# Forensic Radiographic Identification Using Manipulated Digital Dental Images.

Robert Edgar Wood



Dissertation presented for the degree of Doctor of Philosophy at the University of Stellenbosch, March, 1996.

Promoter: Prof. C.J. Nortjé

**Declaration**

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

Signature : ______________________________



Date: May 22 1996

**Acknowledgements**

I would first and foremost like to thank Professor Nortjé for giving me the opportunity to undertake such a project. He has always been kind and generous with his hard-earned material and time. Thanks must also be given to Prof. W.P. Dreyer, Dean of the Faculty of Dentistry for allowing such a project to be completed. I have always considered the Faculty of Dentistry at the University of Stellenbosch my first (and finest) University affiliation. I also express thanks to my advisors who offered constructive criticism and provided direction on this side of the earth. This includes Dr. M.J. Pharoah and Dr. Ross Barlow University of Toronto, Dr. J. Cairns, Deputy Chief Coroner, Province of Ontario; Inspector, H. Leroy, Royal Canadian Mounted Police; Dr. S. Kogon and Dr. D. MacLean, University of Western Ontario, Dr. D. Sweet, University of British Columbia, Mr. B. Blenkinsop and Dr. D. Chiasson of the Office of the Chief Coroner, Province of Ontario, as well as Dr. Angela Harris of the University of Stellenbosch. Special thanks are due to Ms. Anna Dias, Mr. John Jackson, and Mr. Keith Oxley of the Princess Margaret Hospital for assistance in preparation of the manuscript and figures. Finally to my loving wife Joan, and daughter Emily for allowing me precious time to complete the project.

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## English summary:

A technique was developed for the assessment of forensic identification using dental radiographs. The technique involved the digitisation of dental radiographs, cutting of a horizontal section from an antemortem radiograph and superimposing it over the same geographic location on the postmortem radiograph. The technique was useful in vitro and in an in vitro mock mass disaster. It was accurate within both the paediatric and permanent dentition and not useful in subjects with changing dentitions (mixed dentition). Image density (with and without optical enhancement) did not prove to be an impediment to the technique although extremes of image contrast did. Within the range of dental x-ray generators settings, contrast could be altered in a manner to allow matching. Differences in the vertical angulation of the x-ray beam did not influence the technique although horizontal angulation was a critical factor. Alterations in focal-film distance did not adversely affect the use of this technique. The three different scanning systems used were all adequate for the purpose of the technique and the images could be compressed and transferred with little difficulty. Analysis of a group of actual Coroner's cases proved the technique to be useful in a timely fashion, for actual field identifications with minimal inter and intra operator error.

## Afrikaans summary:

‘n Nuwe tegniek is ontwikkel waarin Tandheelkundige x-straalfoto’s gebruik word vir identifikasie in Forensiese tandheelkunde. Die tegniek behels die digitalisering van binnensmondse Tandheelkundige x-straalfoto’s, die afsny van ‘n horisontale gedeelte van die antemortem x-straalfoto wat dan gesuperponeer word oor dieselfde geografiese area van die postmortem x-straalfoto. Die tegniek is in ‘n vitro gesimuleerde massa-ramp bruikbaar gevind. Die tegniek was akkuraat in beide die primêre gebitstadium en permanente gebit maar onsuksesvol in die gemengde gebitstadium. Beelddigtheid (met of sonder optiese versterking) het nie die resultate van die tegniek belemmer nie alhoewel uitermatige beeldkontras wel die tegniek benadeel. Binne die reeks van x-straalbuisverstellings kan die kontras verander word op ‘n wyse wat vergelykbaarheid toelaat. Variasies in die vertikale angulasie van die x-straalbundel het nie die tegniek beinvloed nie, maar variasie in horisontale angulasie is ‘n kritiese faktor. Verstellings in die fokus-film afstand het geen nadelige uitwerking op die tegniek gehad nie.

Die drie verskillende skanderings sisteme wat gebruik is, was elkeen voldoende vir die doel van die tegniek en die beelde kon saamgedruk word en oorgeplaas word sonder enige probleme. Ontleding van ‘n aantal gevalle wat verwys is deur die lykskouer het bewys dat genoemde tegniek ook tydsgewys in die werklike situasie effektief is met geringe inter en intra waarnemer afwykinge.

## Introduction and Literature Review

Identification of the deceased is essential for legal and humanitarian reasons. Many unidentified bodies are homicide victims or missing persons. Investigation of these cases cannot proceed without proper identification. Routine methods of identification include visual recognition, clothing recognition, personal artifacts, fingerprints, DNA matching, as well as medical, skeletal, serological, hair, and dental comparisons. (1-4) Other methods of identification involve lip prints (5) and specific morphological tooth traits. (6,7) Despite the plethora of possible comparisons, in most cases where bodies are decomposed, skeletonised, fragmented, burned, or otherwise mutilated, the human dentition is likely to be evaluable and yield identifying information. (1, 7, 8) This premise holds especially true in fire victims (8-10) and in mass disasters (11-13). Most methods of establishing identity of an unknown body employ a comparison of antemortem and postmortem records. Thus the completeness and availability of antemortem records together with the degree of preservation of the remains are crucial. (1)



The application of radiology in forensic sciences was introduced in an 1896 homicide case to demonstrate the presence of bullets inside a victims head (14). The use of radiographs for identification purposes was first proposed by Schuller in 1921. (15) Subsequent early studies have made comparisons of the cranium, skeletal structures, and paranasal sinuses for identification. (16, 17, 18)

A variety of individual characteristics exist in the human teeth and jaws. Their presence or absence may assist in identification. Nortjé (1986) postulated that a general profile of an individuals age, gender, and race may be established from the postmortem dentition visually and radio graphically. (18) Anatomic landmarks, physical characteristics, and various disease states in the oral-facial region are often available in the form of antemortem dental charts, radiographs, and dental casts.

These antemortem records are important evidence for determining identity. Missing and unerupted teeth, restored teeth, endodontic therapy, prosthetic appliances, tooth and pulp morphology, bone trabeculation, caries, periodontal and periapical pathology are features commonly used for forensic comparisons. (7, 19, 20) Sprawson (1942) (21) and Simpson (1951) (22) were among the first to recognise the potential of dental radiographs for identification. Since teeth are a stable part of the human body and dental restorations are resistant to postmortem change, dental identification is an accurate and durable means of identification. (11, 19) Keiser-Nielsen, in 1977 stressed the importance of evaluating the combination of dental features present. (23) He calculated the number of ways a specific dental configuration (ie. normal, missing, and filled teeth, tooth surfaces, and bridgework) can occur together in the human dentition. Fellingham (1984) expanded this idea to include decayed teeth and conducted two studies on the likelihood or two or more people having identical dental configuration in school children of the South African Cape peninsula. (24) His studies of the dental configuration of school children concluded that out of a total of 810 individuals, 11 persons had identical dental charts ("twins"), three were identical "triplets" and four composed identical "quadruplets." This suggests that although charts alone may be used for identification purposes their use may not always result in definitive identification. This study also does not account for variations or deficiencies in charting methods.



Charting efficiency and accuracy is not absolute and is prone to human error. (25-27) While there have been charting comparison algorithms designed to account for errors in charting they have not become universally accepted and may be difficult to defend in courts of law. (28)

Dental radiographs and dental records are invaluable in body identification in mass disasters, their use highlighted in the investigation of the Noronic disaster. (29) Dental radiographs are of high value in forensic identification since they are an accurate reflection of the condition and anatomy of the teeth and jaws at one point in time. Whereas it is true that they can be of poor quality it is possible to duplicate their exposure parameters at the post mortem radiographic examination.

The concept of superimposing ante mortem and post mortem records in forensic science is not new. Sophisticated techniques such as computational superimposition of two-dimensional digital facial photographs with three dimensional cranial surfaces of an unknown skull have been developed. (30, 31) The author has also developed a version of digital photographic superimposition of ante mortem and post mortem radiographs which is the subject of this thesis.



Traditional methods of antemortem and postmortem dental radiographic examinations centered around visual comparison, presence, shape, and size of dental restorations with less emphasis placed on natural anatomical features such as root shape and bone patterns. (19, 32) In todays population there has been a reduction in the number of dental restorations due to preventive interventions. Obtaining a physical match using restorations therefore is more difficult since there are fewer restorations for comparison on antemortem and postmortem records.

