typing or telegraphing dental descriptions and in 1939 it was recommended by the

Federation Dentaire Internationale (F.D.I.) but it failed to gain universal popularity.

A recent meeting of the F.D.I. (1970) has proposed that a two digit system of designating teeth, developed by J. Viohl of Berlin, be universally accepted. The system is simple to understand and teach, easy to pronounce in conversation and dictation, readily communicable in print or wire, easily coded for computer input, and readily adaptable to standard charts used in dental practice. The first digit of the pair indicates the quadrant while the second digit identifies the tooth within the quadrant (LEATHERMAN 1971).

Permanent teeth are designated:

upper right	upper left
18 17 16 15 14 13 12 11	21 22 23 24 25 26 27 28
48 47 46 45 44 43 42 41	31 32 33 34 35 36 37 38
lower right	lower left

Deciduous teeth are designated:

upper right	upper left
55 54 53 52 51	61 62 63 64 65
85 84 83 82 81	71 72 73 74 75
lower right	lower left

Edentulous individuals provide a special problem in forensic identification. Acrylic dentures are easily lost and in the event of damage or destruction by fire they should be marked or coded in some manner. The coding system must not interfere with the strength of the denture and must be easy to incorporate into the acrylic. The marker should be indestructible and readily visible in the denture acrylic (HARVEY 1966).

The importance of precise, accurate, detailed and continually updated dental records in forensic investigations is widely accepted. Bitewing and orthopantomographic radiographs are also of considerable value in identification procedures. The preceding review has provided some insight into the methods used in forensic dental investigations. There is no doubt that teeth are important in forensic science and methods using dental structures for identification have many advantages over traditional procedures.

This study explores a method for discriminating between sets of dental casts by utilizing modern computers and semi-automatic recording devices. Teeth and dental arches were described by mathematical characters rather than numerical or written records. The methods developed have a direct application in forensic procedures to compare segments of dental arches with previously obtained registrations of known subjects.

MATERIALS AND METHODS CHAPTER 2

The value of dental examinations in certain investigations is now widely accepted. However, comparative and reconstructive techniques of identification are time-consuming and involve people with expert knowledge and training. A method of forensic dental identification utilizing modern technological advances such as computers and semi-automatic recording devices would simplify identification procedures. An identification method discussed in this study makes use of these devices. Photographs of dental casts, obtained in a consistent manner, were placed in the projector of a semi-automatic digital recorder to obtain the coordinates of set reference points. Electrical resistance values, output by the record reader of the semi-automatic recorder are converted to digital values and output onto standard computer punched cards. Two sets of data were obtained for each dental cast. The first set was identified as the first determination, and constituted the master file of subjects. A second set of data, the second determination, was recorded in the same format but located within different Cartesian axes. This second set, constituting the file of test subjects, was matched with the master file. Different combinations and numbers of reference points characterizing molar and incisor segments were selected from second determination data and matched against the master file.

The research material consisted of one hundred dental casts, 50 upper and 50 lower, obtained from students at The University of Adelaide Dental School. Several population groups were represented, Asian, Central and Western European and Australian. The ages of the subjects ranged from 19 years to 28 years. The group comprised of three females and 47 males. The dental health of the subjects was generally very good as judged by the number of teeth missing or extracted, the standard of restorative work and past history of orthodontic treatment. The amount of attrition or tooth wear on molars and incisors was minimal although in most students canines showed wear on the incisal edge. Only one cast showed evidence of excessive wear of molar teeth. The casts were poured in dental stone from alginate impression material and uniformly trimmed.

In an initial investigation 14 reference points were selected for study and these were marked on each cast with a felt-tip pen. In the main study, however, 76 points were marked on each cast. The points were marked in indian ink placed with a very fine nibbed pen. Wax dots were also used to indicate the positions of several reference points. All points were made as small as possible by accurate placement of pen tips or wax instruments.

Fourteen teeth located on both upper and lower arches were selected for the initial and main studies, third molars being excluded. The initial study included the following reference points shown in Figure 1:

mid-points of incisal edges;

cusp tips of canines;

buccal cusp tips of premolars;

mesiobuccal cusp tips of first and second molars.

Reference points in the main study included:

mesiodistal and faciolingual extremities of all teeth;

distobuccal, mesiolingual, mesiobuccal cusp tips of first and second molars;

buccal and lingual cusp tips of premolars.

Figure 2 shows reference points used in the main study. The precise terminology given to these points is discussed subsequently. The points were usually placed on the tips of cusps but if this area was flattened as a result of wear the point was placed in the centre of the area. Faciolingual extremities were located as the points of maximum curvature on the facial and lingual surfaces of molars, premolars, canines and incisors. Mesiodistal extremities of molars and premolars were represented by the lowermost points on the respective marginal ridges. On anterior teeth the analogous points were taken to be the mesial and distal incisal corners.

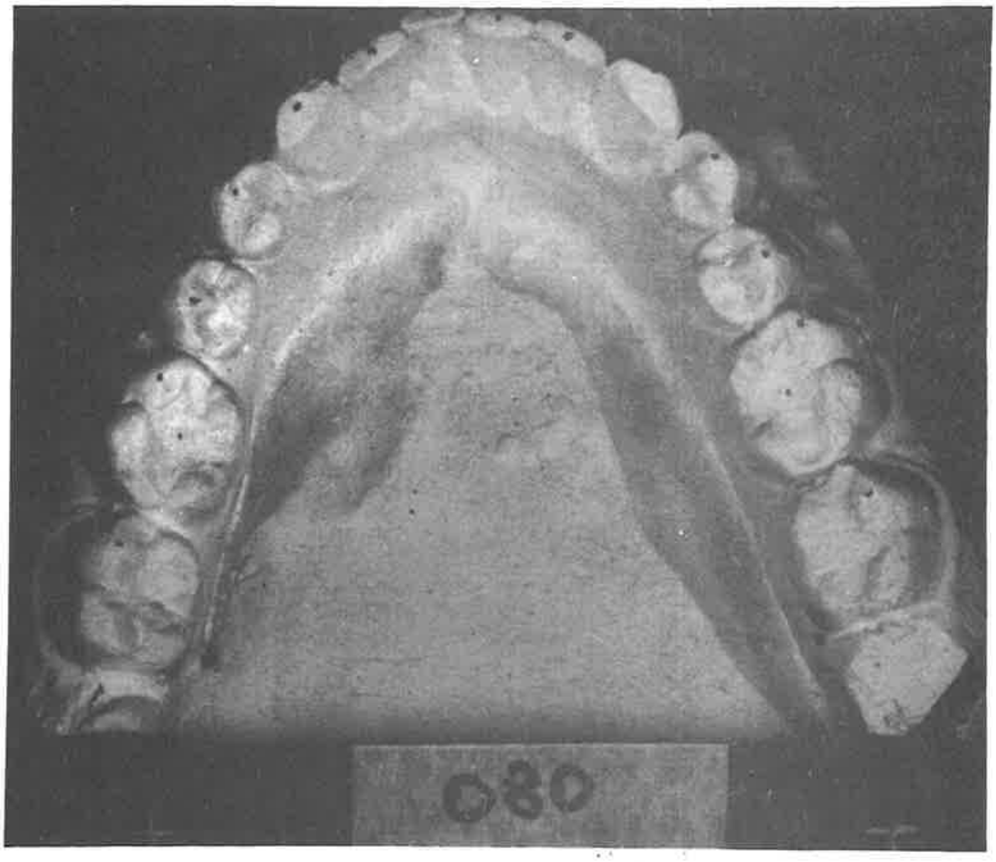

Figure 1 A cast marked with the reference points used in the initial study

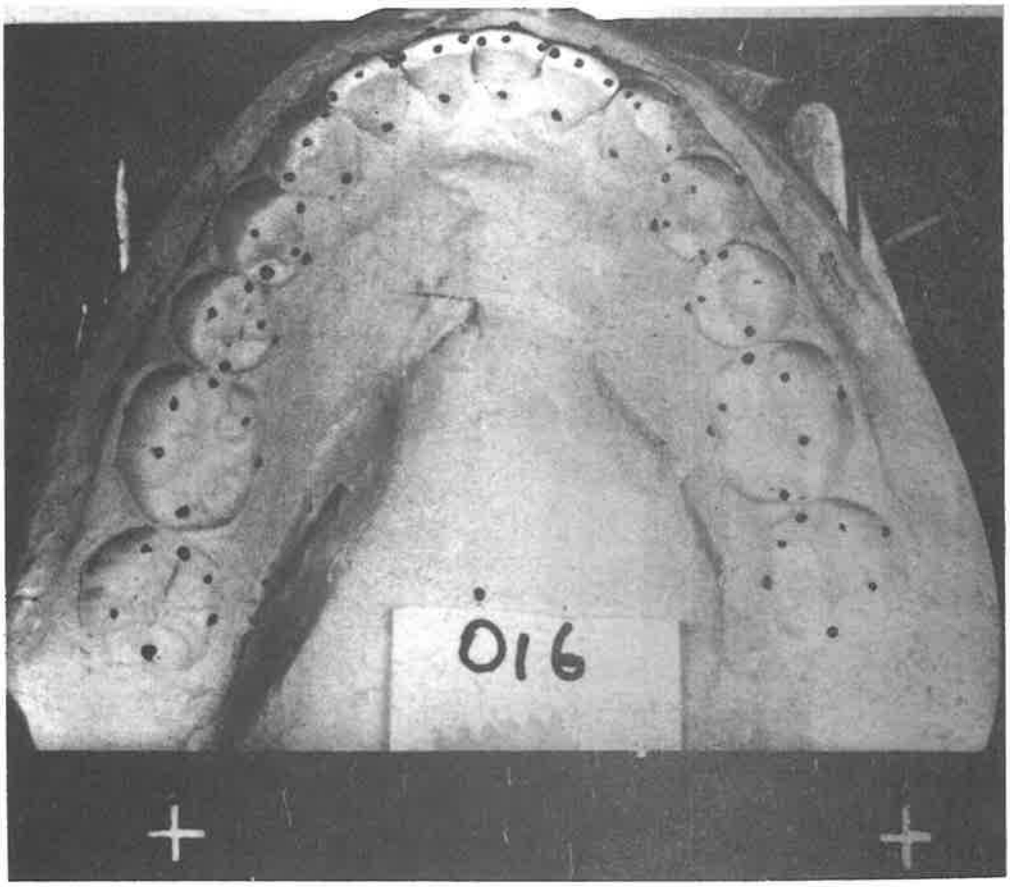

Figure 2   A cast marked with the reference points used in the main study

When marked, each cast was photographed under standardized conditions. The resulting negatives formed a new set of records suitable for use at a later stage. A Hasselblad reflex camera, loaded with Kodak 100 ASA plus-x-pan film, attached to a racking device, was fixed by means of a locking screw to a rigid stand. The camera in such a position could only be moved in a vertical direction by means of the racking device (Figure 3). The base of the stand, 18 inches from the floor, was a flat steel table aligned perpendicularly to the camera and its attachments. On this table was a movable levelling platform (Figure 4) with a tray adjustable in a vertical direction and a rectangular frame located some distance above the tray. The frame provided a plane to which the camera focus could be set to ensure standardized photographs.

A cast was now taken, placed in an adjustable Ney surveyor table*, and positioned on the tray of the movable platform. The cast was made approximately level with the plane of the rectangular frame and the camera distance adjusted, using the racking device, to obtain as large an image of the cast as possible in the viewer of the camera. The cast image in the camera viewer was "squared" by moving the levelling platform on the base.

---

* The Ney Surveyor
The J.M. Ney Company, Hartford, Conn., U.S.A.

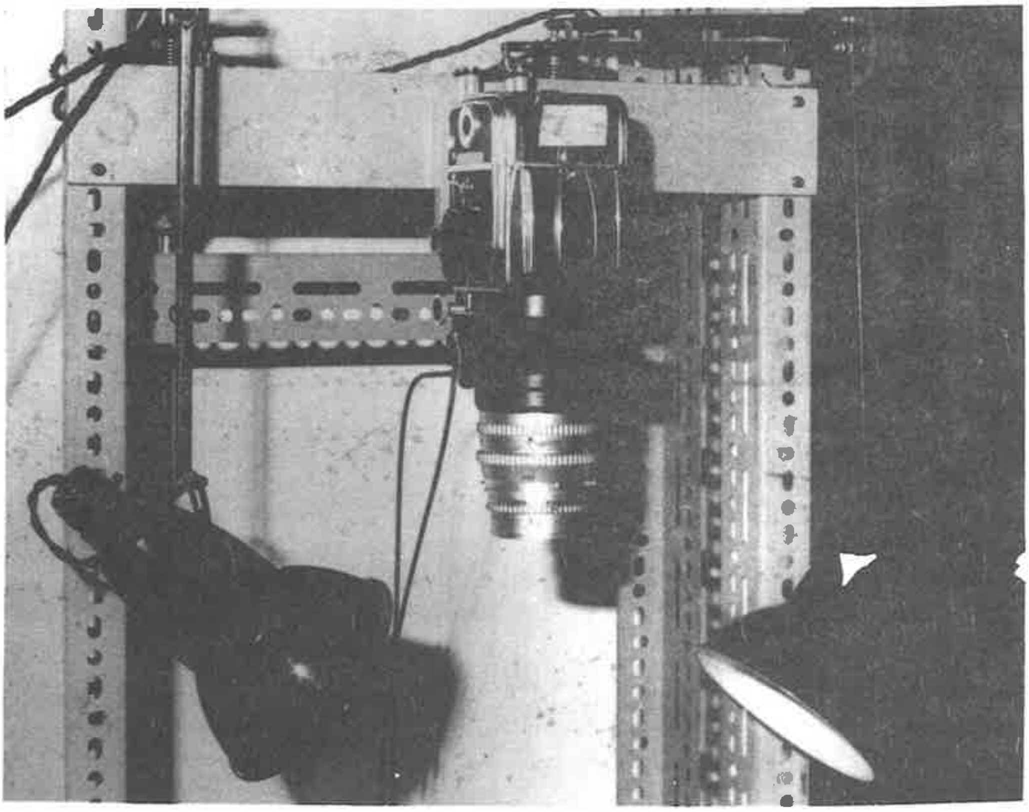

Figure 3 The camera and racking device attached to the stand

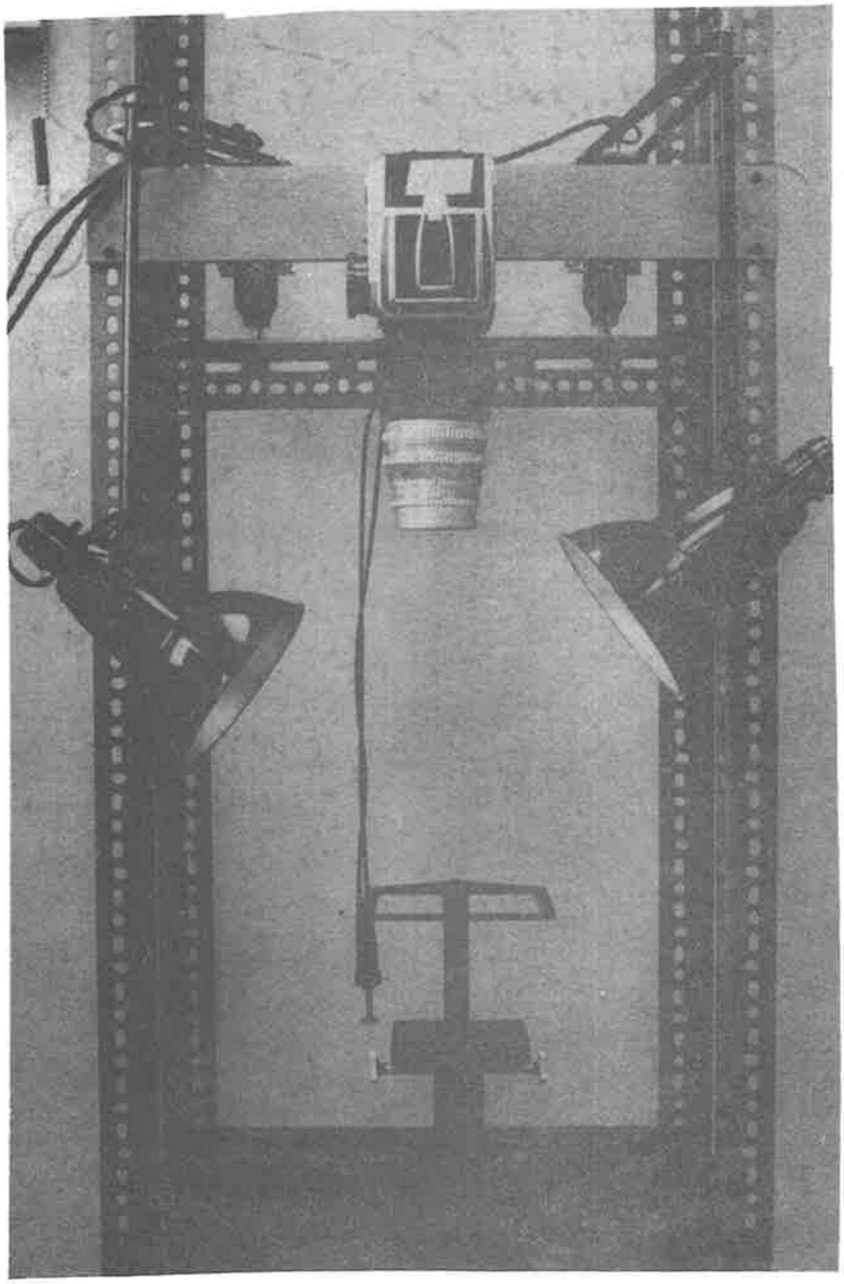

Figure 4 The movable levelling platform on the steel base

The camera and platform were now ready and positioned for photographing each of the 100 casts.

Casts were numbered 1 - 100, with odd numbers representing upper casts and even numbers the lower casts. Each cast was processed in numeric sequence and aligned by the standard method to ensure continuity between photographic records. Firstly, the cast was placed in the adjustable Ney surveyor table and locked in position. With the surveyor table on the steel base a levelling tripod was used to orientate the cast (Figure 5). The two points of the tripod were located in the central fossae of first molars with the arm resting on the incisor teeth. Levelling was achieved by aligning a bubble in the centre of a ring marked on the device.

The surveyor with the levelled cast was placed on the movable platform. The stage of the platform was raised or lowered to make the incisal edges of upper anteriors or the cusp tips of lower first molars level with the plane of the rectangular frame (Figure 6). The heels of upper and lower casts were always positioned toward the operator. A plastic strip with two scale points scribed exactly five centimetres apart was placed adjacent and parallel to the heels of each cast. The width of the marker was such that it fitted onto the rectangular frame in a uniform manner. An

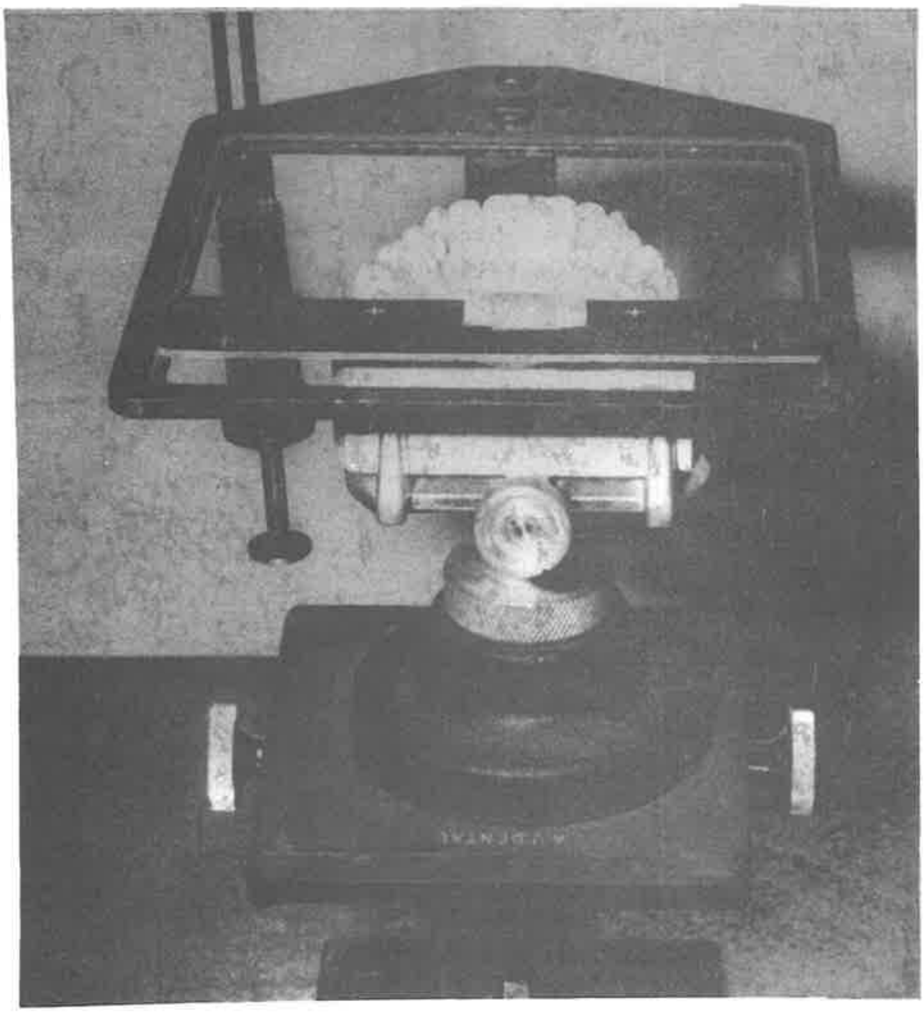

Figure 5   A cast being levelled on a Ney Surveyor table

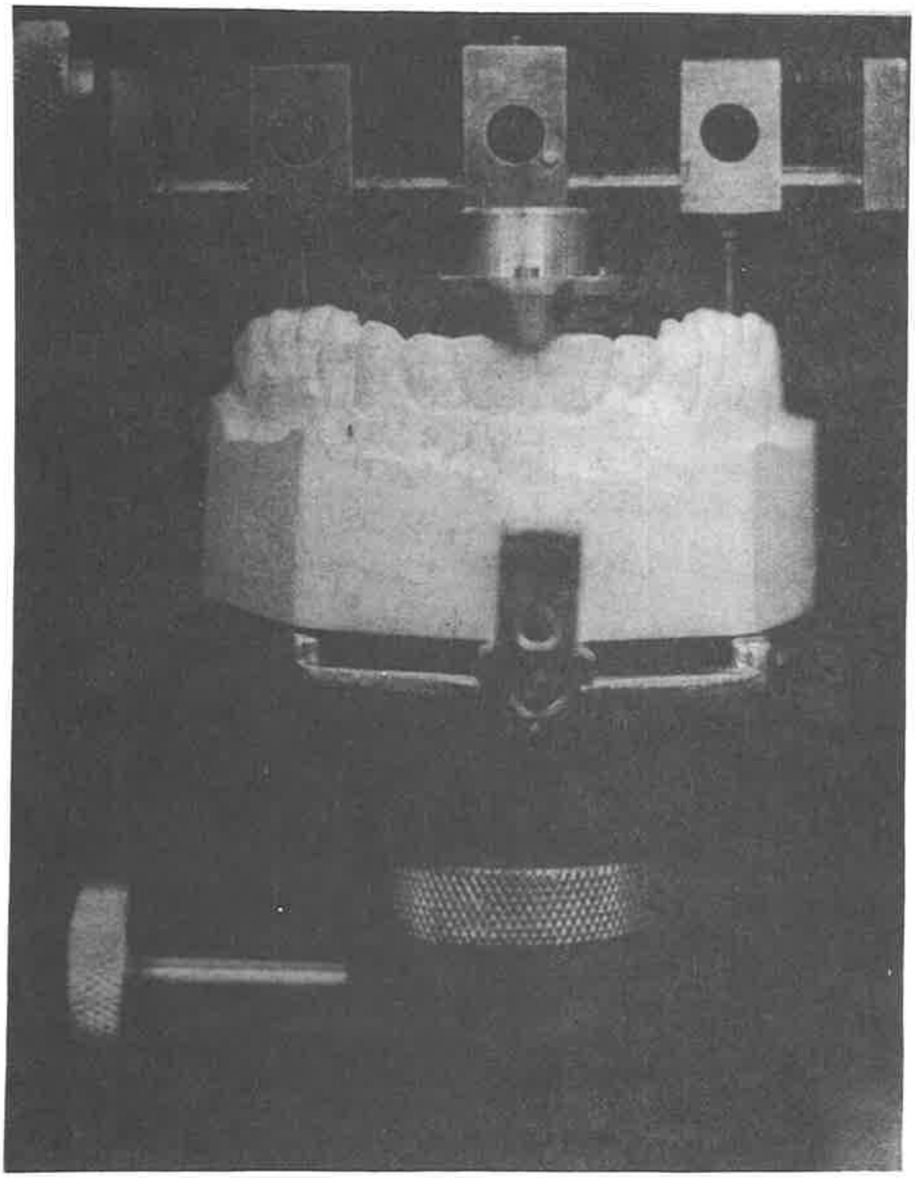

Figure 6 The cast adjusted to the plane of the rectangular frame

identification tag with the cast number was placed on the plastic marker making sure that it did not obscure either scale point.

Lighting was provided by two adjustable desk lamps with 60 watt globes. The light was directioned to avoid shadows forming on occlusal surfaces. Optimal lighting conditions were obtained with the lamps three inches above the rectangular frame and seven inches from the cast at an angle of 45 degrees.

Each cast was then photographed under identical conditions. Camera settings of F 45 at half a second gave the best exposures. The negatives became a new set of records suitable for use in conjunction with a semi-automatic recorder.

The semi-automatic recorder used in this study was the OSCAR F/DCF strip chart and film digitizing system (Figure 7). The machine consists of two parts. Firstly, a console which has a projector, a viewing screen and a movable reading head with X and Y cursors. Electrical resistance values, determined by potentiometers fitted to the X and Y cursors are transmitted from this unit, by depressing a read out button, to the second unit. The latter has electrical relays which convert electrical impulses to digital units. The digital values are transmitted to an IBM 26 punch machine and output on punched cards.

Figure 7 Recording equipment
Left - the digital converter unit,
Centre - the record reader showing projector viewing screen and reading head,
Right - the IBM 26 punch card unit.

The next phase was to use the negatives to scale the OSCAR and establish a precise routine for the recording of data. A negative was introduced into the projector with the smooth, shiny surface toward the projector globe. The image on the screen was focused, with the aid of controls on the projector, to give a clean, sharp outline. Excess light on the viewing screen was restricted by placing a piece of cardboard with a 43 millimetre square hole in front of the negative. The negative was adjusted so that the whole arch as well as the marker with the scale points was clearly visible on the screen. Scale points were always placed at the top of the viewing screen. The OSCAR was then ready for scaling.

A grid constructed to precise mathematical standards was placed over the viewing screen and held in position on either side of the screen by magnetic bars. The grid was used to scale the X and Y axes to predetermined values. The digital converter unit is capable of recording values ranging from -999 to +999. The scale for each axis was determined by achieving correspondence between lines on the grid and digital converter values within the range referred to above. Coordinate values for all reference points marked on the casts could now be obtained. The recording procedure was standardized, all coordinates being recorded in a fixed predetermined sequence.

Coordinates of the two scale points were always recorded first. The scale points were a known distance apart and were included in each record to facilitate data conversion from units output by the OSCAR to millimetres. Recording was commenced on the operator's left and finished on the right. Following the recording of the two scale points the points used to characterize the dental arch were recorded in a fixed sequence. For upper casts the first tooth to be recorded was the upper left second molar, while for lower casts it was the lower right second molar.

Data were punched onto computer cards according to a specified format. The first ten columns of every data card included identification, determination number, card number and cast number. This information was entered by manual key punch before the digitized values of the reference points were automatically recorded. In those instances where teeth were missing, blank fields of four columns indicated the unavailable X and Y coordinate.

Reference Point Terminology

Codes used for the points on each cast were limited to four alphanumeric characters by the selected format for computer input. The two digit system recommended by The Federation Dentaire

Internationale was chosen to code reference points. The first digit refers to a particular quadrant:

1 the upper right quadrant;

2 the upper left quadrant;

3 the lower left quadrant;

4 the lower right quadrant.

The second digit describes the position of the tooth in each quadrant. The system can thus be represented as:

right maxillary	left maxillary
18 17 16 15 14 13 12 11	21 22 23 24 25 26 27 28
48 47 46 45 44 43 42 41	31 32 33 34 35 36 37 38
right mandibular	left mandibular

Identification of points was further clarified by use of the following codes or labels. In the initial study:

IE midpoint of an incisal edge;

C cusp tip of a canine;

B buccal cusp tip of a premolar;

BC mesiobuccal cusp tips of first and second molars.

Identification points in the main study were altered but still conformed to previously set conditions. The classification was as follows:

DM distal marginal ridge of a molar;

MM mesial marginal ridge of a molar;

F the point of maximum curvature on the facial surface of a molar, premolar, canine and incisor;

L the point of maximum curvature on the lingual or palatal surface of a molar, premolar, canine and incisor;

DB the distobuccal cusp tip of a molar;

ML the mesiolingual cusp tip of a molar;

MB the mesiobuccal cusp tip of a molar;

B the buccal cusp tip of a premolar;

Li the lingual cusp tip of a premolar;

D the distoincisal corner of the incisal edge of a canine or incisor;

M the mesioincisal corner of the incisal edge of a canine or incisor.

Thus by using the codes specified for each tooth and reference point location, each reference point was uniquely defined. For example, the reference point located on the distal marginal ridge of an upper right second molar was coded 17DM.

Matching Procedure

A double determination procedure for comparing data derived on two occasions was carried out on a C.D.C. 6400 computer using a mathematical process of least squares differences, which minimizes the discrepancies between two determinations of coordinates (BROWN, BARRETT and CLARKE 1970).

For each subject the coordinates comprising the first determinations were punched onto computer cards according to methods previously outlined. The second determination data for the same subjects were obtained in a similar way except that the orientation of the cast photograph on the viewing screen was changed. Two sets of data were now identically scaled but were located within different Cartesian axes. Thus if there are two sets of coordinates for n points say,

$$(x_i , y_i) \quad \text{and} \quad (x_i' , y_i') \qquad i = 1,2,\ldots,n$$

then the sum at squares of discrepancies (s) between the duplicate recordings is given by:

$$S = \sum_{i=1}^{n} \left[w^x_i \, (x_i' - x_i)^2 + w^y_i \, (y_i' - y_i)^2 \right]$$

where $w^x_1, w^x_2, \ldots, w^x_n$ and $w^y_1, w^y_2, \ldots, w^y_n$ are weights given to the coordinates $x_1, x_2, \ldots, x_n$ and $y_1, y_2, \ldots, y_n$ respectively, depending on their accuracy and the importance of bringing them into alignment. In this study there was no differential weighting of certain points.

The least squares transformation is contingent upon a translation and rotation procedure. The first minimization, with respect to translation, is met when the centres of gravity, $(\bar{x},\bar{y})$ and $(\bar{x}',\bar{y}')$, of the two sets of points agree where:

$$\bar{x} = \Sigma w^x_i \, x_i \Big/ \Sigma w^x_i \quad , \quad \bar{y} = \Sigma w^y_i \, y_i \Big/ \Sigma w^y_i$$

$$\bar{x} = \Sigma w^x_i \, x_i' \Big/ \Sigma w^x_i \quad , \quad \bar{y} = \Sigma w^y_i \, y_i' \Big/ \Sigma w^y_i$$

for $i = 1,2,\ldots, n$.

The coordinates of the two centres of gravity are calculated as above and then the measurements are replaced by the deviations from these centres:

x_i is replaced by $x_i - \bar{x}$

y_i is replaced by $y_i - \bar{y}$

x_i' is replaced by $x_i' - \bar{x}'$

y_i is replaced by $y_i' - \bar{y}'$

for $i = 1,2,\ldots, n$.

The sums of squares of discrepancies is further minimized by a rotation about the common centre of gravity through angle θ , where:

$$\theta =$$

$$\Sigma \left[w^x_i (x_i' - x_i)(-y_i') + w^y_i (y_i' - y_i) \, x_i' \right] \Big/ \left[\Sigma w_i^x \, y_i'^2 + \Sigma w_i^y \, x_i^2 \right]$$

for $i = 1,2,\ldots, n$.

and x_i, y_i, x_i' and y_i' are deviations from the respective centres of gravity computed above.

The rotation of the second set of determinations through angle θ will bring about maximum agreement with set one. We must replace,

x_i' by $(x_i' \cos \theta + y_i' \sin \theta)$ and

y_i' by $(y_i' \cos \theta - x_i' \sin \theta)$ for $i = 1,2,\ldots, n$.

Following the two transformations discrepancies between the two sets of observations will be minimized.

Theoretically it could be expected that an iterative procedure based on the above model would achieve optimal results. In practice, however, repeated iterations did not markedly improve the fit as the two determinations were always in approximate initial agreement.

Criterion For Matching

The sums of least squares differences, determined as the total of the linear discrepancies between first and second determinations of n points, were obtained for each comparison of a test subject with the master file subjects. In each case the linear discrepancies were squared to eliminate negative differences. The first and second determinations in this study were the recordings for a subject from the master file and a test subject respectively. The sum of squares differences was termed "The Index of Similarity".

The minimum index value indicated the closest agreement between a test subject and a subject on the master file.

Table 2 shows results obtained from the initial study when test subject two, described by 14 points, was matched against each of the 50 subjects on the master file. The values of the sums of squares of differences, taken as the indices of similarity, ranged from 0.34 - 270.78. The lower value, 0.34, represented a clear match between test subject two and master file subject two. The nearest value to 0.34 was 44.14 which, relative to the lower value indicated, is 130 times less acute discrimination. The lowest value for the index of similarity between a test subject and a cast on the master file was used as the criterion for identifying the test subjects.

The Master File

The data cards for the first determination of coordinates for the 100 casts became the master file. The file consisted of two sections, one with coordinates characterizing upper casts and the other characterizing lower casts. A computer printout was obtained for each cast using PROGRAM FOREN 1, listing reference points and their coordinates expressed as both digital converter units and millimetres. The scale distance and the calculated value of one

TABLE 2

Summary Of Comparisons Between Test Subject Two And 50 Master File Subjects Lower Dental Casts

master file subject

M.F.S.*	S.I.*	M.F.S.	S.I.
2	0.34	52	74.99
4	216.96	54	101.44
6	109.94	56	52.36
8	85.22	58	137.95
10	253.25	60	141.10
12	168.53	62	128.88
14	168.30	64	74.27
16	99.33	66	61.22
18	155.27	68	63.38
20	154.93	70	95.25
22	105.65	72	126.65
24	70.69	74	119.75
26	72.01	76	56.53
28	179.45	78	87.20
30	42.32	80	61.01
32	61.19	82	53.27
34	70.55	84	270.78
36	44.14	86	133.54
38	78.37	88	91.80
40	98.23	90	264.87
42	206.63	92	147.73
44	145.07	94	64.69
46	143.11	96	97.95
48	65.62	98	128.90
50	103.76	100	135.72

* For details of coding changes see Page 63.

converter unit in terms of millimetres was listed also (Figure 8). Missing data points were located and listed (Figure 8) but were excluded from the matching procedure.