**Process of identification.**

The process of identification is divisible into two main components. These are: the level of confidence with which an identification is made; and the specific methods by which an identification is made.

There are two means by which the level of an identification is made. The first one, which I will elaborate, is the type of identification undertaken. This refers classically to primary identifiers, secondary identifiers and tertiary identifiers. This concept cannot be viewed in isolation, and the methods of primary, secondary and tertiary identification will be discussed below in the section dealing with methods of identification.

Primary identifiers are defined as means which are universally accepted as proof of identification with a high degree of moral certainty. They are sometimes also called "scientific identifiers" (33) Whenever possible, primary scientific identification methods are preferred. Examples of primary identification methods are fingerprint identification, comparison of skeletal remains, medical autopsy, radiographic features, and dental identification. (33)

Secondary identification is undertaken when primary identification is not possible. It includes the use of items such as clothing, laundry markings, jewellry, wallet-contents and other personal documents.(33) It is inherently less reliable in that the presence of such items with the body does not definitively identify the body per se. (33) This method requires an assessment of the probability of the person who is the rightful owner of the personal effects being in possession of them at the time death occurred. This evidentiary link may, at times, be tenuous. Dental identification may also be a source of secondary identifiers as the following illustrative case describes.

Case Report 1 (Figures 1 to 3)

Subject 1. Mr. A.C.
Subject 2. Mr. J.C.C.
Subject 3. Mr. D.C.C.
Date of examination: July 28, 1994.
Date of report:August 1, 1994.
Coroner: Dr. John Lynch

I attended the office of the Chief Forensic Pathologist of Ontario in Toronto on July 28, 1994 to examine the bottled remains of several unidentified human bodies. (Figure 1)

Figure 1. Photographic depiction of sifted human remains obtained from the remote cabin in which three subjects may have perished.

The portions of the bodies provided to me were identified as follows:

**<u>Specimen bottles from person in body bag</u> #3**

Mason type jar ( 33) and specimen bottle 18

Specimen jar 18 contained 5 prosthetic teeth. These teeth were porcelain in structure and were photographed for documentation purposes. The fact that they were porcelain is the reason they survived the fire. Porcelain teeth in testing can resist fire temperatures of at least 900 degrees C for over 1.5 hours with the retentive pins remaining intact. Two of these teeth were upper central incisor teeth. Examination of these teeth revealed no manufacturers markings. Each had two retentive metallic lugs on the lingual surface and both had abrasion on the lingual aspect. These abrasions were either mechanical or from natural wear. Both of these incisor teeth were probably from the same denture since they were the same mould and shade. Bottle 18 also contained a single prosthetic porcelain bicuspid tooth which was likely also from the upper denture. It had no lugs and was also photographed for identification purposes. It appeared to have been ground on its underside to fit the denture at the time the teeth were set up. Bottle 18 contained 2 prosthetic porcelain teeth which could have been either maxillary or mandibular molar or bicuspid teeth. Of these two teeth there was a larger and a smaller one. The smaller of the posterior porcelain prosthetic teeth had holes on the mesial and distal aspect and an undercut central hole beneath its biting surface for retention. Examination with a stereo microscope revealed an inscription on the back consisting of a raised semi-lunar marking, two smaller raised circular markings and what appears to be the inscription "F 2 F". These markings were located around the central hole with the semi-lunar marking appearing at 1 O'clock, the two raised dots at 10 and 11 O'clock and the "2" at 6 O'clock with one "F" at 4 O'clock and the other "F" at 8 O'clock. The larger of the two prosthetic teeth also had markings on its tissue surface. With the stereo microscope the inscription "3 2" followed by a raised dot which in turn was followed by the letter "F." This inscription ran from about 8 O'clock in a counter clockwise direction to about 5 O'clock. These markings were manufacturers markings and while at times they may be quite useful for identification purposes they didn't appear anywhere in the antemortem dental or laboratory records.

Mason jar 33 contained a cast metallic framework lower free-end partial denture. It replaced the following teeth:

mandibular right first permanent molar
mandibular right second premolar
mandibular right permanent lateral incisor
mandibular right permanent central incisor
mandibular left permanent central incisor
mandibular left permanent lateral incisor
mandibular left second premolar
mandibular left first permanent molar

It may have also replaced both mandibular second permanent molar teeth. These teeth, which the partial dentures replace were all missing from the mouth of Mr. A.C. according to the dental records. Interestingly he also had the lower right permanent cuspid tooth added to the partial denture after it was completed. This could have been easily done with the existing framework. I believe that the mandibular partial denture was designed with this eventuality in mind and examination of the framework reveals that the rest which would normally cover the lower right permanent cuspid tooth was smaller than its counterpart on the left side. This indicated a tooth addition which again was consistent with the records.

Examination of the partial lower denture framework (Figures 2 and 3) revealed that the mandibular right and left first premolar teeth had clasps and rests on them and the mandibular permanent cuspid teeth had rests on them. This led me to conclude that at the time the denture was designed the following teeth were present:

mandibular right first premolar
mandibular right permanent cuspid
mandibular left first premolar
mandibular left permanent cuspid



These were the teeth that Mr. A.C. possessed at the time his denture was designed. Of note there was no partial upper framework found. This fits with the design of the upper denture which was an acrylic denture with a gasket around the maxillary right permanent cuspid tooth. These gasket “almost full” dentures are almost always acrylic in total, containing no framework. They also have a relatively low melting point.

Figure 2. Photograph of the cast mandibular partial denture framework found at the scene. This denture framework was similar to a description of the framework apparently provided to Mr. A.C.

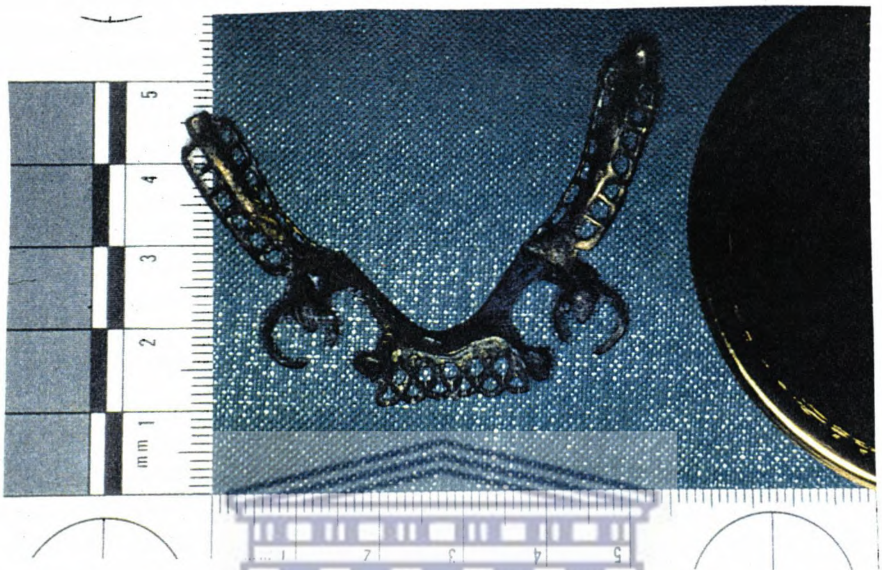





Figure 3. Photograph of the prosthetic teeth found in the sifted human remains.

Why were there no lower denture teeth found? It is probable that the lower teeth and possibly some of the upper teeth were acrylic. Acrylic resins used in denture construction burn at temperatures below 450 deg C and if in contact with actual flames will burn at lower temperatures. Hence the survival of the porcelain elements of the denture and the destruction of the acrylic portions. The cast framework of the denture being of base metal construction could easily have survived temperatures in excess of 1300 deg C. Natural teeth can be incinerated or destroyed at temperatures of 400 deg. C. although parts of the teeth can survive this. This gives us information about the temperatures of the fire and explains the differences in survival of different dental components.

Specimen bottles from person in body bag 1
specimen bottles 47,49,50,52,53

Specimen bottle 47 contained the coronal portion of what I identified as a lower permanent second molar tooth- probably the lower right second permanent molar. Examination of the radiographic flat plate of this tooth revealed development of approximately 1/2 to 2/3 of the crown. This was consistent with a subject aged 6 to 7 years and was inconsistent with a subject less than 5 years of age.

Specimen bottle 49 contained an upper right second permanent molar tooth. Examination of the radiographic flat plate of this tooth revealed development of approximately 1/2 to 2/3 of the crown. This was consistent with a subject aged 6 to 7 years and was inconsistent with a subject less than 5 years of age.

Specimen bottle 50 contained a mandibular left second premolar with bone attached. Examination of the radiographic flat plate of this tooth revealed development of approximately 1/2 to 2/3 of the crown. This was consistent with a subject aged 5 to 6 years and was inconsistent with a subject less than 5 years of age.

Specimen bottle 52 contained a mandibular left permanent second molar tooth. Examination of the radiographic flat plate of this tooth revealed development of approximately 1/2 to 2/3 of the crown. This was consistent with a subject aged 6 to 7 years and was inconsistent with a subject less than 5 years of age.

Specimen bottle 53 contained a segment of the inferior aspect of the mandible and lingual plate of the left mandible (all one piece). It contained a premolar or cuspid crypt on the left side. This crypt would have contained a developing premolar or cuspid tooth. It provides no identifying features other than being consistent with a child less than 8 years of age.



Specimen bottles from person in body bag 2
specimen bottles 35,36,37,38,39,41,42,43.

Specimen bottle 35 contained a partially developed crown of a maxillary left premolar tooth. This is a tooth from the adult tooth series. Examination of the flat plate radiograph of this tooth and clinical examination of the specimen reveal that there was limited crown development. The buccal and lingual portions of this tooth had not completed development. This was consistent with a person aged 4 to 5. By age 6 this tooth would have completed more of its crown development and had early partial root development.

Specimen bottle 36 contained deciduous molar tooth roots which were difficult to describe as belonging to one particular tooth. They were highly curved and examination of the flat plate radiographs revealed very little pulpal calcification. Root development of this tooth however was complete. This was consistent with a dental age greater than 3 but less than 7.

Specimen bottle 37 contained a deciduous molar tooth root which cannot be described as belonging to any one particular tooth. I believed it was a deciduous molar tooth root. Its root development, as seen on the flat plate radiograph was complete and its pulp was wide. This was consistent with a dental age greater than 3 but less than 7.



Specimen bottle 38 when clinically examined revealed a left anterior maxilla exhibiting deciduous tooth root sockets with a clinically visible, partially developed maxillary left permanent cuspid tooth lying in its bony crypt. Examination of the flat plate radiograph of this jaw segment revealed a maxillary left central incisor which had almost complete crown development but no root development. The permanent lateral incisor had similar features. The permanent cuspid tooth had less crown development than the incisors. These radiographic features placed the subject at age 3 to 4. At ages greater than 4, I would expect significantly greater root development in the incisor teeth and more complete development of the cuspid tooth.

Specimen bottle 39 contained a partially developed mandibular left cuspid tooth within its crypt and an erupted mandibular left first primary molar. Beneath the erupted mandibular primary first molar was a partially developed crown of a mandibular left first premolar. The development of the permanent cuspid and first premolar in this specimen was consistent with a subject in the age range of 4 to 6 years.

Examination of the mandibular left first primary molar with a stereo microscope revealed an internal surface which was consistent with machining from a dental drill as one would expect to see prior to restoration placement. This could also be seen on the flat plate radiograph of this tooth. It is known from examination of the antemortem records that subject D.C. had a restoration in this tooth.

Specimen bottle 41 contained a right premaxilla with partially developed crowns of the right permanent central incisor, right permanent lateral incisor, right permanent cuspid, and right first premolar. Examination of the flat plate radiograph revealed presence of the right second premolar. The development of these teeth is consistent with a subject aged 4 to 5 years.

Specimen bottle 42 contained a macerated specimen of what appeared to be a mandibular first permanent molar - probably the lower right first permanent molar. It had minimal root development and immature crown development. It was consistent with a subject aged 3 to 4 years and inconsistent with a child aged 6 years.

Specimen bottle 43 contained a highly immature crown of a maxillary permanent first molar tooth. It is likely that this was the maxillary right first permanent molar tooth. This tooth had to be pieced back together manually into its original form. Examination of the flat plate radiograph of this tooth revealed complete lack of root development and only early crown development. This was consistent with a subject aged 3 to 4 years and inconsistent with a subject aged 6 years.

These three identifications were extremely complex and were based on identification of fragments at three geographically close sites in what must be considered a "closed" population since the hunting camp was 20 kilometres from the nearest road or other domicile. I must commend those that gathered the specimens and catalogued them for a fine piece of work. The radiographic flat plates too were of very high quality and were vital to correct interpretation of the specimens. Almost every piece examined clinically and radiologically was a crucial part of the puzzle in identifying these three individuals. The identifications are further complicated by a lack of antemortem radiographic records and the lack of dental structures on at least one person (A.C) and lack of restorations on the other two persons. Despite this I was satisfied to a high degree of moral certainty of their identity.

1. Body bag 1 and the specimen bottles derived from it as described above, contained a body which was biologically aged 6 years. This subject could have been no less than 5 years of age and no greater than 8 years of age based on dental findings.

The findings were consistent with those in J.C.C.'s dental records. These findings were not specific to this particular individual and identification is made on the basis of consistency with the known age of the individual and concordance with the known age of the specimens, as well as identification by exclusion in this small closed population.

2. Body bag 2 and the specimen bottles derived from it as described above, contained a body which was biologically aged 4 years. This subject was not older than 5 years of age in my opinion and was younger than the specimens from body bag 1 with respect to dental age characteristics. Furthermore there was evidence of previous dental restorative treatment on the mandibular left first primary molar tooth. These findings were consistent with those in D.C.C.'s dental records.

3. Body bag 3 and the specimen bottles derived from it as described above, contained prosthetic dental prostheses which were highly consistent with those worn by A.C. I am satisfied to a high degree of moral certainty that the dental elements found were those worn by Mr. A.C. It is possible to "fake" ones demise by placing the prostheses in the fire situation. I am not personally aware of any case where this has occurred however it remains a possibility. There were no natural teeth present for identification of this fellow and no means of "fitting" the prostheses to any recovered anatomic specimen derived from the site.

Subsequent police investigation revealed that the subject A.C. had previously faked his own death. Although he may have perished in the fire, there is no physical evidence to support this contention and a positive, scientific identification was not possible. Clothing documents and jewellry can be switched with criminal intent. (33) It follows. that dental prostheses may also be switched in order to fake ones own death.

Tertiary identification is the least desirable method of identification. It depends on eye-witness accounts of a sequence of events occurring which places the deceased at the site of death based on (hopefully) eye-witness accounts. It is by far the least reliable method in that it depends on human recall for establishing the link.