In general the conversion of converter units into millimetres can be described in the following way. The coordinates of the two scale points say, (x_1,y_1) and (x_2,y_2) are punched onto data cards as converter unit values. The distance between the two points is fixed at 50 millimetres. The equivalent distance in converter units can be calculated as:

$$\text{scale distance (converter units)} = \sqrt{(x_2-x_1)^2 + (y_2-y_1)^2}$$

$$1 \text{ converter unit} = \frac{50}{\sqrt{(x_2-x_1)^2 + (y_2-y_1)^2}} \text{ mm}$$

A visual check was made on all printed data to ensure coordinate values followed a logical sequence along the X and Y axes. Scale distances were compared to ensure that there was no wide discrepancy between successive values. A difference between the two scale distance determinants of two converter units, approximately 0.2 millimetres, was considered acceptable. After screening the data all scaled values were transferred to magnetic tape which provided a more accessible form of storage for further reference. The master file tape had two sections as did the

SUBJECT 7
SCALE DISTANCE = 494.02 CONV UNITS
ONE CONV. UNIT = .1 04 MMS

POINT		OSCAR READINGS X	Y	SCALED COORDS X	Y
1	27DM	253	599	25.4	60.1
2	27MM	262	530	26.3	53.2
3	27F	211	543	21.2	54.5
4	27L	312	575	31.3	57.7
5	27DB	222	582	22.3	58.4
6	27ML	273	570	27.4	57.2
7	27MB	219	533	22.0	53.5
8	26DM	271	508	27.2	51.0
9	26MM	294	427	29.5	42.9
10	26F	234	445	23.5	44.7
11	26L	333	492	33.4	49.4
12	26DB	242	488	24.3	49.0
13	26ML	305	469	30.6	47.1
14	26MB	255	433	25.6	43.5
15	25DM	294	411	29.5	41.3
16	25MM	317	368	31.8	36.9
17	25F	260	373	26.1	37.4
18	25L	340	410	34.1	41.2
19	25B	279	372	28.0	37.3
20	25LI	325	400	32.6	40.2
21	24DM	323	358	32.4	35.9
22	24MM	350	314	35.1	31.5
23	24F	295	315	29.6	31.6
24	24L	375	347	37.6	34.8
25	24B	316	319	31.7	32.0
26	24LI	363	346	36.4	34.7
27	23D	322	275	32.3	27.6
28	23M	376	238	37.7	23.9
29	23F	341	241	34.2	24.2
30	23L	383	299	38.5	30.0
31	22D	387	213	38.9	21.4
32	22M	443	196	44.5	19.7
33	22F	402	198	40.4	19.9
34	22L	417	259	41.9	26.0
35	21D	-0	-0	0.0	0.0
36	21M	-0	-0	0.0	0.0
37	21F	-0	-0	0.0	0.0
38	21L	-0	-0	0.0	0.0
39	11M	-0	-0	0.0	0.0
40	11D	-0	-0	0.0	0.0
41	11F	-0	-0	0.0	0.0
42	11L	-0	-0	0.0	0.0
43	12M	-0	-0	0.0	0.0
44	12D	-0	-0	0.0	0.0
45	12F	-0	-0	0.0	0.0
46	12L	-0	-0	0.0	0.0
47	13M	615	233	61.7	23.4
48	13D	667	272	67.0	27.3
49	13F	655	241	65.8	24.2
50	13L	612	297	61.4	29.8
51	14MM	649	303	65.2	30.4
52	14DM	671	351	67.4	35.2
53	14F	706	307	70.3	30.8
54	14L	629	346	63.2	34.7
55	14B	682	313	68.5	31.4
56	14LI	633	338	63.6	33.9
57	15MM	681	361	68.4	36.2
58	25DM	705	405	70.8	40.7
59	15F	729	363	73.2	36.4
60	15L	654	399	65.7	41.1
61	15B	713	361	71.6	36.2
62	15LI	666	395	66.9	39.7
63	16MM	704	426	70.7	42.2
64	16DM	727	500	73.0	50.2
65	16F	761	431	76.4	43.3
66	16L	665	479	66.8	48.1
67	16DB	747	473	75.0	47.5
68	16ML	682	459	68.5	46.1
69	16MB	745	423	74.8	42.5
70	17MM	758	508	76.1	51.0
71	17DM	754	578	75.7	58.0
72	17F	796	506	79.9	50.8
73	17L	703	553	70.6	55.5
74	17DB	783	562	78.6	56.4
75	17ML	742	539	74.5	54.1
76	17MB	788	511	79.1	51.3

12 MISSING POINTS FOR THIS SUBJECT

Figure 8 Printout determined by PROGRAM FOREN I for Master File subject 7 listing coordinates for reference points in converter units and millimetres printed master file, coordinates characterizing upper arches and coordinates characterizing lower arches.

The next phase was to complete second determination evaluations for the subjects recorded on the master file. The new sets of coordinates were scaled and recorded in the same manner in which the master file records were prepared. No attempt was made to standardize the orientation of images on the viewing screen of the recording device.

The matching procedure using second determination evaluations was carried out by PROGRAM FOREN 2. This program provided a table listing reference points and coordinates, similar to that obtained with FOREN 1 (Figure 9), as well as new information (Figure 10). During the matching procedure each cast was analysed in sequence by comparison with records of each subject on the master file. That is, each individual upper test subject was compared with the 50 upper subjects on the master file. A similar procedure was followed for lower casts.

The printout for a typical matching procedure is shown in Figure 10. Included in this summary were test subject identification, the number of matchings that had taken place, a list of sums of least squares differences, the relative discrepancy

TEST SUBJECT 5
SCALE DISTANCE = 498.90 CONV. UNITS
1 CONV. UNIT = .1004 MMS

LIST OF RETAINED POINTS

SUMMARY OF TEST DATA

	POINT	ORIGINAL DATA X	ORIGINAL DATA Y	SCALED DATA X	SCALED DATA Y
1	27DM	241	563	24.20	56.53
2	27MM	265	484	26.61	48.59
3	27F	205	500	20.58	50.20
4	27L	311	535	31.22	53.71
5	27DB	208	536	20.88	53.81
6	27ML	278	525	27.91	52.71
7	27MB	223	482	22.39	48.39
8	26DM	263	467	26.41	46.89
9	26MM	305	393	30.62	39.46
10	26F	234	402	23.49	40.36
11	26L	334	449	33.53	45.08
12	26DB	239	435	24.00	43.67
13	26ML	311	430	31.22	43.17
14	26MB	260	387	26.10	38.86
15	25DM	294	365	29.52	36.65
16	25MM	319	316	32.03	31.73
17	25F	259	327	26.00	32.83
18	25L	353	360	35.44	36.14
19	25B	281	323	28.21	32.43
20	25LI	329	344	33.03	34.54
21	24DM	353	300	35.44	30.12
22	24MM	339	252	34.04	25.30
23	24F	295	280	29.62	28.11
24	24L	385	275	38.65	27.61
25	24B	325	269	32.63	27.01
26	24LI	371	261	37.25	26.20
27	23D	359	222	36.04	22.29
28	23M	399	173	40.06	17.37
29	23F	360	184	36.14	18.47
30	23L	419	238	42.07	23.90
31	22D	425	163	42.67	16.37
32	22M	462	146	46.39	14.66
33	22F	432	146	43.37	14.66
34	22L	456	203	45.78	20.38
35	21D	483	145	48.49	14.56
36	21M	560	141	56.22	14.16
37	21F	517	127	51.91	12.75
38	21L	513	202	51.51	20.28
39	11M	577	136	57.93	13.65
40	11D	641	162	64.36	16.26
41	11F	606	134	60.84	13.45
42	11L	595	213	59.74	21.39
43	12M	DATA POINT NOT RECORDED			
44	12D	DATA POINT NOT RECORDED			
45	12F	DATA POINT NOT RECORDED			
46	12L	DATA POINT NOT RECORDED			
47	13M	659	170	66.16	17.07
48	13D	708	215	71.08	21.59
49	13F	702	185	70.48	18.57
50	13L	650	233	65.26	23.39
51	14MM	726	260	72.89	26.10
52	14DM	716	307	71.89	30.82
53	14F	769	283	77.21	28.41
54	14L	683	277	68.57	27.81
55	14B	748	285	75.10	28.61
56	14LI	701	273	70.38	27.41
57	15MM	759	321	76.20	32.23
58	25DM	782	384	78.51	38.55
59	15F	812	335	81.53	33.63
60	15L	726	369	72.89	37.05
61	15B	797	327	80.02	32.83
62	15LI	741	349	74.40	35.04
63	16MM	793	397	79.62	39.86
64	16DM	824	470	82.73	47.19
65	16F	838	403	84.14	40.46
66	16L	754	452	75.70	45.38
67	16DB	845	432	84.84	43.37
68	16ML	781	423	78.41	42.47
69	16MB	825	390	82.83	39.16
70	17MM	824	488	82.73	49.00
71	17DM	844	572	84.74	57.43
72	17F	872	516	87.55	51.81
73	17L	775	544	77.81	54.62
74	17DB	873	538	87.65	54.02
75	17ML	884	532	88.72	53.41
76	17MB	856	493	85.94	49.50

Figure 9 Printout determined by PROGRAM FOREN 2 for test subject 5 listing coordinates for reference points in converter units and millimetres

SUMMARY OF COMPARISONS FOR TEST SUBJECT 5			
COMPARISON	DISCREPANCY	REL. DISCREP.	MATCH
1	454.76	2	1
2	531.55	2	3
3	531.69	2	5
4	962.47	4	7
5	992.40	4	9
6	1219.94	5	11
7	924.44	4	13
8	2214.71	9	15
9	1334.00	5	17
10	1347.64	5	19
11	497.76	2	21
12	373.78	1	23
13	469.87	2	25
14	1435.91	6	27
15	330.22	1	29
16	330.90	1	31
17	475.70	2	33
18	358.45	1	35
19	478.71	2	37
20	660.43	2	39
21	1393.19	6	41
22	2199.69	9	43
23	877.77	3	45
24	230.11	1	47
25	1135.63	4	49
26	539.00	2	51
27	4753.88	20	53
28	312.24	1	55
29	913.47	3	57
30	922.78	4	59
31	814.09	3	61
32	730.75	3	63
33	275.82	1	65
34	645.99	2	67
35	712.35	3	69
36	411.93	1	71
37	1214.55	5	73
38	717.09	3	75
39	833.59	3	77
40	446.36	1	79
41	944.84	4	81
42	1814.93	7	83
43	516.91	2	85
44	739.29	3	87
45	1755.45	7	89
46	961.59	4	91
47	435.58	1	93
48	518.01	2	95
49	1237.51	5	97
50	1698.90	7	99

Figure 10 Printout for the matching procedure when upper test subject 5 was matched against upper master file subjects listing test subject identification, similarity index, relative discrepancy and master file subject identity

and the identity of the subject on the master file against which the test subject was identified. The smallest value of the sums of least squares differences, that is the similarity index, indicated the closest correspondence between the test subject and a subject from the master file.

In the initial study the matching was first carried out using all 14 reference points of both maxillary and mandibular teeth. To test the fineness of discriminatory ability of the method the matching procedure was repeated using subsets of the 14 reference points.

The first subset included reference point determinants on four anterior teeth;

upper cast reference points		lower cast reference points	
point	label	point	label
5	23C	5	43C
6	22IE	6	42IE
7	21IE	7	41IE
8	11IE	8	31IE.

The second subset included reference point determinants on four molar teeth;

upper cast reference points		lower cast reference points	
point	label	point	label
11	14B	11	34B
12	15B	12	35B
13	16BC	13	36BC
14	17BC	14	37BC.

These subsets were selected from second determination data by specified parameter cards entered with the data cards.

In the main study the number of points used to characterize the teeth was increased to 76. Molar teeth were characterized by seven points, premolars by six, canines and incisors by four. Subsets of the reference points were selected to characterize two molars and two incisors in each arch. In all, 27 subsets were used to describe these teeth; reference points used to describe each subset are presented in APPENDIX A.

RESULTS CHAPTER 3

Results of the initial and main studies are presented in Tables 6-33. The initial study results, Tables 6-11, show the success achieved when matching upper and lower casts, represented by the coordinates of specified reference points, against sets of data recorded on the master file. In the initial study when 14 points were used to characterize each upper and lower arch successful identification was achieved in every instance (Tables 6,7). However matching procedures using selected points to describe particular segments was not as successful, (Tables 8,9,10,11).

In some instances no clear match was obtained and test subjects in this category, marked with an asterisk, were either matched with the correct master file subject as well as one or more other subjects on the master file, or they failed to match with the corresponding master file subject. For example, test subject 40, described by four lower molar reference points, failed to be clearly identified when compared against the 50 master file subjects, (Table 3). Two other matchings with subjects 90 and 88 also produced low indices of similarity.

An example of a test subject mismatching with the corresponding master file subject is given in Table 4. In this instance the similarity index was higher than those obtained for some "incorrect" matches. The incorrect matches in the initial study are summarized in Table 5.

The closest match between a test subject and the subjects on the master file was indicated by the index of similarity with the lowest value. In the tables these abbreviations are used for convenience; index of similarity (S.I.), test subject (T.S.), nearest value to the matching similarity (N.S.I.), matching master file subject with the lowest similarity index (M.F.S.).

TABLE 3

Results Of Matching Test Subject 40 Using Four Lower Molar Reference Points

T.S.*	S.I.*	M.F.S.*
40	0.22	90
	0.25	40
	0.32	88

TABLE 4

Mismatch Of Test Subject 61 With The Corresponding Master File Subject

T.S.	S.I.	M.F.S.
61	1.07	61
	0.88	35
	0.82	39
	0.32	77

TABLE 5

Summary Of Incorrect Matches In The Initial Study†

	Table 8	Table 9	Table 10	Table 11
Total number of subjects matched	45	46	46	45
Number of mismatches	4	12	19	11

† Detailed results of initial study shown in Tables 8,9,10,11

* T.S. Test subject
S.I. Similarity index
M.F.S. Master file subject

TABLE 6

Similarity Indices Determined On 46 Subjects Using All 14 Upper Arch Reference Points

T.S.*	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
1	0.20	36.94	1	53	0.43	48.32	53
3	0.41	30.07	3	55	1.36	18.16	55
11	0.16	60.06	11	57	0.69	41.88	57
13	0.32	18.05	13	59	0.77	3.65	59
15	0.12	13.94	15	61	1.45	19.80	61
17	0.50	16.17	17	63	0.56	23.67	63
19	0.39	28.66	19	65	0.54	42.32	65
21	0.41	12.50	21	67	0.56	10.87	67
23	0.50	15.05	23	69	0.26	22.70	69
25	0.64	33.66	25	71	0.46	9.42	71
27	0.49	26.17	27	73	0.76	24.74	73
29	0.39	9.84	29	75	0.53	28.84	75
31	0.41	13.39	31	77	0.87	51.80	77
33	1.08	12.15	33	79	0.30	1.53	79
35	0.62	12.89	35	81	0.79	18.13	81
37	0.57	21.57	37	83	0.37	14.88	83
39	0.82	27.57	39	87	0.41	31.02	87
41	0.45	17.18	41	89	0.64	26.18	89
43	0.49	24.57	43	91	0.51	1.42	91
45	0.45	13.65	45	93	0.64	1.51	93
47	0.88	12.29	47	95	0.35	20.62	95
49	0.34	31.30	49	97	0.21	19.15	97
51	0.46	39.08	51	99	0.18	36.36	99

* T.S. Test Subject

S.I. Similarity Index

N.S.I. Nearest Similarity Index

M.F.S. Master File Subject

TABLE 7

Similarity Indices Determined On 46 Subjects Using All
14 Lower Arch Reference Points

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
2	0.34	42.32	2	56	0.73	15.40	56
12	0.19	18.19	12	58	0.18	26.37	58
14	0.35	16.11	14	60	0.48	3.23	60
16	0.43	16.08	16	62	0.34	19.61	62
18	0.40	24.98	18	64	0.50	21.17	64
20	0.31	21.93	20	66	0.29	65.26	66
22	0.52	17.34	22	68	0.97	9.89	68
24	0.25	14.41	24	70	0.33	27.68	70
26	0.19	28.07	26	72	0.51	23.69	72
28	0.53	43.83	28	74	0.23	19.89	74
30	0.43	11.09	30	76	0.31	21.58	76
32	0.35	11.96	32	78	0.34	17.40	78
34	0.36	9.26	34	80	0.39	3.05	80
36	0.70	14.19	36	82	0.67	23.32	82
38	0.34	14.38	38	84	0.29	20.92	84
40	0.99	17.30	40	86	0.46	30.14	86
42	0.62	31.42	42	88	0.41	11.60	88
44	0.35	25.66	44	90	0.21	11.30	90
46	0.28	28.27	46	92	0.21	3.20	92
48	0.49	11.68	48	94	0.52	2.85	94
50	0.42	59.87	50	96	0.31	26.83	96
52	0.63	15.54	52	98	0.34	17.55	98
54	0.52	48.15	54	100	0.31	22.42	100

TABLE 8

Similarity Indices Determined On 45 Subjects Using
Four Upper Incisor Reference Points

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
1	0.08	3.04	1	55	0.17	1.49	55
3	0.05	2.30	3	57	0.14	3.54	57
11	0.01	0.14	11	59	0.15	0.45	59
13	0.05	0.42	13	61			*
15	0.05	0.59	15	63	0.06	0.36	63
17	0.10	0.41	17	65	0.06	0.54	65
19	0.06	1.44	19	67	0.05	0.23	67
21	0.09	0.12	21	69	0.07	0.50	69
23	0.09	0.29	23	71	0.04	0.35	71
25	0.03	2.17	25	73			
27	0.06	0.60	27	75	0.12	0.60	75
29	0.06	0.56	29	77	0.09	0.74	77
31	0.19	0.41	31	79	0.01	0.20	79
33	0.06	0.34	33	81	0.13	0.56	81
35	0.05	0.40	35	83	0.06	0.64	83
37			*	87	0.06	0.24	87
39	0.16	0.69	39	89	0.13	0.46	89
41	0.01	0.36	41	91	0.04	0.37	91
43	0.07	0.49	43	93			*
45	0.08	1.18	45	95	0.10	1.85	95
47	0.12	1.04	47	97	0.03	0.24	97
49	0.11	0.94	49	99	0.02	0.37	99
51	0.01	0.45	51				

* In these subjects no clear discrimination was achieved. The test subjects either failed to match with the corresponding master file subject or a match was achieved with the corresponding subject as well as with one or more others on the master file.