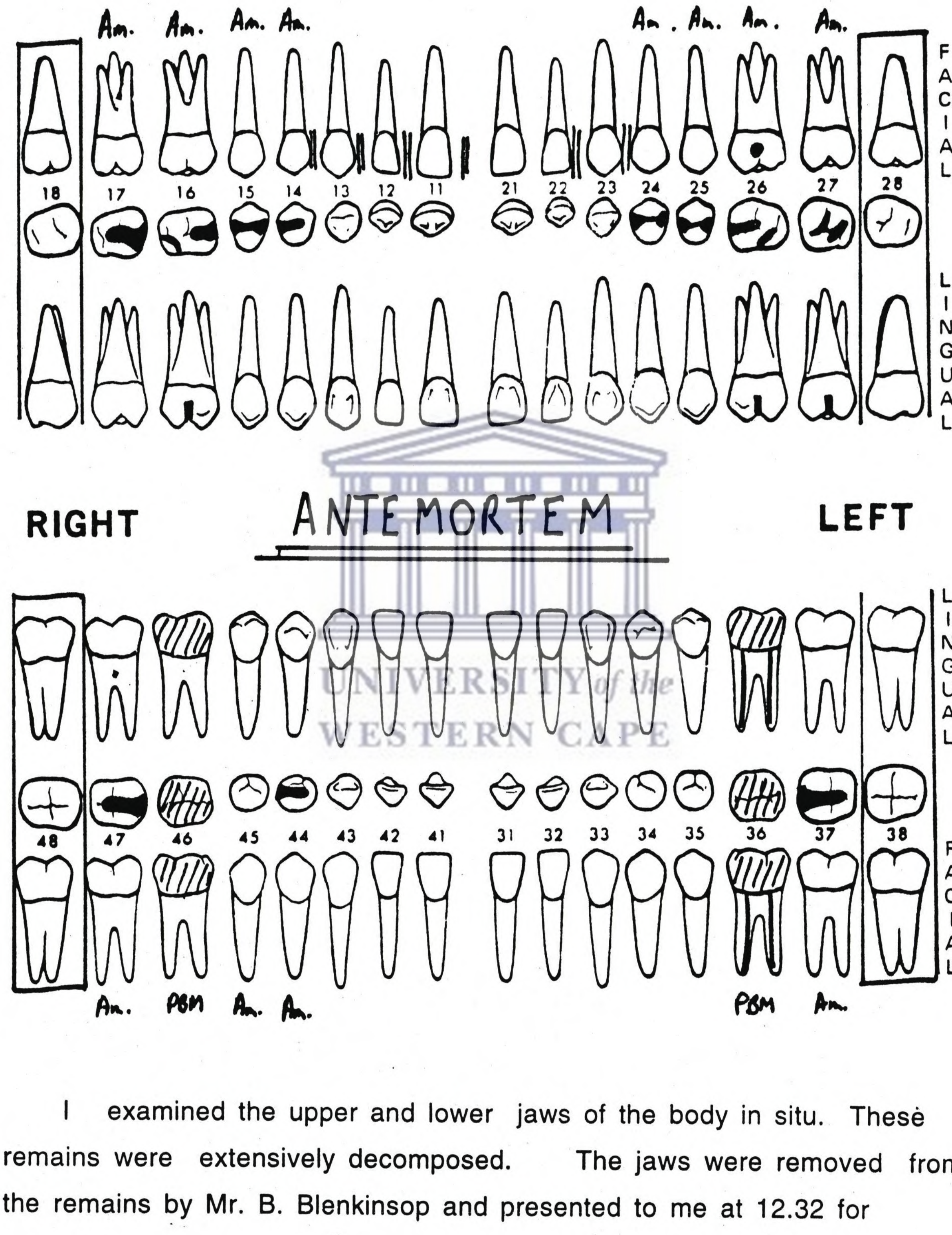
The following case illustrates the problem with identification based on sequence of events. It involved the death of a businessman who was seen entering a building. Later that evening the building was consumed with flames and the subject, who had just had knee surgery was burnt beyond recognition. The medical examiner responsible for the case accepted the sequence of events as acceptable for the purposes of identification. The life insurance corporation did not. The deceased had a multi-million dollar policy which was not honoured due partially to the lack of positive identification. For this reason the body was exhumed approximately 6 months after interment and was re-examined.



Case report 2 : Forensic report on: Mr. V.D.
Date of examination:November 22, 1994
Date of report: November 22, 1994
F.P.B. # 352-94
Pathologist:Dr. D. Chiasson

I attended the office of the Chief Forensic Pathologist of Ontario in Toronto on November 22, 1994 to examine the exhumed remains of a putatively unidentified human body. An antemortem odontogram was presented at the time of exhumation (Figure 4)

Figure 4. Antemortem odontogram of subject V.D. prepared from the treating dentists chart.






I examined the upper and lower jaws of the body in situ. These remains were extensively decomposed. The jaws were removed from the remains by Mr. B. Blenkinsop and presented to me at 12.32 for examination and evaluation which was undertaken at 12.33. At that time I prepared an odontogram charting of the post mortem specimens. (Figure 5) based on examination of the excised jaws (Figure 6).

Figure 5. Postmortem odontogram of subject V.D. prepared from examination of the exhumed post mortem specimens.

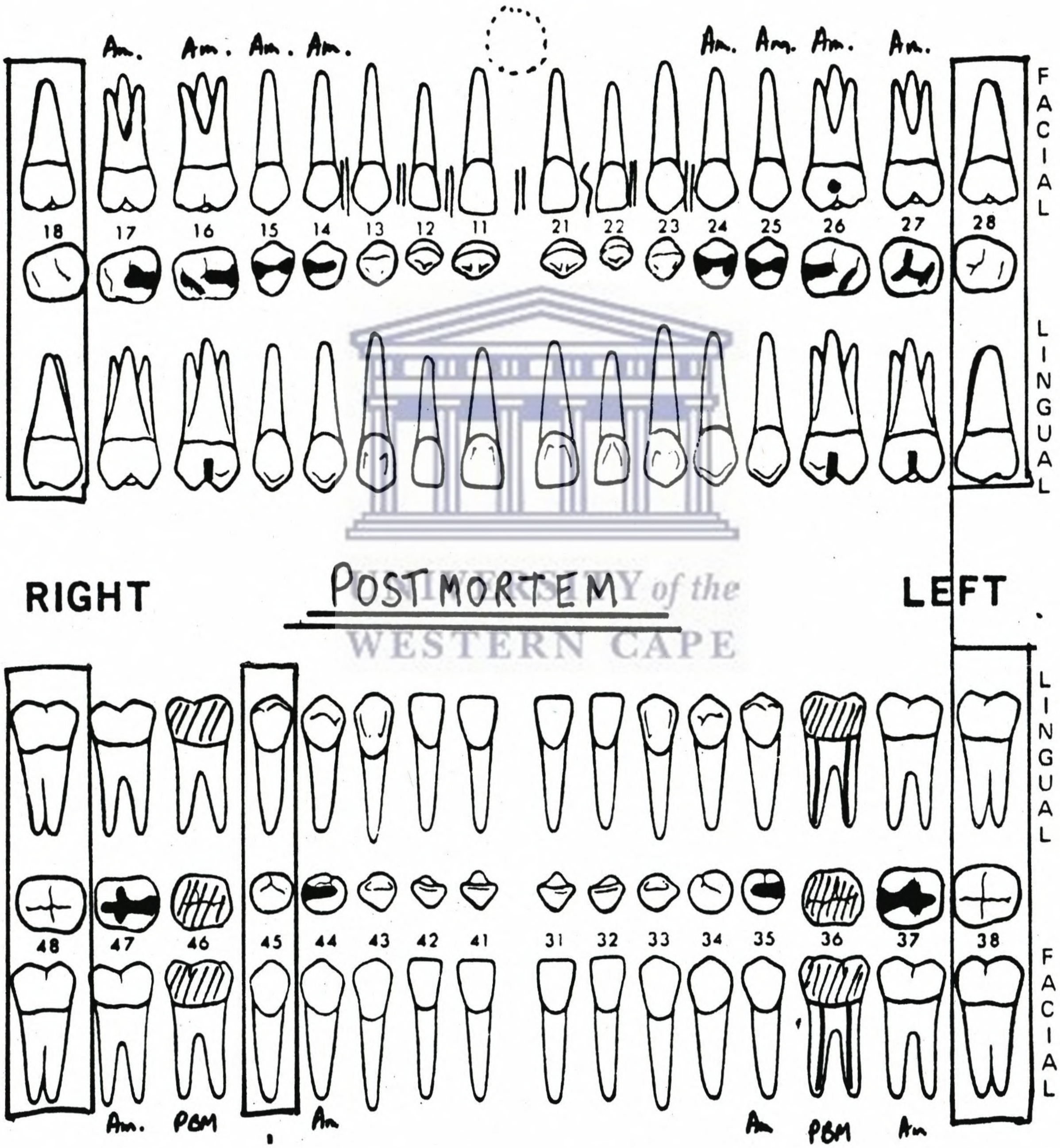
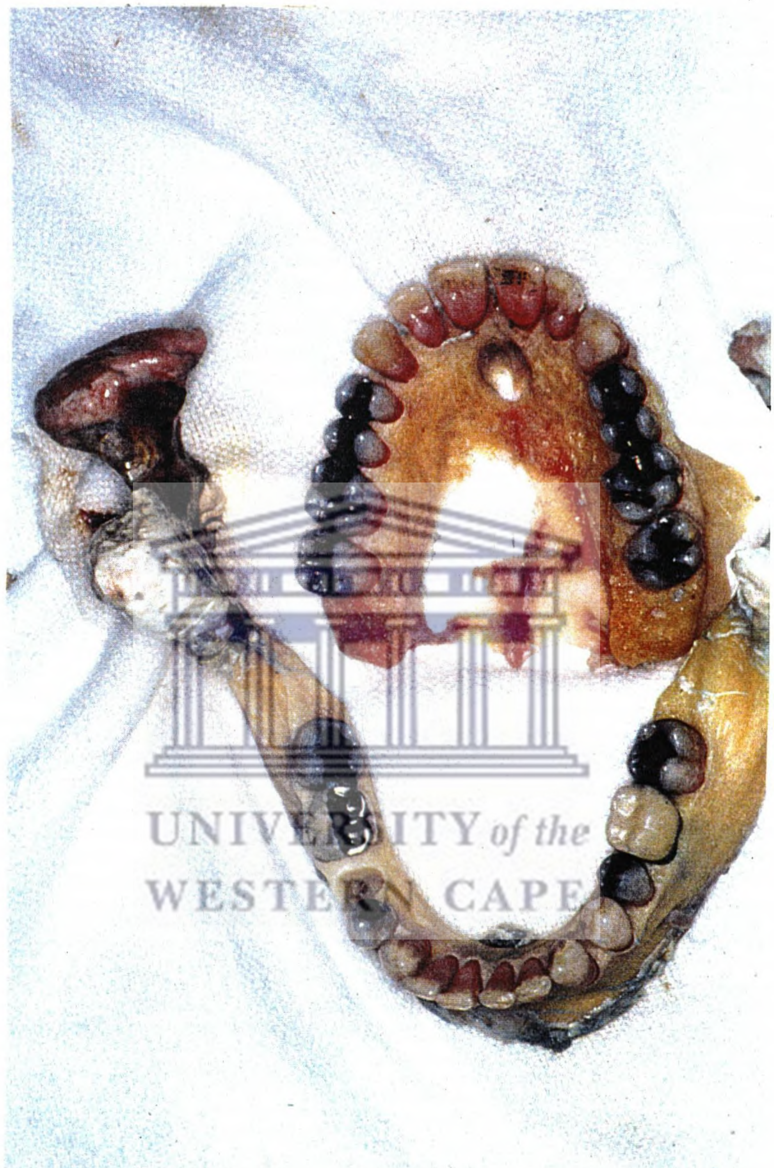