TABLE 9

Similarity Indices Determined on 46 Subjects Using
Four Lower Incisor Reference Points

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
2	0.15	7.86	2	56	0.07	0.27	56
12			*	58	0.04	1.97	58
14			*	60	0.08	0.23	60
16	0.08	0.63	16	62			*
18	0.04	0.25	18	64	0.07	0.30	64
20	0.06	0.47	20	66	0.06	4.75	66
22	0.03	0.37	22	68	0.04	0.28	68
24			*	70	0.04	0.26	70
26	0.00	3.29	26	72	0.09	0.32	72
28			*	74	0.03	0.47	74
30			*	76			*
32			*	78			*
34	0.07	0.16	34	80	0.09	0.39	80
36			*	82	0.16	0.78	82
38	0.05	0.29	38	84	0.06	0.23	84
40	0.06	0.26	40	86	0.04	0.38	86
42	0.14	0.63	42	88	0.12	0.34	88
44	0.08	0.75	44	90	0.07	0.86	90
46	0.07	0.17	46	92	0.05	0.56	92
48	0.09	0.15	48	94	0.13	0.39	94
50	0.28	0.57	50	96	0.09	0.25	96
52	0.10	0.69	52	98	0.04	0.17	98
54			*	100			*

* In these instances no clear match was observed.
See Table 8 footnote.

TABLE 10

Similarity Indices Determined On 46 Subjects Using Four Upper Molar Reference Points

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
1	0.03	0.36	1	53			*
3			*	55			*
11	0.02	0.55	11	57	0.07	0.81	57
13	0.03	0.20	13	59	0.07	0.55	59
15	0.01	0.12	15	61			*
17	0.05	0.52	17	63	0.11	0.62	63
19	0.06	0.54	19	65			*
21			*	67	0.05	0.54	67
23			*	69	0.04	0.54	69
25	0.15	3.33	25	71			*
27	0.12	0.57	27	73	0.04	1.73	73
29			*	75			*
31			*	77	0.04	0.70	77
33			*	79			*
35			*	81			*
37	0.07	0.66	37	83	0.01	0.12	83
39	0.23	0.98	39	87	0.07	0.55	87
41	0.14	0.58	41	89			*
43	0.14	1.01	43	91			*
45	0.08	0.73	45	93			*
47			*	95	0.09	1.33	95
49	0.07	0.29	49	97	0.02	0.28	97
51	0.19	0.60	51	99	0.03	0.47	99

* In these instances no clear match was observed. See Table 8 footnote.

TABLE 11

Similarity Indices Determined On 45 Subjects Using
Four Lower Molar Reference Points

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
2	0.04	0.52	2	56	0.18	0.60	56
12	0.01	0.47	12	58	0.07	0.53	58
14	0.03	0.31	14	60			*
16	0.11	0.70	16	62	0.03	0.08	62
18	0.08	0.29	18	64	0.08	0.34	64
20	0.05	0.29	20	66	0.05	0.45	66
22	0.11	0.53	22	68			*
24	0.03	0.29	24	70	0.08	1.11	70
26	0.06	0.47	26	72	0.07	1.56	72
28	0.15	1.69	28	74	0.07	1.06	74
30	0.07	0.10	30	76	0.08	0.51	76
32	0.03	0.26	32	78	0.03	0.23	78
34	0.09	0.41	34	80	0.04	0.20	80
36	0.13	0.23	36	82			*
38	0.10	1.79	38	84			*
40			*	86	0.06	1.07	86
42	0.24	1.09	42	88			*
46	0.03	0.95	46	90	0.03	0.15	90
48	0.06	0.15	48	92			*
50			*	94	0.11	0.29	94
52			*	96	0.04	0.68	96
54			*	98			*
				100	0.07	1.01	100

* In these instances no clear match was observed.
See Table 8 footnote.

The main study included many combinations of reference points and demonstrated more clearly the success of the method outlined in Chapter two. Small molar and incisor segments were characterized with varying numbers and combinations of reference points. Each subset of points was matched in turn with master file subjects.

Results obtained when matching test subjects, described by 76 reference points, against the master file are presented in Tables 12,23. Results of matching the various subsets are presented in Tables 13-22,24-33. Tables 12,13,14,16,19,20,23, 24,25,27,29,31 are presented in full listing test subject, similarity index, nearest similarity index and master file subject. Results for the other subsets are summarized presenting test subject and similarity index (Tables, 15,17,19,21,22,26,28, 30,32,33).

The criterion for matching conformed to previous standards, that is, the lowest similarity index was taken to indicate a match between test subject and master file subject. Mismatches are indicated by an asterisk in the appropriate tables. A double asterisk is used to indicate subjects which could not be matched because one or more of the appropriate teeth included in the subset were missing. PROGRAM FOREN 2 specified that three or more points must be recorded for any one subject before the matching procedure could proceed.

In some instances, mismatching was clearly a consequence of errors in the data recording procedure as a result of limitations in either the observer or the equipment being used. Errors arising from these sources are discussed in Chapter four.

TABLE 12

Similarity Indices Determined On 50 Subjects Using
76 Upper Arch Reference Points

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
1	4.11	150.13	1	51	3.02	203.83	51
3	1.66	203.84	3	53			*
5			*	55	2.96	145.86	55
7	1.39	119.03	7	57	1.94	242.96	57
9	3.96	38.29	9	59	2.63	32.51	59
11	3.25	331.89	11	61	12.40	197.60	61
13	2.34	177.28	13	63	2.44	193.82	63
15	2.12	197.45	15	65	10.44	193.25	65
17	2.80	84.23	17	67	3.59	108.29	67
19	3.77	155.29	19	69	3.03	239.04	69
21	4.31	89.45	21	71	2.07	99.06	71
23	2.94	102.64	23	73	3.03	138.13	73
25	2.16	205.11	25	75	2.24	233.23	75
27			*	77	2.93	173.47	77
29	2.27	88.56	29	79	3.03	42.84	79
31	2.60	90.23	31	81	3.30	119.35	81
33	2.28	105.03	33	83			*
35	4.09	92.75	35	85	3.35	152.02	85
37	3.10	143.65	37	87	4.27	187.37	87
39	2.76	140.93	39	89			*
41	3.67	89.58	41	91	3.41	42.02	91
43	1.66	114.21	43	93	8.47	37.41	93
45	4.80	100.68	45	95	5.55	184.00	95
47	3.22	123.23	47	97	4.15	172.56	97
49	4.44	211.29	49	99	4.27	200.30	99

* In these instances no clear match was observed.
See Table 8 footnote.

TABLE 13

Similarity Indices Determined On 50 Subjects Using 14 Points To Characterize Two Upper Right Molars

† Reference points for this subset are MM MD F L DB ML MB

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
1	0.28	7.40	1	51	0.46	8.72	51
3	0.34	9.87	3	53	0.32	6.62	53
5	0.76	6.64	5	55	0.49	8.57	55
7	0.23	15.33	7	57	0.21	9.00	57
9	0.46	5.09	9	59	0.61	4.08	59
11	0.54	7.97	11	61	4.19	13.41	61
13	0.43	6.81	13	63	0.22	19.09	63
15	0.46	5.44	15	65	0.67	9.79	65
17	0.61	4.14	17	67	0.37	12.21	67
19	0.55	6.45	19	69	1.12	5.90	69
21	0.36	5.89	21	71	0.41	8.10	71
23	0.37	10.95	23	73	0.75	8.53	73
25	0.33	9.39	25	75	0.17	8.52	75
27	0.22	7.86	27	77	0.32	6.21	77
29	0.26	5.60	29	79	0.42	4.86	79
31	0.66	5.99	31	81	0.60	5.75	81
33	0.34	9.07	33	83	0.35	7.82	83
35	0.89	7.23	35	85	0.32	6.26	85
37	0.57	12.73	37	87	0.60	10.29	87
39	0.35	10.84	39	89			*
41	0.81	7.93	41	91	0.44	4.74	91
43	0.15	13.71	43	93	0.64	8.41	93
45	0.45	8.88	45	95	0.46	10.91	95
47	0.84	7.88	47	97	0.72	3.61	97
49	0.30	7.37	49	99	0.44	7.74	99

* In these instances no clear match was observed. See Table 8 footnote.

† For details of subset coding see pages 48, 49.

TABLE 14

Similarity Indices Determined On 50 Subjects Using
14 Points To Characterize Two Upper Left Molars

† Reference points for this subset are MM MD F L DB ML MB

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
1	0.22	5.36	1	51	0.37	11.09	51
3	0.33	12.17	3	53	0.31	5.64	53
5	0.48	4.55	5	55	0.45	8.74	55
7	0.20	4.96	7	57	0.21	16.88	57
9	0.47	4.29	9	59	0.28	3.91	59
11	0.22	4.63	11	61	2.68	11.47	61
13	0.48	6.31	13	63	0.40	4.70	63
16	0.41	5.32	15	65	0.28	6.07	65
17	0.39	4.62	17	67	0.44	3.19	67
19	0.51	10.34	19	69	0.30	14.08	69
21	0.33	4.99	21	71	0.30	4.36	71
23	0.39	6.88	23	73	0.31	8.85	73
25	0.29	8.18	25	75			*
27	0.14	5.76	27	77	0.70	6.56	77
29	0.21	3.27	29	79	0.80	4.75	79
31	0.35	5.75	31	81	0.62	5.37	81
33	0.33	5.90	33	83			*
35	0.28	4.75	35	85	0.59	8.14	85
37	0.64	3.77	37	87	1.68	4.72	87
39	0.63	3.44	39	89	0.46	9.92	89
41	0.32	5.56	41	91	0.70	3.91	91
43	0.30	9.94	43	93	0.71	7.82	93
45	0.22	5.14	45	95	0.50	9.48	95
47	0.34	5.66	47	97	0.53	6.54	97
49			*	99	0.79	5.82	99

* In these instances no clear match was observed.
See Table 8 footnote.

† For details of subset coding see pages 48, 49.

TABLE 15

Similarity Indices Determined On 50 Subjects Using Two Subsets of 10 Points To Characterize Two Upper Left Molars

†Subset																										
F L DB ML MB	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.14	0.18	0.37	0.11	0.39	0.17	0.35	0.32	0.36	0.25	0.24	0.27	0.24	0.11	0.17	0.32	0.29	0.18	0.18	0.29	0.25	0.22	0.20	0.24	5.01
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.28	0.21	0.35	0.13	0.24	2.25	0.28	0.18	0.33	0.23	0.23	0.22	*	0.42	0.13	0.53	*	0.33	0.31	0.34	0.30	0.44	0.41	0.38	0.56
MM DM DB ML MB	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.14	0.16	0.11	0.29	0.29	0.14	0.35*	0.17	0.19	0.45	0.23	0.29	0.11	0.09	0.06	0.28	0.24	0.19	0.50	0.37	0.22	0.13	0.17	0.28	2.66
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.20	0.26	0.21	0.16	0.18	0.31	0.23	0.17	0.28	0.20	0.19	0.26	0.20	0.49	0.71	0.26	*	0.55	1.56	0.16	0.57	0.54	0.30	0.44	0.65

* In these instances no clear match was obtained. See Table 8 footnote.

† For details of subset coding see pages 48, 49.

TABLE 16

Similarity Indices Determined On 50 Subjects Using Eight Points To Characterize Two Upper Left Molars

† Reference points for this subset are MM DM F L

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
1	0.10	3.67	1	51	0.23	4.41	51
3	0.10	5.07	3	53	0.11	2.24	53
5	0.25	2.51	5	55	0.32	3.20	55
7	0.16	1.51	7	57	0.10	6.32	57
9	0.24	3.28	9	59	0.12	1.71	59
11	0.11	1.51	11	61	2.13	5.24	61
13	0.24	2.86	13	63	0.15	2.80	63
15	0.30	2.37	15	65	0.17	3.19	65
17	0.21	2.26	17	67	0.23	1.98	67
19	0.30	2.48	19	69	0.15	5.94	69
21	0.14	2.31	21	71	0.14	1.89	71
23	0.18	1.74	23	73	0.13	3.27	73
25	0.20	3.14	25	75	0.12	3.93	75
27	0.08	3.98	27	77	0.43	2.96	77
29	0.17	1.62	29	79	0.66	2.53	79
31	0.12	2.67	31	81	0.43	2.02	81
33	0.10	3.24	33	83	0.83	2.23	83
35	0.14	2.40	35	85	0.21	2.51	85
37	0.54	2.32	37	87	1.34	2.35	87
39	0.50	1.38	39	89	0.37	2.40	89
41	0.13	2.19	41	91	0.48	2.58	91
43	0.15	5.59	43	93	0.36	3.93	93
45	0.05	3.09	45	95	0.26	3.60	95
47	0.14	2.57	47	97	0.14	3.41	97
49	0.04	4.98	49	99	0.31	2.95	99

† For details of subset coding see pages 48, 49.

TABLE 17

Similarity Indices Determined On 50 Subjects Using Six Subsets Of Eight Points To Characterize Two Upper Left Molars

†Subset																										
MM	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
DM	S.I.	0.08	0.12	0.15	0.10	0.21	0.12	0.22	0.11	0.15	0.32	0.10	0.15	0.10	0.07	0.04	0.23	0.22	0.13	0.47	0.32	0.18	0.15	0.08	0.13	*
DB	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
ML	S.I.	0.14	0.23	0.14	0.15	0.15	0.22	0.19	0.16	0.25	0.13	0.16	0.22	0.15	0.42	0.62	0.16	0.34	0.46	*	0.14	0.45	0.46	0.19	0.41	0.59
MM	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
DM	S.I.	0.15	0.08	0.22	0.10	0.15	0.10	0.29	0.15	0.14	0.39	0.21	0.20	0.11	0.05	0.04	0.20	0.09	0.14	0.45	0.33	0.19	0.18	0.12	0.21	0.27
MB	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
DB	S.I.	0.15	0.13	0.18	0.08	0.05	0.23	0.24	0.07	0.27	0.15	0.19	0.22	0.16	0.42	0.69	0.21	*	0.30	*	0.15	0.47	0.44	0.23	0.21	0.39
MM	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
DM	S.I.	0.11	0.09	0.24	0.10	0.25	0.10	0.27	0.15	0.07	0.43	0.18	0.27	0.06	0.08	0.05	0.17	0.20	0.18	0.46	0.31	0.11	0.10	0.16	0.27	*
ML	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	777	79	81	83	85	87	89	91	93	95	97	99
MB	S.I.	0.15	0.23	0.18	0.15	0.17	0.22	0.21	0.15	0.12	0.16	0.09	0.14	0.14	0.36	0.65	0.21	*	0.51	*	0.13	0.50	0.40	0.20	0.33	0.50
F	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
L	S.I.	0.09	0.12	0.33	0.10	0.35	0.12	0.29	0.28	0.23	0.22	0.22	0.25	0.18	0.09	0.13	0.21	0.22	0.18	0.16	0.24	0.13	0.13	0.19	0.23	4.98
ML	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
MB	S.I.	0.22	0.19	0.29	0.10	0.24	1.88	0.20	0.17	0.20	0.16	0.13	0.10	*	0.18	0.11	0.48	*	0.32	0.14	0.32	0.13	0.26	0.28	0.30	0.41
F	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
L	S.I.	0.12	0.13	0.27	0.07	0.25	0.13	0.30	0.30	0.31	0.17	0.22	0.19	0.23	0.07	0.16	0.23	0.13	0.14	0.17	0.28	0.21	0.21	0.13	0.18	0.47
DB	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
MB	S.I.	0.24	0.09	0.30	0.06	0.11	2.04	0.24	0.12	0.30	0.19	0.02	0.18	0.18	0.38	0.10	0.46	*	0.08	0.27	0.30	0.25	0.36	0.35	0.19	0.33
F	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
L	S.I.	0.08	0.16	0.26	0.10	0.32	0.15	0.19	0.24	0.31	0.12	0.09	0.15	0.23	0.09	0.17	0.25	0.26	0.12	0.10	0.24	0.21	0.19	0.11	0.07	*
DB	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
ML	S.I.	0.24	0.19	0.30	0.11	0.21	2.04	0.16	0.16	0.30	0.17	0.20	0.19	*	0.39	0.08	0.45	0.31	0.29	0.28	0.28	0.24	0.32	0.33	0.34	0.51

* In these instances no clear match was obtained. See Table 8 footnote.