Figure 6. Photograph of excised jaws from exhumed human remains.



Following this, several post mortem radiographs were exposed by Ms. B. Bulger of the Office of the Chief Forensic Pathologist. The radiographs were exposed in a fashion to mimic the antemortem bitewing and periapical radiographs which were in the possession of Dr. George Burgman, consultant forensic odontologist for the family.

The post mortem radiographs were of high quality and suitable for comparison purposes. The ante mortem radiographs were also of high quality and suitable for comparison purposes. Dental charts were available for identification purposes in the form of an odontogram which was also in the possession of Dr. George Burgman. The jaws were photographed for documentation purposes.

Although the odontogram prepared by Dr. Burgman was of high quality it is my experience that radiographs provide more objective data for comparison purposes. For this reason, the post mortem radiographs and the ante mortem radiographs formed the basis of my identification procedure.



Concordant points:

1. There was a metallic restoration present on the mesio-occlusal aspect of the maxillary right second permanent molar which was highly similar in shape and location on the antemortem and postmortem radiographic examination.

2. There was a metallic restoration present on the mesio-occlusal-distal aspect of the maxillary right first permanent molar which was highly similar in shape and location on the antemortem and postmortem radiographic examinations.

3. There was a metallic restoration present on the mesio-occlusal-distal aspect of the maxillary right second premolar which was highly similar in shape and location on the antemortem and postmortem radiographic examinations.

4. There was a metallic restoration present on the disto-occlusal aspect of the maxillary right first premolar which was highly similar in shape and location on the antemortem and postmortem radiographic examinations.

5. There were two subtle radiopaque striations present beneath the restoration on the maxillary right second premolar tooth. I have never seen this feature before and would say that it is unique. It was present on both antemortem and postmortem radiographs.

6. There was a metallic restoration present on the mesio-occlusal-distal aspect of the maxillary left first premolar which was highly similar in shape and location on the antemortem and postmortem radiographic examinations.

7. There was a metallic restoration present on the mesio-occlusal-distal aspect of the maxillary left second premolar which was highly similar in shape and location on the antemortem and postmortem radiographic examinations.

8. There was a two part metallic restoration present on the maxillary left first permanent molar which was highly similar in shape and location on the antemortem and postmortem radiographic examinations.

9. There was a metallic restoration present on the maxillary left second permanent molar which was highly similar in shape and location on the antemortem and postmortem radiographic examinations.

10. There was a metallic restoration present on the mandibular left second permanent molar which was highly similar in shape and location on the antemortem and postmortem radiographic examinations.

11. There was a crown present with a uniquely placed retentive pin and endodontic treatment on the mandibular left first permanent molar tooth which was highly similar on the antemortem and postmortem radiographic examinations.

12. There was a metallic restoration present on the disto-occlusal aspect of the mandibular left second premolar tooth which was highly similar in shape and location on the antemortem and postmortem radiographic examinations.

13. There was a crown present with a retentive pin visible beneath it on the mandibular right first permanent molar tooth which was highly similar in shape and location on the antemortem and postmortem radiographic examinations.

14. There was a metallic restoration present on the mandibular right second permanent molar tooth which was highly similar in shape and location on the antemortem and postmortem radiographic examinations.

Discordant points:

1. The mandibular right second premolar tooth was not present at the time of examination. Examination of the root socket revealed it to be consistent with being missing post mortem. This is not unusual. With decomposition of the remains the periodontal ligaments of the teeth allow the teeth to loosen. This feature, in my experience is common and in no way precluded identification.

There were no other discordant points of any significance.

Summary: I was satisfied that the antemortem and postmortem records were of a sufficiently close match and stated with a high degree of moral certainty that they were of the same person. For this reason I stated without equivocation that the unidentified human remains (F.P.B. # 352-94 ) were those of Mr. V.D.



This case illustrated the simplicity by which this body could have been identified using dental means had they been used initially. Even though the medical examiner was satisfied, and a death certificate had been issued, the beneficiaries were left with no recompense from the life insurance company. In addition, family members were also left with the unpleasant thought that their loved one was not dead but may have faked his death or participated in the death of another.

With respect to the level of confidence with which an identification is made, one may pose two questions. What constitutes an identification? What level of confidence was this match made with?

The American Board of Forensic Odontology (A.B.F.O.) lists four possibilities for identification in their 1991 manual. (34) These are positive identification which is defined as a match between the antemortem and postmortem information with sufficient detail to establish that they are from the same person. With a positive identification there are no unexplainable discrepancies. (34) A lower level of identification is termed "possible identification" in which the antemortem and postmortem data have consistent features but due to the quality of either the postmortem or antemortem evidence, a positive identification is not possible. (34) The third possibility outlined by the A.B.F.O. is insufficient evidence which is self-explanatory, and finally, exclusion where the antemortem and postmortem comparison reveals that they could not have come from the same person. (34) The term "exclusion" must not be confused with the term "identification by exclusion" which may be applied to cases in which a closed population exists. If a person is excluded as a possibility they are positively pronounced not to be the unknown whereas identification by exclusion means that all other persons are accounted for and the remaining body must therefore be a certain person.