† For details of subset coding see pages 48, 49.

TABLE 18

Similarity Indices Determined On 50 Subjects Using
Eight Points To Characterize Two Upper Left Incisors

† Reference points for this subset are D M F L

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
1	0.20	2.96	1	51	0.10	0.20	51
3	0.20	0.49	3	53	0.14	0.31	53
5	0.11	1.37	5	55	0.45	0.50	55
7	0.03	0.08	7	57	0.23	3.58	57
9	0.19	0.72	9	59	0.25	0.43	59
11	0.17	0.43	11	61	0.23	0.85	61
13	0.12	1.61	13	63	0.46	1.69	63
15	0.15	1.22	15	65	0.13	1.73	65
17	0.21	3.92	17	67	0.09	1.13	67
19			*	69	0.24	1.11	69
21	0.20	1.42	21	71	0.12	1.52	71
23	0.14	1.03	23	73	0.14	1.21	73
25	0.22	0.77	25	75	0.09	1.35	75
27	0.06	0.39	27	77	0.25	0.72	77
29	0.24	1.28	29	79	0.16	0.93	79
31	0.07	0.79	31	81	0.11	0.86	81
33	0.23	1.35	33	83			*
35	0.17	0.65	35	85	0.20	1.05	85
37	0.17	1.29	37	87	0.10	0.90	87
39	0.28	1.51	39	89	0.22	0.85	89
41			*	91	0.15	2.77	91
43	0.17	0.85	43	93	0.42	0.66	93
45	0.17	1.36	45	95	0.31	2.63	95
47	0.36	1.23	47	97	0.32	1.81	97
49	0.25	1.99	49	99	0.22	0.46	99

* In these instances no clear match was obtained. See Table 8 footnote.

† For details of subset coding see pages 48, 49.

TABLE 19

Similarity Indices Determined On 50 Subjects Using Seven Subsets of Six Points
To Characterize Two Upper Left Molars

†Subset																										
MM DM DB	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.06	0.07	0.12	0.09	0.08	0.08	0.17	0.10	0.10	0.26	0.06	0.09	0.10	0.03	0.02	0.14	0.06	0.06	0.43	0.27	0.16	0.15	0.02	0.10	0.18
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.07	0.10	0.11	0.17	0.03	0.13	0.16	0.07	0.23	0.08	0.15	0.18	0.11	0.33	0.58	0.12	0.25	0.18	*	0.12	0.32	0.37	0.14	0.18	0.33
MM DM ML	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.04	0.07	0.14	0.08	0.18	0.08	0.18	0.10	0.05	0.29	0.07	0.14	0.05	0.06	0.03	0.11	0.18	0.11	0.42	0.25	0.07	0.07	0.07	0.12	*
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.11	0.10	0.12	0.13	0.14	0.12	0.09	0.15	0.08	0.09	0.06	0.10	0.09	0.32	0.52	0.10	0.22	0.41	*	0.11	0.41	0.34	0.10	0.31	0.45
MM DM DB	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.10	0.04	0.13	0.09	0.12	0.07	0.19	0.13	0.03	0.37	0.17	0.17	0.06	0.04	0.03	0.09	0.04	0.12	0.39	0.27	0.09	0.09	0.10	0.19	0.05
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.10	0.10	0.15	0.07	0.04	0.16	0.19	0.05	0.11	0.11	0.08	0.11	0.11	0.31	0.62	0.16	*	0.27	1.14	0.12	*	0.30	0.14	0.07	0.25
F L ML	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.04	0.09	0.23	0.09	0.28	0.08	0.16	0.20	0.20	0.10	0.09	0.14	0.17	0.07	0.12	0.14	0.19	0.12	0.06	0.19	0.09	0.10	0.10	0.06	*
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.20	0.16	0.25	0.08	0.20	1.48	0.02	0.15	0.17	0.10	0.11	0.08	*	0.14	0.06	0.40	0.15	0.27	0.08	0.27	0.09	0.13	0.19	0.26	0.34
F L MB	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.05	0.06	0.20	0.06	0.21	0.08	0.23	0.25	0.20	0.15	0.20	0.15	0.17	0.06	0.11	0.13	0.07	0.13	0.15	0.22	0.08	0.12	0.12	0.17	0.34
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.19	0.07	0.22	0.03	0.10	1.59	0.18	0.11	0.18	0.12	0.12	0.07	0.15	0.15	0.08	0.40	*	0.07	0.11	0.28	0.09	0.19	0.21	0.10	0.18
F L DB	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.05	0.11	0.15	0.06	0.19	0.11	0.14	0.21	0.25	0.05	0.05	0.09	0.22	0.06	0.15	0.15	0.11	0.08	0.09	0.23	0.18	0.18	0.05	0.04	0.33
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.18	0.07	0.26	0.05	0.09	1.75	0.14	0.11	0.26	0.14	0.18	0.15	0.10	0.34	0.05	0.39	0.25	0.04	0.25	0.20	0.18	0.24	0.29	0.14	0.27
DB ML MB	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.11	0.11	0.15	0.02	0.22	0.08	0.21	0.08	0.16	0.19	0.13	0.19	0.06	0.06	0.04	0.22	0.21	0.09	0.08	0.08	0.15	0.09	0.16	0.18	*
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	81	83	85	87	89
	S.I.	0.12	0.13	0.11	0.09	0.44	0.20	0.14	0.07	0.15	0.15	0.09	0.17	*	0.19	0.09	0.17	*	0.27	0.15	0.04	0.21	0.24	0.22	0.26	0.39

* In these instances no clear match was obtained. See Table 8 footnote.

† For details of subset coding see pages 48, 49.

TABLE 20

Similarity Indices Determined On 50 Subjects Using Four Points To Characterize Two Upper Left Molars

† Reference points for this subset are MM DM

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
1	0.03	0.25	1	51	0.05	1.53	51
3	0.02	1.61	3	53	0.05	0.60	53
5	0.10	0.44	5	55	0.10	0.14	55
7	0.08	0.24	7	57	0.06	0.34	57
9	0.05	0.66	9	59	0.02	0.54	59
11	0.05	0.19	11	61	0.06	0.63	61
13	0.12	0.33	13	63	0.07	0.37	63
15	0.88	0.11	15	65	0.03	0.32	65
17	0.02	0.29	17	67	0.06	0.26	67
19	0.23	0.37	19	69	0.04	1.00	69
21	0.04	0.24	21	71	0.04	0.33	71
23	0.06	0.50	23	73	0.07	0.20	73
25	0.04	0.19	25	75	0.05	0.37	75
27	0.03	0.37	27	77	0.25	0.45	77
29	0.02	0.05	29	79	0.46	0.68	79
31	0.02	0.63	31	81	0.06	0.42	81
33	0.02	0.18	33	83	0.16	0.29	83
35	0.04	0.25	35	85	0.12	0.55	85
37	0.36	0.70	37	87			*
39	0.18	0.39	39	89	0.10	0.38	89
41	0.06	0.85	41	91			*
43	0.05	0.86	43	93	0.25	0.60	93
45	0.01	0.56	45	95	0.06	0.57	95
47	0.09	0.22	47	97	0.02	0.32	97
49	0.00	1.21	49	99	0.19	0.31	99

* In these instances no clear match was obtained. See Table 8 footnote.

† For details of subset coding see pages 48, 49.

TABLE 21

Similarity Indices Determined On 50 Subjects Using Four Subsets Of Four Points
To Characterize Two Upper Left Molars

†Subset																										
F L	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.01	0.04	0.07	0.05	0.14	0.05	0.11	0.16	0.17	0.02	0.05	0.05	0.15	0.05	0.11	0.04	0.04	0.07	0.05	*	0.06	0.08	0.04	0.03	0.09
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.15	0.04	0.18	0.02	0.08	0.95	0.02	0.10	0.14	0.07	0.09	0.04	0.08	0.11	0.04	0.33	0.10	0.03	0.04	0.18	0.05	0.05	0.14	0.04	0.12
ML MB	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.05	0.06	0.11	0.02	*	0.03	0.12	0.06	0.03	0.17	0.04	0.18	0.01	0.04	0.01	0.12	0.17	0.08	0.05	0.05	0.05	0.03	0.14	0.17	*
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.02	0.12	0.08	0.07	0.14	0.09	0.08	0.07	0.01	0.09	0.02	0.05	*	0.05	0.07	0.13	*	0.24	0.06	0.00	0.07	0.09	0.12	0.19	0.25
DB MB	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.10	0.05	0.11	0.00	0.09	0.04	0.14	0.06	*	0.12	0.11	0.12	0.05	0.02	0.03	*	0.05	0.05	0.04	0.05	0.11	0.08	0.09	0.08	0.03
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.09	0.01	0.08	0.02	0.02	0.14	0.05	0.01	0.12	0.09	0.08	0.14	0.09	0.12	0.06	*	*	0.02	0.06	0.03	*	*	0.15	0.10	0.15
DB ML	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	51	53	45	47	49
	S.I.	0.04	0.09	0.03	0.01	0.15	0.07	0.08	0.02	0.10	0.07	0.03	0.04	0.04	0.03	0.03	0.17	0.18	0.03	0.03	0.02	0.09	0.05	0.06	0.03	*
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.08	0.12	0.03	0.07	0.10	0.12	0.09	0.04	*	0.08	0.05	0.14	*	0.14	0.03	0.09	0.15	0.23	0.10	0.03	0.11	*	0.12	0.22	0.34

* In these instances no clear match was obtained. See Table 8 footnote.

† For details of subset coding see pages 48, 49.

TABLE 22

Similarity Indices Determined On 50 Subjects Using Two Subsets Of Four Points To Characterize Two Upper Left Incisors

†Subset																										
D M	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.11	0.06	0.04	**	*	0.08	0.03	0.01	0.09	0.06	0.07	0.06	0.04	0.02	0.03	0.02	0.12	0.10	0.05	0.14	*	0.14	0.04	*	0.10
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.01	**	**	0.10	0.12	0.05	0.06	0.03	0.05	0.06	0.08	0.06	0.06	0.03	0.06	0.04	0.14	0.09	0.03	0.08	0.06	0.16	0.08	0.18	0.08
F L	T.S.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49
	S.I.	0.04	0.06	0.07	**	0.03	0.03	0.02	0.07	0.11	0.62	0.12	0.07	0.12	0.02	0.14	0.04	0.10	0.06	0.11	0.07	*	0.01	0.07	0.18	0.13
	T.S.	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	S.I.	0.08	**	0.05	0.06	0.07	0.12	*	0.05	0.02	0.12	0.03	0.04	0.02	0.04	0.04	0.04	0.07	0.09	0.02	0.06	0.08	*	0.15	0.09	*

* In these instances no clear match was obtained. See Table 8 footnote.

** Insufficient data were recorded because of missing teeth, see page 98.

† For details of subset coding see pages 48, 49.

TABLE 23

Similarity Indices Determined On 50 Subjects Using
76 Lower Arch Reference Points

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
2	2.88	173.50	2	52	2.79	76.28	52
4	1.73	163.79	4	54	2.12	237.09	54
6	2.01	304.88	6	56	2.44	132.56	56
8	2.75	201.50	88	58	4.43	113.10	58
10	1.97	57.06	10	60	1.96	61.60	60
12	5.57	106.73	12	62			*
14	2.22	104.86	14	64	2.19	234.52	64
16	2.42	120.21	16	66	2.38	185.90	66
18	8.46	108.03	18	68	2.08	93.72	68
20	5.58	155.14	20	70	6.44	171.55	70
22	2.11	94.85	22	72	1.53	130.58	72
24	3.20	91.54	24	74	1.73	131.68	74
26	3.42	223.58	26	76	3.79	182.12	76
28	4.54	256.68	28	78	12.58	87.57	78
30	2.05	104.74	30	80	3.33	25.51	80
32	2.08	98.57	32	82	3.95	209.74	82
34	2.95	90.69	34	84	2.04	163.62	84
36			*	86	3.39	205.70	86
38	2.23	128.85	38	88			*
40	3.32	109.20	40	90	5.61	164.81	90
42	2.54	213.56	42	92			*
44	1.42	149.82	44	94	4.08	27.16	94
46	15.29	145.58	46	96	2.81	187.79	96
48	3.48	88.72	48	98	3.81	114.12	98
50	2.12	351.80	50	100			*

* In these instances no clear match was obtained.
See Table 8 footnote.

TABLE 24

Similarity Indices Determined On 50 Subjects Using
14 Points To Characterize Two Lower Right Molars

† Reference points for this subset are MM DM F L DB ML MB

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
2	0.26	10.66	2	52	0.37	4.52	52
4	0.20	5.79	4	54	0.37	4.34	54
6	0.28	5.75	6	56	0.34	4.74	56
8	0.28	2.75	8	58	1.61	8.95	58
10	0.37	2.76	10	60	0.26	2.64	60
12			*	62			*
14	0.43	4.97	14	64	0.58	4.01	64
16	0.27	7.09	16	66	0.26	5.25	66
18	0.47	2.28	18	68	0.28	3.90	68
20	2.52	7.29	20	70	2.42	6.10	70
22	0.36	6.59	22	72	0.11	2.05	72
24	0.27	4.72	24	74	0.14	4.61	74
26	0.27	13.55	26	76	0.21	5.76	76
28	0.60	5.48	28	78	0.33	7.51	78
30	0.45	4.26	30	80	0.20	3.94	80
32	0.36	3.53	32	82	0.84	6.60	82
34	0.27	3.05	34	84	0.45	3.87	84
36	0.36	4.01	36	86	0.28	7.57	86
38	0.25	6.41	38	88	0.48	3.72	88
40	0.72	5.22	40	90	2.34	8.10	90
42	0.21	3.66	42	92	0.48	4.00	92
44	0.40	6.38	44	94	0.50	6.19	94
46	0.51	6.64	46	96	0.30	14.14	96
48	1.29	4.80	48	98	0.40	5.99	98
50	0.26	6.48	50	100	0.83	2.48	100

* In these instances no clear match was obtained.
See Table 8 footnote.

† For details of subset coding see pages 48, 49.

TABLE 25

Similarity Indices Determined On 50 Subjects Using
14 Points To Characterize Two Lower Left Molars

† Reference points for this subset are MM DM F L DB ML MB

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
2	0.41	1.92	2	52	0.41	3.26	52
4	0.31	2.98	4	54	0.25	2.69	54
6	0.39	2.57	6	56	0.30	7.71	56
8	0.28	2.87	8	58	0.36	4.06	58
10	0.37	2.43	10	60	0.40	3.30	60
12	0.50	4.33	12	62	0.36	4.64	62
14	0.41	5.03	14	64	0.25	5.38	64
16	0.36	2.95	16	66	0.57	7.53	66
18	0.38	4.35	18	68	0.33	1.71	68
20	1.34	2.89	20	70	0.35	2.71	70
22	0.30	1.83	22	72	0.19	1.57	72
24	1.15	2.94	24	74	0.36	3.12	74
26	0.14	4.20	26	76	0.53	3.10	76
28	0.22	2.35	28	78	0.61	4.59	78
30	0.18	4.67	30	80	0.62	4.01	80
32	0.26	4.68	32	82	0.28	2.72	82
34	0.56	4.23	34	84	0.79	3.78	84
36			*	86	0.87	4.37	86
38	0.60	3.11	38	88	0.31	2.95	88
40	0.46	6.22	40	90	1.10	3.09	90
42	0.63	2.18	42	92	0.50	2.19	92
44	0.10	1.71	44	94	1.41	3.61	94
46	0.31	6.16	46	96	0.58	9.08	96
48	0.33	3.78	48	98	0.56	9.52	98
50	0.36	5.64	50	100	0.45	5.04	100

* In these instances no match was obtained.
See Table 8 footnote.

† For details of subset coding see pages 48, 49.

TABLE 26

Similarity Indices Determined On 50 Subjects Using Two Subsets of 10 Points
To Characterize Two Lower Right Molars

†Subset																										
MM	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
DM	S.I.	0.11	0.14	0.24	0.22	0.18	*	0.40	0.21	0.37	*	0.25	0.24	0.16	0.48	0.20	0.29	0.12	0.24	0.19	0.42	0.07	0.25	0.29	*	0.20
MB																										
ML	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
DB	S.I.	0.13	0.29	0.29	1.49	0.19	*	0.44	0.13	0.25	0.15	**	0.09	0.17	0.12	0.10	0.53	0.23	0.22	0.29	*	0.40	0.34	0.15	0.24	0.44
F	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
L	S.I.	0.14	0.14	0.18	0.17	0.23	1.37	0.35	0.17	0.34	0.32	0.28	0.20	0.21	0.08	0.40	0.19	0.23	0.30	0.16	0.43	0.17	0.33	0.41	0.19	0.16
MB																										
ML	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
DB	S.I.	0.33	0.24	0.29	1.28	0.16	0.26	0.38	0.18	0.12	*	**	0.11	0.11	0.25	0.14	0.79	0.25	0.17	0.39	0.35	0.36	0.34	0.27	0.31	0.72

* In these instances no clear match was obtained. See Table 8 footnote.

** Insufficient data were recorded because of missing teeth, refer page 98.

† For details of subset coding see pages 48, 49.