Dorion (1990) (3) supplemented the A.B.F.O. categories of identification in that he adds the term "probable identification" which would occupy a position in the confidence level between positive identification and possible identification. (3) Dorion (1990) defined the difference between a probable identification and possible identification as a matter of degree of confidence with probable identification having a greater degree of confidence. (3) In addition Dorion (1990) used the term "elimination" to describe a non-match rather than "exclusion" which is more suitable since it is not easily confused with "identification by exclusion." (3)

Identification by exclusion is possible when there is a closed population. (35) This is possible in accidents such as aircraft accidents in which the correct number of bodies have been found and there is an accurate passenger manifest. (35) With respect to dental identification by exclusion, if a dentition can be shown by a number of factors not to be from any missing persons known to have died in the incident except for one person, it may be assumed that the remains are of that person. (35)

Thus far I have discussed the types of identification methods in terms of primary, secondary or tertiary identifiers as well as the level of confidence with which an identification is made. No discussion of the basics of identification would be complete without discussing the concepts of comparative identification and reconstructive identification. (36)

The process by which identifications of any type and level are made are divisible into two broad groups. These are the comparative group and the reconstructive group. (37) The comparative group of identifications are used when there are antemortem records available. These records may be fingerprint, dental, skeletal etcetera and are discussed below. This process of identification implies that there is a putative or possible candidate for identification prior to the comparison procedure. (37) It is the most common form of identification of the two. The other identification process - reconstructive identification is used when there are no antemortem records or no suspected identity. (37) It is accomplished by relying on information derived from the recovered body itself. (36) Reconstructive methods may allow one to determine the age, gender, race, occupation and country of origin. (36) Reconstructive methods may yield clues as to where to search for antemortem records which would then permit comparative identification. (36) There are numerous examples of soft tissue and hard tissue reconstructive identification methods described in the literature. van Wyk (1976) (38) lists many oral features which can assist in determining behaviours or environmental influences which may aid in identification of the deceased. These include: bobby-pin injury to upper incisors, chipping of upper central incisors from biting thread, extensive abrasion of the anterior surfaces of the upper front teeth in rural African blacks , tooth-brush abrasion along the buccal surfaces of the teeth, erosion, fluorosis, pipe-smoking, mucosal recession from snuff-dipping, loss of anterior teeth in South African Cape Coloured persons to facilitate sexual acts, chronic lip burning from smoking cigarettes to the stub,. betel quid chewing, lip and cheek chewing in mental patients, dilantin hyperplasia, and lead lines in mucosa from chronic lead poisoning. Smith (1991) also discussed regressive changes in dental perikymata which indicated the presence or absence of denture clasps. (39)

In summary, the forensic odontologist may use both comparative and reconstructive processes in the application of primary, secondary and tertiary identifiers to establish an identification. The results of these tests provide identification with varying levels of confidence. In the next section I will discuss the different types of potential identification data and describe both their utility and level of confidence with which they may be used.

**Methods of Identification**

## Visual Identification

Visual identification is probably the most frequently used method of identifying the dead. (1) Its usefulness is limited to cases where the facial features are intact and the identifying persons are located soon after death. The deceased may not be recognisable after as short a time as 24 hours following death. (1) Others report that visual identification is possible, if adequate soft tissue preservation is present, as long as 3 to 4 months postmortem. (33) Visual recognition is highly dependent on the preservation of soft tissues. (33) In addition, these facial features must not be distorted. (33) At first glance, visual identification would seem to be relatively simple since the person performing the identification is presumably familiar with the face of the deceased. In practice however contraction of expressive muscles that may occur just before death may alter facial expression to a point where visual identification within a few minutes after death may be impossible or misleading even when the cadaver is face to face with near relatives.



If relatives are located, the experience of identifying a loved one is a highly-charged, emotional experience and failure to achieve visual identification is not uncommon. (1) Haines (1967), reporting on the Stockport disaster, stated that visual identification was difficult, upsetting to relatives, and unreliable whereas dental identification provided one of the least emotional and most reliable forms of identification. (40) According to van Wyk (1969) visual examination by relatives in the Windhoek air disaster was undesirable because it was disturbing to relatives and because mistakes were likely to occur. (41) Ashley (1970) reports a case in which a father misidentified a live, hospitalised child as his son following the boys rescue from an air crash. (42) This misidentification underscores the denial that may accompany the death of a loved one. In addition, bodies have been purposely misidentified for reasons of fraud or mischief. (29)

Visual identification is frequently useless in high speed aircraft crashes with visual identification possible in only 2 of 256 victims in the Gander Newfoundland air crash (43) and 2 of 23 bodies in the Kaimai aircraft crash. (44) Frykholm (1956) described an interesting case in a disaster at sea in which a father misidentified a person as his son using visual means. (45) The body was buried but later identified, using dental means, as the body of someone else. This resulted in its exhumation and interment of the correct body in its place. (45) Frykholm (1956) states "to recognise is not the same thing as to identify a body which may be greatly changed in appearance." (45) van Wyk (1969) reported another case in which the body of a young female was claimed by the wrong people. A dental chart was produced which proved the correct identity of the body. (41)



## Fingerprint identification

Fingerprint matching and identification remains the most commonly used of the scientific comparative identification techniques. (46) The detailed analysis of fingerprints for identification purposes is beyond the scope of this thesis. According to Keiser-Nielsen (1980) (47) fingerprint identification methods have been accepted worldwide for years as "an objective and reliable means of establishing identity." Fingerprint analysis is a pure comparative identification method since there is no attempt to quantify the frequency of each form of fingerprint pattern. Comparisons are made between known and unknown samples and concordant points between the two evaluated. (47) The specificity of this method cannot be challenged since there are no two sets of prints alike in the 84 million person file of the Federal Bureau of Investigation (F.B.I.) in Washington D.C. (48) Buchner (1985) describes fingerprint identification as the most reliable method of comparative identification since fingerprints are unique to the individual. (1) Ligthelm (1983) states that only fingerprints and dental characteristics are specific for an individual. (8)

There are many different features of fingerprint characteristics which are assessed including:bridges, deltas, dots, double bifurcations, ending ridges, eyes, islands, forks, island ridges, spurs, hooks, and trifurcations among others. (49) According to Cottone (1982) only about one half of the surface area of each fingerprint surface is required for identification if a list of possible identitities has been established. (46, 49) Burgman (1977) reports an interesting case in which a denture and fingerprint were used in tandem in an attempted identification of an unknown person. (50) A denture was found adjacent to a dead body. On the denture there was a fingerprint which did not belong to the deceased. A silver powder was used to adhere to the denture and a radiograph of the denture was taken revealing the fingerprint. The fingerprint was considered suitable for comparison purposes. (50)

Keiser-Nielsen (1980) mentions that 12 concordant points are normally required for an identification. (47) There is however no fixed number of points so long as the fingerprint expert is satisfied to a high degree of moral certainty that the unknown is congruous with the known. Osterburg (1964 ) noted that the number of details required and the similarity between such details necessary to establish identity cannot be stated with certainty. (49) Although fingerprints are accepted worldwide for identification purposes it is interesting to note that there are jurisdictional differences with regards to the number of concordant points required in order to make an identification. (Table I) According to Phillips (1990) the South African Courts of law are prepared to accept 7 concordant characteristics as being beyond reasonable doubt in the case of finger, hand and foot prints. (20)

**Table I Number of points of identification required for fingerprint identification in various jurisdictions** (20, 49)

| **Country** | **number of points** |
|---|---|
| Spain | 10 to 12 |
| Switzerland | 12 to 14 |
| Austria | at least 12 |
| England | at least 16 |
| France | at least 17 |
| Germany | 8 to 12* |
| South Africa | 7 to 12* |
| United States | no specific number† |
| Canada | no specific number† |

* as long as certain conditions are met

† comparisons must exhibit enough similar characteristics to satisfy the examiner to a high degree of moral certainty.

If fingerprints are useful and accurate as a scientific method for identification of the deceased, the question must be posed as to why they are not used more frequently for identification purposes ? The answer is two-fold. The primary reason is that no antemortem fingerprint records exist. Cottone (1982) states that it is very uncommon for women and children to have fingerprints on file. (46) Only 25 per cent of Americans, for example have fingerprints recorded by the

F.B.I. according to Bernstein (1985).(51) Even those who have fingerprints on file with the F.B.I. may have them recorded in such a manner as to make them unclassifiable in the F.B.I. classification system and useless as a source of antemortem data. (36) United States military personnel are routinely fingerprinted which was of benefit after World War II when United States war dead were identified more frequently than German war dead due to the presence of antemortem fingerprint material. (36) Civilians have resisted mass fingerprinting because they do not want to be treated "like criminals." (36) Finally, antemortem print records may be gathered from objects the deceased was known to have touched. (1) The chain of evidence however is not complete in many such cases introducing another potential source of misidentification.

The second major pitfall experienced with fingerprint identification is related to soft tissue decomposition. Fingerprint comparison can only be undertaken if the tips of the fingers are preserved. With incineration, water immersion, or weathering, the soft tissue is lost. Gustafson (1966) noted however that fingertips are protected better than other parts of the body in certain cases such as fires where they are bent inwards as the deceased takes on the typical "pugilistic" pose during the process of incineration. (36) The "pugilistic attitude" has been described in fire victims previously. (8,10)

## Skeletal identification

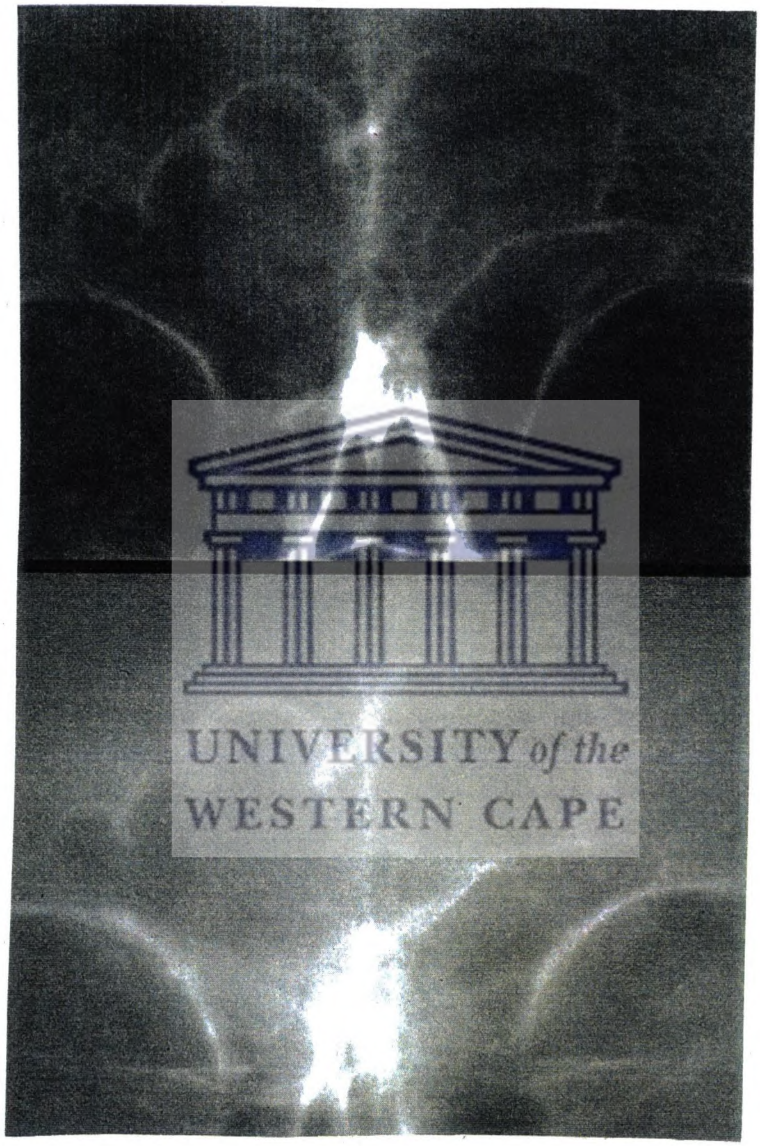
Clinical and radiological skeletal examinations may be used for the purpose of identification using comparative means. (1) Alternately they may be used reconstructively as an aid in determining the age, gender, ethnic origin, or stature of an individual. (52) Often skeletal examination focuses the identity within a likely population segment and other, definitive antemortem records are sought in an effort to determine identification. (33)

## Comparative skeletal identification

Numerous portions of the skeleton have been used as a means of comparison for the purpose of body identification. For the purpose of this thesis I will describe some of the types of skeletal identification which have been used beginning at the cranial end of the human skeleton and progressing towards the feet. Chandra-Sekharan, (1985) examined the suture pattern of 320 randomly selected human skulls. Analysis of this suture pattern revealed that the ectocranial suture patterns are highly individualistic and that no two skulls had an identical pattern. The possibility of these suture patterns being recorded incidentally in routine diagnostic radiographs was verified by examining the skull radiographs found in affiliated radiology departments. An important caveat using this technique was that the characteristic individualising pattern was formed only on the ectocranial surface - not the intracranial one and therefore one needs to be sure that the radiographic view clearly demonstrates the ectocranial surface. (53) A second weakness of this technique is the availability of antemortem radiographic evidence which shows the ectocranial suture pattern. (53) In addition to ectocranial suture patterns, positive identification has been accomplished by comparison of diploic vascular grooves in the frontal and temperoparietal regions and by superimposition of various points of the skull including the overall configuration of the calvarium and the sella turcica. (54) In the case reported by Messmer (1986) the antemortem and postmortem radiographs were separated by a period of 7 years. (54) Comparison of the radiographic features of the endocranial arterial pattern was also used by Rhine, 1991 to aid in the diagnosis of skeletonised human remains. (55) In this case, although the unknown deceased was "identified" using physical anthropological means, the identification was later confirmed using dental radiographs. (55)

Knight (1984) stated that "identification is possibly the most important forensic use of radiography, measured in terms of numbers of cases." (16) He cited the uniqueness of the frontal sinus shadows as a prime example since no two people, including identical twins, have the same sinus configuration. (16) Culbert in 1927 was one of the first to demonstrate that radiographic evaluation of the paranasal sinuses, and more specifically the mastoid sinuses, could be used as a means of forensic identification. (56) In his evaluation of his unknown deceased he made 20 points of identification from a comparison of antemortem and postmortem radiographs. (56) In this oft-quoted paper it is interesting to note that the identification of the unknown body in question was later "corroborated" by dental identification using gold inlays as the means of confirming the skeletal identification. (56) Culbert (1927) also correctly pointed out that the frontal sinuses may not be absolutely stable throughout life. He stated that allowances must be made for age-related growth, disease processes, and rarefaction of bone in the aged. (56) Culbert (1927) was not alone in the use of air-containing sinuses as a means of identification. The technique has been used as recently as 1991 with respect to analysis of mastoid air cells. (55) When comparing antemortem and postmortem radiological skull features it is important to attempt to duplicate the antemortem films by using various angulations until a view can be obtained that closely approximates the original film.(7, 56) Even with correct beam-object-film orientation it is important to remember that remains with soft tissue are generally given approximately the normal radiographic exposure whereas radiography of skeletonised remains should receive approximately one half the standard exposure(7) Yoshino et al (1987) examined the frontal sinuses in an analytic manner, specifically examining the sinus radiographs for area, skewness and kurtosis, bilateral symmetry, classification of the outline of the upper margin of the frontal sinuses, presence or absence of dividing septae, and presence of supra-orbital cells. (57) Similar studies have been undertaken by Harris (1987). (17) An ongoing analysis of material from the office of the Chief Coroner of Ontario in Toronto reveals that 39 cases of body identification were made by comparison of the radiographic features of the frontal sinuses since 1980. (Figure 7) (58)

Figure 7. Identification based on frontal sinus comparison using antemortem microfiche skull radiographic data.





Leaving the skull, we enter the zone of the vertebral column and its potential use in body identification. Farman (1984) examined physical features of the first cervical vertebrae including the following:

morphology of the posterior margin of the superior articular process, posterior tubercle, anterior tubercle, inferior articular surface and general size and shape of the atlas.(59) He noted that these structures remained stable over time and that although there were few radiographically appreciable differences in many of the features no two individuals involved in the study could be confused with another using these physical features. (59) He did note that the spine, including the first cervical vertebrae, is subject to degenerative changes that modify its shape - particularly in the aged. (59) While Farman's study was undertaken using the radiographic features seen in live subjects Rhine and Sperry (1991) reported an identification in which congenital fusion of the bodies of both arches of the second and third cervical vertebrae aided in identification. (55) Radiographic comparison of an entire vertebral column showed abundant arthritic changes allowing 14 points of similarity which aided in an identification reported by Jensen (1991) This was accepted even in the presence of disagreement regarding blood typing. (60)



In addition to the vertebral column, the lateral border of the scapula has been used for identification in one case in which it showed a well-developed extended notch in the inferior third that matched exactly with the lateral border of the right scapula.(61) Martel (1977) postulated that the thorax was a particularly useful area for assessment in skeletal identification. (62) He described the pattern of costal cartilage ossification in the lower ribs as being "distinctive" as were the size and shapes of ribs relative to one another. (62) The thorax region was also used because it often revealed acquired lesions, healed fractures and numerous other landmarks. It was also noted that antemortem chest films may be more commonly available than other radiographs. (62)

Moving inferiorly on the skeleton we reach the pelvis. The pelvis is often used as an aid in gender determination. This however is not a comparative means of identification but a reconstructive one. Moser (1990) noted that various skeletal characteristics of the bony pelvis have aided as forensic markers.(63) He describes the configuration of the nutrient groove of the ilium as being a potential means of identification in the analysis of remains from an aircraft accident. (63)