TABLE 27

Similarity Indices Determined On 50 Subjects Using Eight Points To Characterize Two Lower Right Molars

† Reference points for this subset are MM DM F L

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
2	0.21	2.27	2	52	0.27	1.66	52
4	0.10	2.36	4	54	0.16	1.09	54
6	0.10	1.35	6	56	0.08	2.88	56
8	0.10	1.29	8	58	0.20	3.69	58
10	0.25	1.02	10	60	0.15	1.51	60
12			*	62			*
14	0.28	2.35	14	64	0.31	1.85	64
16	0.13	2.72	16	66	0.19	2.62	66
18	0.18	1.02	18	68	0.17	1.63	68
20	0.32	2.71	20	70			*
22	0.15	1.17	22	72	0.06	0.73	72
24	0.06	1.08	24	74	0.07	2.39	74
26	0.16	5.35	26	76	0.12	3.72	76
28	0.55	1.56	28	78	0.21	0.84	78
30	0.22	1.16	30	80	0.15	0.77	80
32	0.24	1.50	32	82	0.28	2.81	82
34	0.16	0.81	34	84	0.33	1.74	84
36	0.14	1.75	36	86	0.14	3.63	86
38	0.13	4.14	38	88	0.23	2.40	88
40	0.54	2.77	40	90	1.98	5.26	90
42	0.15	2.26	42	92	0.16	2.30	92
44	0.21	3.48	44	94	0.26	2.83	94
46	0.26	1.73	46	96	0.16	7.34	96
48	1.17	1.99	48	98	0.20	2.92	98
50	0.14	1.33	50	100	0.42	1.47	100

* In these instances no clear match was obtained. See Table 8 footnote.

† For details of subset coding see pages 48, 49.

TABLE 28

Similarity Indices Determined On 50 Subjects Using Six Subsets Of Eight Points
To Characterize Two Lower Right Molars

†Subset																										
MM	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
DM	S.I.	0.08	0.13	0.08	0.17	0.16	*	0.19	0.16	0.30	*	0.10	0.11	0.06	0.45	0.19	0.28	0.07	0.12	0.12	0.36	0.06	0.13	0.19	*	0.14
DB	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
ML	S.I.	0.12	0.24	0.20	1.41	0.17	*	0.43	0.12	0.24	0.12	*	0.05	0.16	0.11	0.07	0.46	0.17	0.18	0.18	*	0.36	0.25	0.09	0.19	0.40
MM	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
DM	S.I.	0.11	0.11	0.24	0.17	0.16	*	0.15	0.15	0.19	0.78	0.24	0.22	0.14	0.46	0.08	0.18	0.11	0.19	0.12	0.34	0.05	0.21	0.25	*	0.15
DB	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
MB	S.I.	0.10	0.14	0.24	0.21	0.18	*	0.29	0.10	0.17	0.12	*	0.08	0.13	0.05	*	0.17	0.21	0.14	0.26	*	0.27	0.25	0.08	0.22	*
F	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
L	S.I.	0.10	0.09	0.21	0.16	0.09	*	0.11	0.18	*	*	0.21	0.20	0.15	0.42	0.17	0.27	0.10	0.20	0.17	0.36	0.04	0.18	0.15	*	0.18
ML	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
MB	S.I.	0.06	0.26	0.17	1.42	0.10	*	0.31	0.12	0.23	0.13	0.13	0.07	0.13	0.11	0.10	0.27	0.22	0.16	0.22	*	0.26	0.31	0.14	0.14	0.12
F	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
L	S.I.	0.13	0.10	0.14	0.13	0.20	1.36	0.24	0.12	0.34	1.62	0.23	0.17	0.20	0.07	0.37	0.17	0.21	0.25	0.13	0.40	0.16	0.28	0.17	0.15	0.15
ML	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
MB	S.I.	0.26	0.22	0.15	1.16	0.09	0.20	0.27	0.17	0.10	*	**	0.09	0.07	0.24	0.13	0.47	0.24	0.15	0.30	0.30	0.23	0.30	0.26	0.21	0.42
F	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
L	S.I.	0.11	0.10	0.16	0.09	0.19	0.28	0.32	0.13	0.15	0.54	0.27	0.19	0.19	0.06	0.26	0.09	0.21	0.26	0.11	0.36	0.15	0.28	0.39	0.13	0.12
DB	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
MB	S.I.	0.30	0.11	0.22	0.22	0.13	0.22	0.22	0.16	0.05	*	**	0.10	0.07	0.18	0.12	0.51	0.22	0.14	0.37	0.23	0.20	0.22	0.18	0.29	0.59
F	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
L	S.I.	0.11	0.12	0.05	0.15	0.15	1.29	0.33	0.13	0.32	*	0.13	0.06	0.11	0.07	0.39	0.18	0.17	0.18	0.12	0.40	0.15	0.20	0.36	0.12	0.08
DB	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
ML	S.I.	0.32	0.20	0.21	1.14	0.12	0.19	0.37	0.16	0.10	2.07	**	0.06	0.09	0.20	0.10	0.71	0.20	0.08	0.27	0.25	0.34	0.23	0.21	0.28	0.66

* In these instances no clear match was obtained. See Table 8 footnote.
** Insufficient data were recorded because of missing teeth, refer page 98.
† For details of subset coding see pages 48, 49.

TABLE 29

Similarity Indices Determined On 50 Subjects Using Eight Points To Characterize Two Lower Left Incisors

† Reference points for this subset are M D F L

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
2	0.20	2.06	2	52	0.38	1.70	52
4	0.19	0.86	4	54	0.24	1.41	54
6	0.07	0.78	6	56	0.14	0.93	56
8	0.17	2.26	8	58	0.22	2.89	58
10	0.12	1.71	10	60	0.12	1.84	60
12	0.21	1.05	12	62	0.32	0.86	62
14	0.13	1.03	14	64	0.10	1.56	64
16	0.20	1.48	16	66	0.06	4.07	66
18	0.32	1.08	18	68	0.18	0.77	68
20	0.07	1.26	20	70	0.12	1.16	70
22	0.24	0.82	22	72	0.13	0.89	72
24	0.12	0.88	24	74	0.24	2.53	74
26	0.16	4.94	26	76	0.19	1.11	76
28	0.05	0.86	28	78	0.12	1.12	78
30	0.10	0.94	30	80	0.18	0.81	80
32	0.15	0.76	32	82	0.31	2.47	82
34	0.24	2.76	34	84	0.17	0.75	84
36	0.16	0.97	36	86	0.09	1.95	86
38	0.12	1.50	38	88	0.25	1.15	88
40	0.17	1.25	40	90	0.22	0.98	90
42	0.13	1.70	42	92	0.17	1.15	92
44	0.11	2.90	44	94	0.34	0.80	94
46	0.26	1.13	46	96	0.04	1.86	96
48	0.20	1.01	48	98	0.24	1.57	98
50	0.24	1.73	50	100	0.19	1.92	100

† For details of subset coding see pages 48, 49.

TABLE 30

Similarity Indices Determined On 50 Subjects Using Seven Subsets Of Six Points To Characterize Two Lower Right Molars

†Subset																										
	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
MM	S.I.	0.07	0.08	0.08	0.12	0.14	*	0.14	0.09	0.11	0.74	0.09	0.07	0.05	0.43	0.07	0.18	0.06	0.07	0.66	0.29	0.04	0.11	0.13	*	0.11
DM	T.S.	52	54	56	58	60	62	64	66	68	79	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
DB	S.I.	0.09	0.10	0.17	0.10	0.16	*	*	0.08	0.15	0.07	0.07	0.04	0.12	0.04	0.06	0.23	0.13	0.12	0.15	*	0.25	0.18	0.02	0.17	*
	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
MM	S.I.	0.07	0.08	0.06	0.07	0.08	*	0.10	0.12	*	*	0.07	0.06	0.05	0.38	0.16	0.26	0.04	0.09	0.11	0.28	0.04	0.08	0.09	*	0.13
DM	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
ML	S.I.	0.05	0.19	0.08	1.33	0.08	*	0.28	0.10	0.22	0.09	*	0.03	0.11	0.11	0.06	0.17	0.15	0.14	0.09	*	0.21	0.21	0.07	0.08	0.10
	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
MM	S.I.	0.10	0.06	0.20	0.11	0.07	*	0.06	0.12	0.04	0.18	0.20	0.18	0.13	0.38	0.04	0.17	0.09	0.14	0.11	0.29	0.01	0.14	0.13	*	0.11
DM	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
MB	S.I.	0.03	0.12	0.12	0.15	0.10	*	0.17	0.08	0.14	0.09	*	0.07	0.09	0.04	0.09	0.09	0.19	0.05	0.20	*	0.14	0.23	0.07	0.12	0.06
	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
F	S.I.	0.09	0.09	0.02	0.10	*	1.29	0.22	0.08	0.22	1.54	0.10	0.04	0.11	0.06	0.35	0.15	0.15	0.14	0.09	0.35	0.14	0.17	0.12	0.08	0.07
L	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
ML	S.I.	0.24	0.18	0.07	0.98	0.05	0.15	0.25	0.15	0.08	*	*	0.04	0.05	0.18	0.18	0.33	0.18	0.06	0.16	0.20	0.20	0.18	0.20	0.17	0.38
	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
F	S.I.	0.09	0.07	0.12	0.04	0.16	0.2	0.21	0.09	0.06	0.06	0.22	0.16	0.19	0.05	0.21	0.07	0.19	0.21	0.08	0.33	0.13	0.23	0.15	0.10	0.09
L	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
MB	S.I.	0.24	0.10	0.08	0.18	0.08	0.15	0.14	0.14	0.03	*	*	0.08	0.03	0.16	0.11	0.27	0.11	0.10	0.29	0.19	0.07	0.18	0.17	0.19	0.31
	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
F	S.I.	0.08	0.07	0.04	0.07	0.09	0.11	0.30	0.09	0.12	0.51	0.12	0.04	0.11	0.05	0.23	0.08	0.15	0.15	0.07	0.33	0.12	0.16	0.34	0.05	0.05
L	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
DB	S.I.	0.29	0.08	0.16	0.11	0.08	0.17	0.21	0.14	0.04	*	*	0.05	0.04	0.11	0.09	0.44	0.15	0.06	0.26	0.11	0.18	0.12	0.14	0.25	0.46
	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
DB	S.I.	0.03	0.08	0.14	0.10	0.08	*	0.14	0.12	0.24	*	0.16	0.16	0.10	0.02	0.12	0.12	0.07	0.16	0.10	0.12	0.05	0.17	0.22	0.12	0.09
ML	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
MB	S.I.	0.09	*	0.24	1.06	0.09	0.12	0.24	0.05	0.08	0.06	**	0.07	0.08	0.06	0.04	0.48	0.05	0.12	0.17	0.20	0.27	*	0.12	0.12	*

* In these instances there was no clear match obtained. See Table 8 footnote.
** Insufficient data were recorded because of missing teeth, refer page 98.
† For details of subset coding see pages 48, 49.

TABLE 31

Similarity Indices Determined On 50 Subjects Using
Four Points To Characterize Two Lower Right Molars

† Reference points for this subset are MM DM

T.S.	S.I.	N.S.I.	M.F.S.	T.S.	S.I.	N.S.I.	M.F.S.
2	0.06	0.32	2	52	0.03	1.24	52
4	0.05	0.48	4	54	0.06	0.17	54
6	0.05	0.51	6	56	0.05	0.36	56
8	0.01	0.86	8	58	0.03	0.65	58
10	0.06	0.68	10	60	0.08	0.45	66
12			*	62			*
14	0.05	0.41	14	64	0.15	0.47	64
16	0.04	0.12	16	66	0.06	0.47	66
18	0.04	0.34	18	68	0.12	0.17	68
20	0.10	1.56	20	70	0.04	0.40	70
22	0.05	0.25	22	72			**
24	0.20	0.13	24	74	0.02	0.14	74
26	0.04	0.98	26	76	0.08	0.36	76
28			*	78	0.03	0.07	78
30	0.02	0.35	30	80	0.05	0.18	80
32	0.16	0.46	32	82	0.04	0.73	82
34	0.03	0.49	34	84	0.10	0.58	84
36	0.03	0.22	36	86	0.04	0.47	86
38	0.05	0.95	38	88	0.07	0.39	88
40			*	90			*
42	0.01	0.41	42	92	0.11	0.62	92
44	0.05	0.15	44	94	0.14	0.41	94
46	0.05	0.33	46	96	0.01	1.25	96
48			*	98	0.05	0.54	98
50	0.09	0.54	50	100	0.03	0.32	100

* In these instances no clear match was obtained.
See Table 8 footnote.

** Insufficient data were recorded because of missing teeth, refer page 98

† For details of subset coding see pages 48, 49.

TABLE 32

Similarity Indices Determined On 50 Subjects Using Four Subsets Of Four Points To Characterize Two Lower Right Molars

†Subset																										
F L	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
	S.I.	0.05	0.05	0.02	0.03	0.05	0.12	0.19	0.05	0.05	0.05	0.09	0.02	0.10	0.04	0.18	0.06	0.12	0.10	0.05	0.30	0.11	0.14	0.11	0.01	0.04
	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
	S.I.	0.22	0.07	0.02	0.06	0.20	0.11	0.12	0.13	0.02	*	*	0.04	0.00	0.07	0.08	*	0.12	0.04	0.15	0.10	0.04	0.05	0.12	0.13	0.23
ML MB	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
	S.I.	0.02	0.02	0.08	0.06	0.01	*	0.03	0.07	0.13	*	0.09	0.13	0.09	0.01	0.09	0.10	0.05	0.11	0.07	0.10	0.02	0.09	0.05	0.08	0.07
	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
	S.I.	0.02	0.10	0.11	0.80	0.02	0.08	0.14	0.04	0.07	0.02	**	0.04	0.05	0.04	0.04	*	0.03	0.09	0.10	0.15	0.14	0.10	0.11	0.03	0.06
DB MB	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
	S.I.	0.02	0.05	0.11	0.03	0.07	0.07	0.09	0.07	0.08	0.25	0.15	0.15	0.07	0.01	0.02	0.01	0.06	*	0.05	0.02	0.03	*	0.10	0.07	0.06
	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
	S.I.	0.06	0.03	0.16	0.12	0.07	0.10	0.07	0.02	0.02	0.04	**	0.05	0.04	0.02	0.04	0.13	0.04	0.08	0.12	0.12	0.12	0.04	0.03	0.09	0.26
DB ML	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
	S.I.	0.01	0.07	0.02	0.08	0.05	*	0.12	0.09	0.20	*	0.04	0.02	0.01	0.01	0.08	0.11	0.01	0.03	0.04	0.09	0.02	0.04	0.12	0.07	0.01
	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
	S.I.	0.08	0.08	0.14	*	0.07	0.03	*	0.02	0.06	0.05	**	0.02	0.07	0.04	0.00	*	0.02	0.02	0.09	0.07	*	0.10	0.07	0.10	0.34

* In these instances no clear match was obtained. See Table 8 footnote.

** Insufficient data were recorded because of missing teeth, refer page 98.

† For details of subset coding see pages 48, 49.

TABLE 33

Similarity Indices Determined On 50 Subjects Using Two Subsets Of Four Points To Characterize Two Lower Left Incisors

†Subset																										
DM	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
	S.I.	0.02	0.09	0.03	0.08	0.06	0.03	0.03	0.06	0.21	0.01	0.11	0.06	0.04	0.00	0.06	0.13	0.09	0.05	0.07	0.01	0.05	0.03	0.04	0.06	0.15
	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
	S.I.	*	0.04	0.05	0.04	0.10	*	0.06	0.04	0.03	0.04	0.03	*	0.10	0.06	0.06	0.05	0.06	0.03	0.07	0.17	0.09	0.14	0.02	0.08	0.07
FL	T.S.	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
	S.I.	0.09	0.07	0.00	0.06	0.05	0.07	0.04	0.12	0.10	0.01	0.02	0.05	0.10	0.04	0.01	0.02	0.07	0.04	0.04	0.07	0.04	0.04	*	0.13	0.05
	T.S.	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
	S.I.	0.11	0.15	0.02	0.03	0.02	*	0.01	0.01	0.07	0.05	0.07	0.07	0.05	0.05	*	0.07	0.08	0.04	*	0.04	0.03	*	0.02	0.09	0.11

* In these instances no clear match was obtained. See Table 8 footnote.

† For details of subset coding see pages 48, 49.

ERRORS CHAPTER 4

The results have shown that some test subjects were not matched clearly with the corresponding master file subjects (Table 34). This was indicated when the sum of least squares differences between the coordinates obtained from a test subject and the corresponding master file subject was greater than other values obtained in the set of matchings.

Failure to obtain the smallest possible similarity index for a test subject and its corresponding master file subject in a matching procedure could be attributed to experimental errors of two main types, systematic and observer. Systematic errors were concerned with limitations in the equipment used, the Oscar semi-automatic digitizing unit, and limitations in the marking of casts. The Oscar F/DCF recording apparatus (Figure 7) can output incorrect digital values for the coordinates if the electrical relays of the digital converter unit become worn or coated. This situation causes false signals to be emitted to the IBM punch card machine. The reading head of the record reader is also limited in its precision, particularly as movement of the reading head controls and movement of the reading head over the screen are not completely uniform. However this error was consistent throughout the recording procedures.

TABLE 34

The Number Of Mismatches For Upper And Lower Casts Compared With The Total Number Of Matches

	mismatch	total number of matchings
Upper arch	67	1350
Lower arch	107	1350
TOTAL	174	2700

The alignment of the X and Y cursors over the image of the reference point is achieved by crossing hair lines. Because the same operator digitized all records, errors arising from the location of reference points were reduced. The discrepancy between the actual centre of a reference point and the recorded centre was consistent for all records. Evidence to support this statement is presented in a subsequent section concerning double determinations.

The placement of reference points on dental casts was an additional source of systematic error. Size of the points varied between 0.5 mm and 1.5 mm when projected onto the viewing screen. This variation at times produced difficulties in the estimation of the centre of the point.

Observer error, the second category of experimental error, is concerned with the manner in which the recording device was used. The alignment of cross hairs of the X and Y cursors over the centre of a reference point could only be accepted as an estimate of the actual centre in most instances. However, discrepancies between the true centre and the estimated centre were consistent because a standard recording procedure was adopted.

The orientation of negatives in the projector was of vital importance. Any deviation from the standard method could lead to incorrect recording of coordinates and misleading results from the matching process. Discrepancies in the classification of missing teeth, particularly premolars, in the two determinations was a source of further observer error that could lead to mismatching. Thus rigid standards for classifying the teeth examined were necessary.

Close scrutiny of data revealed that several errors were responsible for incorrect matchings between test subjects and master file subjects. Some test subjects had teeth missing in the segments being matched with the master file subjects. The number of subjects in this category are listed in Table 35 under the column headed C. For example in test subject 7, the teeth missing were 21 11 12 and a match with the two upper left incisors of the master file subject could therefore not be made.

Some test subjects matched more closely with other master file subjects than with the corresponding subject. The number of subjects in this category is shown in column B of Table 35. Column A, Table 35, shows the number of subjects for whom geniune recording errors were found in both first and second determination data. Incorrect coordinates were either the result of a

TABLE 35

Classification Of Errors Showing Numbers Of Upper And Lower Casts In Each Group

Error	*A	*B	*C	TOTAL
number of upper casts	44	19	4	67
number of lower casts	60	28	19	107
				174

* A is the number of subjects for whom recording errors were present in first or second determinations

B is the number of subjects that matched more closely with other master file subjects

C is the number of subjects for whom there were teeth missing in the segments being matched malfunction in the digital converter unit or observer recording error. In the latter there were noticeable differences in coordinates for the first and second determinations.

The large number of recording errors indicates the need for accurate coordinate recording. The master file must be absolutely free of errors. One possible procedure to eliminate such errors is by the use of a double determination method similar to that used in PROGRAM FOREN 2. Essentially digitized records of the same subject or subjects are obtained on two different occasions - first and second determinations. The latter are compared using PROGRAM CHEX 1.

The computer printout lists for each point the differences in abscissa and ordinate as well as the absolute linear distance discrepancy, in millimetres, between the two locations. A summary of the two determinations on results obtained for 50 test subjects, 25 upper and 25 lower, using PROGRAM CHEX 1 is presented in Tables 36 and 37. The mean linear discrepancy values provide an indication of observer consistency during the recording procedure. The small values indicate that the methods used to estimate the centre of reference points were reasonably accurate and reliable. Refinement in the size of reference points may result in a further reduction of the mean linear discrepancy values.

TABLE 36

Summary Of Double Determinations For 25 Lower Subjects

reference point	*mean	†E (M)	reference point	mean	E (M)
47DM	1.17	0.15	31M	0.72	0.10
47MM	0.97	0.13	31D	0.58	0.10
47F	0.17	0.16	31F	0.67	0.10
47L	0.98	0.13	31L	0.66	0.10
47DB	1.12	0.15	32M	0.72	0.10
47ML	1.01	0.13	32D	0.53	0.09
47MB	1.05	0.14	32F	0.65	0.10
46DM	1.94	0.94	33L	0.62	0.10
46MM	0.77	0.11	33M	0.67	0.10
46F	1.00	0.13	33D	0.54	0.09
46L	0.73	0.11	33F	5.33	0.47
46DB	0.98	0.13	33L	0.63	0.10
46ML	0.72	0.10	34MM	0.63	0.11
46MB	0.87	0.12	34DM	0.61	0.10
45DM	5.34	0.47	34F	0.46	0.09
45MM	0.76	0.10	34L	0.48	0.10
45F	0.74	0.10	34B	0.51	0.08
45L	0.90	0.12	34Li	0.61	0.10
45B	0.67	0.10	35MM	0.41	0.08
45Li	0.81	0.11	35DM	0.51	0.10
44DM	0.72	0.10	35F	0.46	0.11
44MM	0.73	0.10	35L	0.52	0.09
44F	0.75	0.11	35B	0.55	0.09
44L	0.82	0.11	35Li	0.64	0.10
44B	0.59	0.09	36MM	0.43	0.08
44Li	0.78	0.11	36DM	0.51	0.10
43D	0.83	0.14	36F	0.45	0.09
43M	0.83	0.12	36L	5.34	0.47
43F	0.73	0.11	36DB	1.27	0.81
43L	0.86	0.10	36ML	1.02	0.37
42D	0.64	0.10	36ML	1.21	0.56
42M	5.34	0.47	37MM	1.12	0.65
42F	0.75	0.10	37DM	0.98	0.33
42L	0.72	0.11	37F	1.04	0.58
41D	0.76	0.10	37L	3.78	3.24
41M	0.58	0.09	37DB	4.13	3.44
41F	0.71	0.10	37ML	1.56	0.68
41L	0.70	0.10	37MB	1.07	0.21

* Represents the mean of the linear distance between a point measured on two separate occasions

† Represents the linear discrepancy between a point measured on two separate occasions

TABLE 37

Summary Of Double Determinations For 25 Upper Subjects

reference point	*mean	†E (M)	reference point	mean	E (M)
27DM	1.09	0.13	11M	0.82	0.09
27MM	0.98	0.12	11D	0.62	0.07
27F	1.13	0.13	11F	0.73	0.08
27L	0.95	0.11	11L	0.70	0.08
27DB	1.17	0.14	12M	7.73	0.09
27ML	1.03	0.11	12D	0.55	0.06
27MB	1.09	0.13	12F	0.67	0.07
26DM	0.91	0.11	12L	0.64	0.07
26MM	0.80	0.08	13M	0.67	0.07
26F	1.00	0.11	13D	0.50	0.05
26L	0.74	0.09	13F	5.56	0.47
26DB	0.99	0.11	13L	0.65	0.07
26ML	0.81	0.09	14MM	0.59	0.07
26MB	0.91	0.11	14DM	0.64	0.07
25DM	5.57	0.47	14F	0.44	0.05
25MM	0.80	0.09	14L	0.45	0.05
25F	0.70	0.08	14B	0.48	0.04
25L	0.92	0.11	14Li	0.57	0.07
25DB	0.67	0.07	15MM	0.34	0.04
25Li	0.90	0.09	15DM	0.53	0.05
24DM	0.82	0.11	15F	0.35	0.04
24MM	0.75	0.08	15L	0.46	0.05
24F	0.76	0.08	15B	0.49	0.06
24L	0.85	0.10	15Li	0.61	0.06
24B	0.64	0.07	16MM	0.39	0.04
24Li	0.82	0.08	16DM	0.51	0.05
23D	0.75	0.13	16F	0.38	0.05
23M	0.80	0.10	16L	5.55	0.47
23F	0.77	0.08	16DB	0.50	0.05
23L	0.84	0.10	16ML	0.64	0.07
22D	0.61	0.07	16MB	0.64	0.07
22M	5.57	0.47	17MM	0.43	0.04
22F	0.80	0.08	17DM	0.72	0.07
22L	0.75	0.09	17F	0.47	0.06
21D	0.76	0.09	17L	0.54	0.06
21M	0.66	0.08	17DB	0.64	0.07
21F	0.80	0.09	17ML	0.79	0.09
21L	0.78	0.09	17MB	0.79	0.09

* Represents the mean of the linear distance between a point measured on two separate occasions

† Represents the linear discrepancy between a point measured on two separate occasions

The methods outlined in this study introduce sources of experimental error. To provide an objective approach to the problem of experimental error it would seem that a tolerance value, based on the maximum allowable total error should be calculated. The similarity index, defined as the sums of least squares differences, indicates the total of the linear discrepancies between first and second determinations of data. The maximum allowable error must be calculated theoretically using basic considerations such as the number of reference points describing a segment, the theoretical distance between two points, an enlargement factor and the maximum distance the estimated centre of a reference point may vary from the real centre. This maximum theoretical value can then be used to assess whether or not recorded similarity indices are within the limits of experimental error. An index that is markedly greater than the calculated maximum error value indicates some doubt as to the positive identification of the particular test subject. Indices below, near, equal to or just above the maximum error value may still indicate positive identification.

The maximum linear error between estimated and real centre of a reference point is on the circumference of a circle whose centre is the real centre of a reference point and whose radius is one and a half millimetres. This distance was calculated from reference point images on the viewing screen. The distance between points $P_1(x_1, y_1)$ and $P_2(x_2,y_2)$ on the Oscar viewing screen can be calculated as follows:

$$P_1 - P_2 = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} = 1.5 \text{ mm}$$

The distance between these points on the original record can be determined by dividing by an enlargement factor (E). In this study the image on the viewing screen was five times the size of the original dental cast. Thus the tolerated distance between the two determinations of a point is:

$$\frac{1.5}{E} \qquad \text{where } E = 5.$$

In terms of the similarity index, catering for n points, the total sums of squares of differences that would be tolerated is:

$$\frac{(1.5)^2.n}{E^2} \quad .$$

Tables 38 and 39 present mean values of lowest indices for each subset compared with the calculated maximum possible error (M). Subsets are listed according to the number of reference points used.

TABLE 38

Means Of The Similarity Indices For 27 Upper Subsets Compared With The Maximum Allowable Error For Each Subset

subset	mean index S.I.	*M $\left(\frac{(1.5)^2 . n}{E^2}\right)$
76	3.61	6.84
14	0.49	1.26
14	0.55	1.26
10	0.42	0.90
10	0.78	
8	0.29	0.72
8	0.22	
8	0.22	
8	0.22	
8	0.35	
8	0.26	
8	0.26	
8	0.20	
6	0.15	0.54
6	0.16	
6	0.17	
6	0.18	
6	0.18	
6	0.19	
6	0.16	
4	0.09	0.36
4	0.10	
4	0.17	
4	0.07	
4	0.09	
4	0.07	
4	0.08	

* M represents the maximum theoretical error

TABLE 39

Means Of The Similarity Indices For 27 Lower Subsets Compared With The Maximum Allowable Error For Each Subset

subset	mean index S.I.	*M $(\frac{(1.5)^2 . n}{E^2})$
76	3.59	6.84
14	0.54	1.26
14	0.47	
10	0.27	0.90
10	0.35	
8	0.26	0.72
8	0.21	
8	0.19	
8	0.20	
8	0.28	
8	0.21	
8	0.30	
8	0.18	
6	0.15	0.54
6	0.15	
6	0.13	
6	0.22	
6	0.15	
6	0.15	
6	0.15	
4	0.06	0.36
4	0.09	
4	0.07	
4	0.08	
4	0.07	
4	0.06	
4	0.05	

* M represents the maximum theoretical error

DISCUSSION CHAPTER 5

The investigation was undertaken with the objective of designing a method for forensic investigation based on metric characters of the dentitions and dental arches. A CDC 6400 computer and a F/DCF Oscar strip chart and film digitizing system were used as integral parts of the method. A precise mathematical procedure, based on a least-squares technique to minimize discrepancies between two determinations of coordinates, was used to calculate a similarity index which assisted with the identification of unknown subjects.

An extensive literature review relating to forensic odontology confirms that examination of dental structures can play an important role in the identification of unknown subjects. Dental structures have been shown to be more resistant to destruction than the conventional features used for identification, such as finger prints, items of clothing, jewellery or personal belongings. The methods of forensic investigation that were reviewed are quite laborious, taking many hours to complete, especially if many subjects have to be identified. Considerable importance was placed on accurate up-to-date written dental records as well as radiographic records.

The problems associated with these types of records were discussed. Reconstructive techniques of identification have a disadvantage, not only in the time and equipment required but also in the dependence on persons with expert knowledge and training.

If there is a need, therefore, for new methods of forensic dental identification that are less demanding use should be made of computers and automatic recording devices. Particular attention could be focused on details of the dentition and dental arches. Studies have shown that dental arch shape and size can be defined by placement of reference points at selected sites in a dentition.

The method designed for forensic identification in this investigation was based on anatomical characters of teeth and dental arches. An initial study showed clearly that dental arches could be identified by metric characterization. The second study was concerned with certain conclusions arising from the initial study. The results of both studies have helped to assess the general usefulness of the method in forensic dental identification, but more detailed analyses could be carried out in the future.

The method developed permitted reference points marked on dental casts to be expressed as precise metric quantities that could be entered into a computer. At no stage were conventional linear or angular measurements used to describe the dental features of subjects. Each subject was characterized by the coordinates of reference points located within a Cartesian system of orthogonal X and Y axes.

Research material consisted of 100 plaster casts of 50 students enrolled at the University of Adelaide Dental School. Photographs were taken of each cast after selected reference points had been marked on appropriate teeth. The negatives were projected onto the screen of a semi-automatic recording device and coordinates were obtained for each of the reference points. A master file was created which contained sets of coordinate data for the 100 subjects in two sections, 50 upper cast subjects and 50 lower last subjects.

On a second occasion further sets of coordinates were obtained for 92 subjects in an initial study and 100 subjects in the main study. These subjects were then compared in turn with each of the 100 subjects recorded on the master file by a matching technique described in the text. The smallest value for a similarity index, based on the sums of least squares difference between all the points belonging to the pair being matched, a test subject and a master file subject, indicated agreement between a subject and one of the master file subjects.

In the initial study 14 coded reference points and various subsets of 4 points were compared against records on the master file. In the main study, 76 coded reference points were used to describe the dentition and dental arches. From these many subsets of 14, 10, 8, 6 and 4 reference points were compared for each cast against records of the master file. Details of subsets are found in Chapter 2 and Appendix A.

When 14 points were used to define arch size and shape in the matching procedure 100 percent success was achieved. Thus the initial objective was realized; dental subjects could be identified by metric characterization. However when subsets of four incisor points and four molar points for upper and lower subjects were each matched against master file subjects, clear identification of test subjects was not achieved in every instance. The latter result suggested that the number of reference points was insufficient to adequately describe small segments. Further the points chosen, the mesiobuccal cusp tip and mid-point of an incisal edge, may be unreliable to use in matching procedures.

The main study was designed to use small molar and incisor segments described by many more points in various combinations.

In the main study each cast was characterized by 76 points and in a matching procedure 90 percent success was achieved. Two molars and two incisors in both the upper and lower arch were described by reference points marking, an estimate of mesiodistal and faciolingual width, as well as cusp tips excluding the distolingual cusp of molars. Thus the maximum number of points describing a molar segment was 14. Incisor segments were described by a maximum of 8 points. Subsets of varying number and different combinations of parts, listed in the text, were matched with master file subjects.

Results were conclusive even though 100 percent success was not achieved. Considering upper casts only, matching molar and incisor segments described by 26 subsets of points, a total of 1300 matchings, 95 percent success was achieved. In the case of lower arches the matching procedures returned 92 percent success. No particular subset was more successful than another and there was no marked variation in the number of mismatches in each subset from the mean mismatch number for the 26 subsets - 2.5 in upper casts and 3.9 in lower casts.

Satisfactory results were obtained using two points per tooth, that is four per segment. For example, when mesiodistal reference points were used, successful matching was achieved in most cases for upper and lower test subjects (Tables 20, 31). It was apparent, however, that when more points were used to characterize teeth clearer discrimination was achieved. For example test subject 3 in Table 20 the similarity index obtained when a molar segment described by mesiodistal reference points was matched with master file subjects the similarity index was 0.03. The nearest similarity index was 1.61. However, when 14 points were used to describe a molar sigment, subject 3 Table 13, the matching similarity index was somewhat greater but nevertheless significantly lower than the nearest other index. This was especially pronounced when 76 points were used to describe test subjects (Tables 12, 23).

As the number of reference points increases the value of the sums of least squares differences between the points of two matching subjects must increase resulting in a larger similarity index. Thus subjects are more easily identified. The differences between points of the test subject and its matching master file subject will not be as great as those between the same subject and another master file subject.

Double determinations carried out on 25 upper and 25 lower subjects revealed that for this study certain reference points were less reliable than others. This supports the analyses of mismatchings that occurred in the main study. Failure of a test subject to be identified with the corresponding master file subject was due to three types of error. Examination of data coordinates revealed that recording errors occurred in 104 of the total number of errors. The error was present in either the first and second determination data or both. Reasons for the errors are discussed in the text.

In some cases a genuine similarity existed between a test subject and one or more master file subjects. A third cause for mismatching arose from the rigid experimental routine followed in the main study. In most subsets two upper left molars, two upper left incisors, two lower right molars and two lower right incisors were selected as segments to be matched with master file subjects. There were instances however, where a tooth or teeth in a particular segment were missing. A factor which resulted in insufficient reference points being recorded for the matching procedure to occur. This was found particularly in lower casts of test subjects.

The evidence strongly suggests that accurate data must be obtained before proceeding with any attempt to identify unknown subjects. Particular attention must be focused on the master file data. The double determination procedure discussed in the text and in this chapter would be an ideal method of checking the accuracy of recorded data. Any inconsistencies would be immediately obvious. The same procedure could also be applied to data obtained from the unknown subjects prior to the matching with master file subjects.

The method of identification using a mathematical technique has merit as evidenced by the results of the study. However certain aspects need review and modification. Errors in this study arose because of equipment limitation and observer error. Inadequacies of the semi-automatic recording device resulted in systematic error. Discrepancies not only existed in the reading head and the X and Y cursors but the digital converter unit emitted false signals in some instances. Reference points marked on dental casts vary in size because of the method of placement. The recording of the centre of these reference points from the screen of the recording device by aligning cross hairs of the X and Y cursors relies on the observer's ability to interpolate the point of intersection of two lines onto the centre of each reference point; an ability that may vary from time to time in one observer and must vary between observers. Tables 36 and 37 reveal, however, that apart from those few incorrectly recorded coordinates the majority of recorded data were reliable and within accepted limits for this study. Any errors resulting from limitations of the recording equipment and observer have been consistently reproduced throughout the study and are not of great significance as far as the interpretation of results is concerned.

A maximum error value has been calculated using basic theories applied to this study. The maximum calculated error, M can be represented as follows:

$$M = \frac{\left(\begin{array}{l}\text{maximum allowable discrepancy}\\ \text{between real and actual}\\ \text{centre of a reference point}\end{array}\right)^2}{(\text{an enlargement factor})^2} \times \begin{array}{l}\text{the number of reference}\\ \text{points used in a}\\ \text{particular subset}\end{array}$$

All values in the expression are real and not calculated from results of the study. The values obtained more than favourably compare with the calculated values for the 27 subsets of coordinates (Tables 38, 39). This evidence provides further confirmation that the method has merit.

This study has proposed a new scientific method that may have a role in future forensic dental identification. The method has a sound theoretical basis but some practical details require further consideration. The method demonstrates many advantages compared with traditional means of dental identification. There is no dependence on the collection of dental records or radiographs, no laborious comparison of pre and post mortem records and no complex reconstructive techniques to identify unknown subjects. The time involved for the proposed method of identification is considerably less than traditional methods. A further advantage is the use of operators who do not need intensive training to implement the identification programme. With satisfactory techniques incorporated into the manual and computer procedures the method may be more reliable than conventional collation and comparison of records.

Further research is necessary relating to the number and combinations of points that are most reliable. It may be impractical in a field situation to have a dental arch described by say, 76 reference points. Dental casts of subjects may provide a means by which other techniques, more applicable in a real situation, may be developed. Certainly subjects chosen for research should be available for further studies one, two or three years after an initial study is commenced. Such a long term study would determine if the points chosen to characterize dentitions and dental arches were relatively stable over a period of time, even though dental restorations would probably have changed in the same period.

Photography, too, may play a more important role in forensic dental investigation. Photographic records provide precise, accurate, detailed images that transcend all language barriers. They are certainly suitable for use in conjunction with a semi-automatic recording device. Some form of photographic record suitable for direct digitization would be an improvement on the method developed in this study. Research into this area would require a reassessment of the characterizing reference points. In particular, evaluation of pre and post mortem photographs would be difficult unless standard procedures were developed.

The evidence presented in Tables 36 and 37 indicates that it is essential to have correctly digitized records not only in the master file but in the second determination data of unknown subjects. The double determination procedure discussed in the text is one way of checking the consistency of recorded points.

Evaluation of observer reliability when digitizing reference points under differing conditions is essential. The reliability of records digitized by different observers also needs to be assessed.

Use of a semi-automatic recording device is essential to the method outlined in this investigation. The disadvantages of the Oscar F/DCF strip chart and film digitizing unit have been discussed in the text. Other similar recording devices should be examined for their possible use in the proposed method of forensic identification.

Identification of casts, described by metric characters, using precise mathematical techniques has been demonstrated. This investigation has discussed in detail the method by which this was achieved, the results and errors of the method that resulted in the failure of certain subjects to be identified. Certain procedures have been critically analysed and suggestions for further research have been made. Hopefully this investigation will lead to further research, thus contributing to the advancement of forensic dental investigation.

APPENDIX A

Subsets with reference points characterizing molar and incisor segments

Subset	Teeth Used	Reference Points
1 14 points	maxillary left first and second molar	27DM 27MM 27F 27L 27DB 27ML 27MB 27DM 26MM 26F 27L 27DB 27ML 27MD
	mandibular right first and second molar	27DM 47MM 47F 47L 47DB 47ML 47MB 46DM 46MM 46F 46L 46DB 46ML 46MB
2 14 points	maxillary right first and second molar	16MM 16DM 16F 16L 16DB 16ML 16MB 17MM 17DM 17F 17L 17DB 17ML 17MB
	mandibular left first and second molar	36MM 36DM 36F 36L 36DB 36ML 36MB 37MM 37DM 37F 37L 37DB 37ML 37MB
3 10 points	maxillary left first and second molar	27F 27L 27DB 27ML 27MB 26F 26L 26DB 26ML 26MB
	mandibular right first and second molar	47F 47L 47DB 47ML 47MB 46F 46L 46DB 46ML 46MB
4 10 points	maxillary left first and second molar	27DM 27MM 27DB 27ML 27MB 26DM 26MM 26DB 26ML 26MB
	mandibular right first and second molar	47DM 47MM 47DB 47ML 47MB 46DM 46MM 46DB 46ML 46MB
5 8 points	maxillary left first and second molar	27DM 27MM 27F 27L 26DM 26MM 26F 26L
	mandibular right first and second molar	47DM 47MM 47F 47L 46DM 46MM 46F 46L
6 8 points	maxillary left first and second molar	27DM 27MM 27DB 27ML 26DM 26MM 26DB 26ML
	mandibular right first and second molar	27DM 47MM 47DB 47ML 46DM 46MM 46DB 46ML

Subset	Teeth Used	Reference Points
7 8 points	maxillary left first and second molar	27DM 27MM 27DB 27MB 26DM 26MM 26DB 26MB
	mandibular right first and second molar	47DM 47MM 47DB 47MB 46DM 46MM 46DB 46MB
8 8 points	maxillary left first and second molar	27DM 27MM 27ML 27MB 26DM 26MM 26ML 26MB
	mandibular right and second molar	47DM 47MM 47ML 47MB 46DM 46MM 46ML 46MB
9 8 points	maxillary left first and second molar	27F 27L 27DB 27ML 26F 26L 26DB 26ML
	mandibular right first and second molar	47F 47L 47DB 47ML 46F 46L 46DB 46ML
10 8 points	maxillary left first and second molar	27F 27L 27DB 27MB 26F 26L 26DB 26MB
	mandibular right first and second molar	47F 47L 47DB 47MB 46F 46L 46DB 46MB
11 8 points	maxillary left first and second molar	27F 27L 27ML 27MB 26F 26L 26ML 26MB
	mandibular right first and second molar	47F 47L 47ML 47MB 46F 46L 46ML 46MB
12 6 points	maxillary left first and second molar	27F 27L 27DB 26F 26L 26DB
	mandibular right first and second molar	47F 47L 47DB 46F 46L 46DB
13 6 points	maxillary left first and second molar	27F 27L 27ML 26F 26L 26ML
	mandibular right first and second molar	47F 47L 47ML 46F 46L 46ML

Subset	Teeth Used	Reference Points
14 6 points	maxillary left first and second molar	27F 27L 27MB 26F 26L 26MB
	mandibular right first and second molar	47F 47L 47MB 46F 46L 46MB
15 6 points	maxillary left first and second molar	27DM 27MM 27DB 26DM 26MM 26DB
	mandibular right first and second molar	47DM 47MM 47DB 46DM 46MM 46DB
16 6 points	maxillary left first and second molar	27DM 27MM 27ML 26DM 26MM 26ML
	mandibular right first and second molar	27DM 47MM 47ML 46DM 46MM 46ML
17 6 points	maxillary left first and second molar	27DM 27MM 27MB 26DM 26MM 26MB
	mandibular right first and second molar	47DM 47MM 47MB 46DM 46MM 46MB
18 6 points	maxillary left first and second molar	27DB 27ML 27MB 26DB 26ML 26MB
	mandibular right first and second molar	47DB 47ML 47MB 46DB 46ML 46MB
19 4 points	maxillary left first and second molar	27DM 27MM 26DM 26MM
	mandibular right first and second molar	47DM 47MM 46DM 46MM
20 4 points	maxillary left first and second molar	27F 27L 26F 26L
	mandibular right first and second molar	47F 47L 46F 46L

Subset	Teeth Used	Reference Points
21 4 points	maxillary left first and second molar	27DB 27ML 26DB 26ML
	mandibular right first and second molar	47DB 47ML 46DB 46ML
22 4 points	maxillary left first and second molar	27DB 27MB 26DB 26MB
	mandibular right first and second molar	47DB 47MB 46DB 46MB
23 4 points	maxillary left first and second molar	27ML 27MB 26ML 26MB
	mandibular right first and second molar	47ML 47MB 46ML 46MB
24 4 points	maxillary left central and lateral incisor	22F 22L 21F 21L
	mandibular right central and lateral incisor	42F 42L 41F 41L
25 4 points	maxillary left central and lateral incisor	22D 22M 21D 21M
	mandibular right central and lateral incisor	42D 42M 41D 41M
26 8 points	maxillary left central and lateral incisor	22D 22M 22F 22L 21D 21M 21F 21L
	mandibular right central and lateral incisor	42D 42M 42F 42L 41D 41M 41F 41L

Subset	Teeth Used	Reference Points
27 76 points	maxillary arch (excluding third molars)	27DM 27MM 27F 27L 27DB 27ML 27MB 26DM 26MM 26F 26L 26DB 26ML 26MB 25DM 25MM 25F 25L 25B 25Li 24DM 24MM 24F 24L 24B 24Li 23D 23M 23F 23L 22D 22M 22F 22L 21D 21M 21F 21L 11M 11D 11F 11L 12M 12D 12F 12L 13M 13D 13F 13L 14MM 14DM 14F 14L 14B 14Li 15MM 15DM 15F 15L 15B 15Li 16MM 16DM 16F 16L 16DB 16ML 16MB 17MM 17DM 17F 17L 17DB 17ML 17MB
	mandibular arch (excluding third molars)	47DM 47MM 47F 47L 47DB 47ML 47MB 46DM 46MM 46F 46L 46DB 46ML 46MB 45DM 45MM 45F 45L 45B 45Li 44DM 44MM 44F 44L 44B 44Li 43D 43M 43F 43L 42D 42M 42F 42L 41D 41M 41F 41L 31M 31D 31F 31L 32M 32D 32F 32L 33M 33D 33F 33L 34MM 34DM 34F 34L 34B 34Li 35MM 35DM 35F 35L 35B 35Li 36MM 36DM 36F 36L 36DB 36ML 36MB 37MM 37DM 37F 37L 37DB 37ML 37MB

The subsets required were selected from second determination data by specified parameter cards entered with PROGRAM FOREN 2.

REFERENCES

ASHLEY, K.F. (1970). Identification of children in a mass disaster by estimation of dental age. Brit. D.J. 129, 167.

BANG, G., RAMM, E. (1970). Determination of age in humans from root dentin transparency. Acta. Odont. Scand. 28, 3.

BJÖRK, A. (1947). A face in profile. Svensk Tandlakare Tidskrite 40, 5B.

BROADBENT, B.H. (1937). The face of the normal child. Angle Orthod. 7, 183.

BROWN, T., BARRETT, M.J., CLARKE, H.T. (1970). Refinement of metric data from cephalograms and other records. Aust. D.J. 15, No. 6, 482.

CREER, R.P. (1935). The photography of the oral cavity. J. Biol. Photog. Assn. 4, 68.

DAHLBERG, A.A. (1963). Dental traits as identification tools. Dent. Prog. 3, No. 3, 27.

DYCE, J.M. (1948). Photographic aids to clinical practice. Staples Press London.

FANNING, E.A., BROWN, T. (1971). Primary and permanent tooth development. Aust. D.J. 16, No. 1, 141.

FRYKHOLM, K.O., LYSELL, L. (1962). Different systems for the recording of teeth and teeth surfaces. Int. Dent. J. 12, 194.

FURNESS, J. (1968). A new method for the identification of teeth marks in cases of assault and homicide. Brit. D.J. 127, 261.

FURNESS, J. (1969). The identification of victims of mass disasters and also the identification of individual remains. Brit. D.J. 127, 501.

FURUHATA, T., YAMAMOTO, K. (1967). Forensic odontology. C.C. Thomas U.S.A.

GUSTAFSON, G. (1966). Forensic odontology. Staples London.

________ (1962). Forensic odontology. Aust. D.J. 7, 293.

________ (1963). Forensic dentistry. J. Dent. Res. 42, No. 4, 252.

GUSTAFSON, G., JOHANSEN, G. (1963). The value of certain characteristics in dental identification. Acta. Odont. Scand. 21, 367.

HARVEY, W. (1966). Identity by teeth and the marking of dentures. Brit. D.J. 121, 334.

HENRIKSON, C.O., SOREMARK, R., FRYKHOLM, K.O. (1962). The use of an iodine - 125 unit in forensic odontology. Odont. Rev. 13, 130.

HUMBLE, B.H. (1933). Brit. D.J. 54, 528.

JOHANSEN, G., LINDENSTAM, B. (1961). Dental evidence in identification. Acta. Odont. Scand. 19, 101.

KALZIN, H.M., CARLIN, R. (1943). A new clinical camera. Dent. Outl. 30, 318.

KEISER-NIELSEN, S. (1963). Dental investigation in mass disasters. J. Dent. Res. 42, 303.

________ (1965). Geographic factors in forensic odontology. Int. Dent. J. 15, 343.

KEISER-NIELSON, S., FRYKHOLM, K.O., STRØM, F. (1964). Identification of unknown bodies. Int. Dent. J. 14, 317.

KORKHOUS, G. (1953). Die Leica in den zahn-, mund- und kieferheilkunde. Die Leica in Benif und wissenschaft. IV Auflager. Umschau Verlag, Frankfurt am main. (original not seen)

LEATHERMAN, G. (1971). Two digit system of designating teeth - FDI submission. Aust. D.J. 16, No. 6, 394.

LUNZ, L. (1968). Dental radiography and photography in identification. Dent. Radiog. and Photog. 40, 78.

MacINTOSH, H.G. (1937). A standardized technique for oral photography. Brit. D.J. 62, 70.

MIDDA, M. (1969). Disclosing solution for synthetic fillings. Brit. D.J. 127, 579.

MILES, A.E.W. (1963). Dentition in the estimation of age. J. Dent. Res. 42, 255.

MORGAN, W.D., LESTER, H.M. (1938). The leica manual. 3rd Edition N.Y. 425.

MOORREES, C.F.A., FANNING, E.A., HUNT, E.E., Jr. (1963). Age variation of formation stages for ten permanent teeth. J. Dent. Res. 42, 1490.

MÜLLER, W. (1957). Den nasenbogen bei identifizierungsvenfahren zahnartztl. Welt. 58, 598.

RUDDIMAN, R.A., et al. (1969). Forensic odontology. Identification by comparison. Brit. D.J. 127, 505.

SASSOUNI, V. (1959). Cephalometric identification. A proposed method of identification of war dead by means of roentgenographic cephalometry. J. Forensic Sci. 4, 1.

_______ (1963). Dentofacial radiography in forensic dentistry. J. Dent. Res. 42, 274.

SCHOUR, I., MASSLER, M. (1940). Studies in tooth development: the growth pattern of human teeth.
Part I J.A.D.A. 27, 1728.
Part II J.A.D.A. 27, 1918.

STEWART, T.D. (1963). New developments in evaluating evidence from the skeleton. J. Dent. Res. 42, 264.

STRØM, F. (1963). Investigation of bite marks. J. Dent. Res. 42, 312.

TAYLOR, B.L., SCHLACK, C.A. Oral colour photography. Naval Medical Research Institute Bethesda Maryland. Project NM 012604. X - 767 Report No. 2.

TAYLOR, D.V. (1963). The law and the dentist. Brit. D.J. 114, 389.

The importance of the dental record. (1970). Aust. D.J. 15, No. 2, 133.

WASHBURN, S.L. (1948). Sex differences in the pubic bone. Amer. J. Phys. Anthrop., N.S., 6, 199.

SUPPLEMENTARY REFERENCES

Since initial compilation of this report several articles dealing with related topics have been published. Many were located by a MEDLARS literature search initiated by the National Library of Australia. The most relevant of these are listed below.

BANG, G. (1972). Factors of importance in dental identification. Forensic Sci., 1, 91.

BUTLER, O.H. (1973). The value of bite mark evidence. Int. J. Forensic Dent., 1, 23.

DANIELSEN, K. (1973). Editorial. Forensic Dentistry. Int. J. Forensic Dent., 1, 2.

DORION, R.B. (1973). Factors in the identification of human skeletal remains. J. Can. Dent. Assoc., 39, 626.

________ (1972). Marking of dentures. J. Can. Dent. Assoc., 38, 305.

________ (1972). Dental Records. J. Can. Dent. Assoc., 38, 262.

FURNESS, J. (1973). Editorial. Forensic Dentistry. Int. J. Forensic Dent., 1, 2.

FORD, M.A. (1973). Dental nomenclature. Int. J. Forensic Dent., 1, 16.

HAINES, D.H. (1973). Identification in mass disasters from dental prostheses. Int. J. Forensic Dent., 1, 11.

KOGAN, S.L., PETERSEN, K.B., LOCKE, J.W., PETERSEN, N.O., BALL, R.G. (1974). A computerized aid to dental identification in mass disasters. Forensic Sci., 3, 151.

LUNT, D.A. (1974). Identification and tooth morphology.
Int. J. Forensic Dent., 2, 3.

PILLAI, P.S., BHASKAR, G.R. (1974). Age estimation from teeth using Gustafson's method - a study in India. Forensic Sci., 3, 135.

STODDART, T.J. (1973). Bite marks in perishable substances. A method of producing accurate permanent models. Br. Dent. J., 135, 285.

YANO, M. (1973). Experimental studies on bite marks. Int. J. Forensic Dent., 1, 13.