The appendicular skeleton has also been used in comparative skeletal identification. Comparison of antemortem radiographs of a missing person and postmortem leg radiographs of a John Doe revealed 12 points of similarity including shape characteristics of the long bone diaphysis, measured correspondence in the location of transverse lines of arrested growth (Harris lines) in the distal tibiae, shape and extent of periosteal reaction on both tibiae and fibulae, osteophyte development, and shape of the right calcaneus. (64) Analysis of similarities in the femur were used to aid identification in another case. (61) Perhaps the most interesting use of radiographs of the appendicular skeleton is described by Greulich (1960) who compiled most of the carpal radiograph age data and personally examined a large number of wrist and hand radiographs. (65) He believed that analysis of the following radiographic features of the wrist could differentiate between two individuals:shape and relative size of the styloid processes of the radius and ulna; shape of the individual carpal bones; size and shape of the individual metacarpals; the relative widths of metacarpal cortices and their medullary cavities, the individual differences in the outline of the margin of the carpal cortices immediately adjacent the medullary cavity; and the shape and position of the white lines visible in the heads of the metacarpals; differences in the shape and proportions of the individual phalanges and the fine details of the trabecular pattern visible in the shafts of the various bones especially in the proximal and middle phalanges. (65) Greulich (1960) claimed to be able to differentiate between the hands of identical twins. (2)

Much of the discussion on comparative skeletal identification thus far has focussed on comparisons of antemortem and postmortem similarities based on anatomical features. It is also important to examine the antemortem and postmortem radiographs for evidence of pathology. Anatomical abnormalities such as sesamoid bones, bone cysts, tumours, old fractures, metal prostheses, radiopaque foreign bodies provide excellent unique identifiers in skeletal comparison. (2, 66) Materials used in surgery and even intrauterine devices and penile implants may be used to aid identification. (66)

**Reconstructive skeletal identification**



Reconstructive aids in identification using the skeleton usually involves estimation of age, gender, and occasionally race. MacLaughlin and Oldale (1992) state that gender determination using the pelvis is 95 per cent accurate. (67) The skull, long bones, and vertebral column may also be used for gender determination with accuracy ranging from 80 to 90 per cent. (67) Owsley and Mann (1992) utilised a forensic anthropologist to estimate age, gender, and race of an unknown skeleton. Following this a potential match was found and comparative methods were used to confirm the identification. (68) The cranial base can be used to determine the gender from fragmented or deformed skulls. (69) An initial study used measurements taken from 100 crania in the Terry collection. In this detailed study,six regression models were formulated that predicted correctly the gender of the sample with 71-90% accuracy. (69) In a separate test, a control sample of 20 skulls also drawn from the Terry collection but not involved with formulating the regression equations, gender was correctly classified with 70-85% accuracy. (69)

Age determination methods from population studies may also be applied to single individuals depending on the availability and condition of the skeletal material according to Lynnerup (1990). He defined five age-related phases based on radiograph appearances. The relationship between the actual ages and the defined phases was found to be highly significant. (70)

Taylor (1984) used reconstructive means to complete a skull/portrait superimposition and with the identity known, the reconstructive data was compared to the features the deceased was known to have. (71) Part of this reconstruction involved re-assembling the jaws and skull to determine the racial origin of the deceased. It is again interesting to note that actual identification was completed using dental identification methods. (71)

Varga and Takacs (1991) report an interesting case in which a pair of sandals were found, one of which exhibited a striking deformity due to overuse. This was related to a congenital acetabular dislocation. The radiographic finding formed the basis of a police search for the missing person amongst a group of patients registered as having this deformity. The person was subsequently identified. (72)

What are the disadvantages in using skeletal means of identification? Principally they involve three basic issues namely: absence of appropriate antemortem data, bone is a metabolically active tissue, and animal scavenging or commingling of remains. Other than commingling and animal scavenging, bone is reasonably stable. Holland (1989) noted that the average change from wet to burned bone is less than 1 %. (73) He also noted that a change of 1 % is less than intra-observer error and that low temperature burning- such as an average house fire - does not significantly impair the accuracy of skeletal identification techniques. (73)

Although bone is metabolically active Lynnerup (1990) stated that after youth, the age-related changes in trabecular bone structure proceed at a slower rate and then possibly accelerate in very old age. (70)

Antemortem data acquisition may be a problem since long term storage of medical radiographs is time-consuming and expensive. The author has undertaken identification using skull radiographs using microfiche records of antemortem radiographs. (Figure 7) There is little doubt however that dental radiographs are more readily available than medical radiographs, at least in the authors jurisdiction.

Animal scavenging and purposeful disarticulation of the skeleton by humans have both been reported. (52, 74) With regards to animal scavenging, Haglund (1989) report that it is dependent on at least four factors:the presence of human population in the area, circumstances which may protect the remains from scavengers (ie burial), position of the remains, and cause of death. (74) One must also be aware that different scavenging species are present at different times of the year and exhibit differing behaviours. (74) The amount of food available may also influence scavenging behaviour. (74) Animals may use human remains for shelter, food, or as a source of nesting material. (75) Animals may scatter remains as may humans, with remains being distant from the site of death by as much as one eighth of a mile (animal) to 185 miles (human). (52) It is likely that such dispersed bones would be outside a normal search perimeter. (52) Finally, certain body parts are less likely to be recovered such as those in current-driven water and hands and feet from heavily canid-scavenged remains.(52)

The author has personally observed amputation of the exposed hands by the common snapping turtle ( _Chelydra serpentina_ ) in a cadaver that had been submerged in fresh water for over one year.

**Serological identification**

The use of serological techniques (excluding DNA) is not, in Canada proof of identification. Many multi-disciplinary identification teams use and record serological data but few use it as definitive proof of identification. (8, 76) It may, however be used as a platform for further identification studies and as we will see below provide material for DNA analysis.



A B O (H) blood-group antigens are present in dental tissue although only dental pulp can be grouped correctly using elution techniques. (77) Heat diffusion through enamel and dentin reveal them to be poor insulators and in fires where temperatures are high, only teeth well-protected by soft tissues of the face and tongue may provide stable material for evaluation. (77)The thermostability of ABO blood-group antigens in human dental pulp has been described by Korszun (1978) as have the ability of the enamel and dentin to protect the ABO(H) antigens from thermal damage. (77)

Sharma and Chattopadhyay (1993) examined paired human teeth and fresh blood samples for numerous genetic markers. They discovered that the ABO blood groups could be determined from dentin, pulp, and cementum samples whereas only dental pulp could be typed for different isoenzymes.(78) Further serological studies on the persistence of these genetic markers in teeth stored at room temperature showed that ABO blood groups were the most stable. (78) Studies on tissue exposed to soil ( and therefore soil fungi ) revealed that blood group specificity may be lost as a direct consequence of such exposure. (79)

**Deoxyribonucleic acid (DNA) analysis for identification**

Any attempt to write about the analysis of DNA as a means of identification is complicated by the rapid advancements in technology in this area. In 1993 Fregeau and Fourney stated that "human identification through DNA analysis has faced tremendous changes in the past seven years." (80) The trend continues as DNA analysis enters the public lexicon and continues in a dynamic state through technical improvement.



With respect to DNA as a means of identification, the onus is on scientists to demonstrate the reliability, accuracy, and relevance of DNA profiling so that there is no exaggeration of its utility or potential. (81) The scientist must also convey the information regarding the technique in a manner that is understandable by the trier of fact. (81)

The foundation for the concept of unique human DNA lengths was established with the hallmark observation by Wyman and White (1980) of a polymorphic DNA locus characterised by a variable-length restriction fragment length polymorphisms (RFLP) (82) Polymorphism, ie the character of occurring in several different forms is a feature of

DNA throughout the human genome and differences in DNA are the ultimate basis of the protein differences between people. (83)

With respect to identification, if the DNA fragment profiles from two specimens are identical, the samples are, with very high probability, from the same source. (82) Having said that, according to Hegele (1989) the establishment of a persons identity with a high degree of probability may require simultaneous typing of several (sometimes 20 or more) proteins. (83) To increase the efficiency and power of identification, the use of highly polymorphic loci is necessary. (83) When considering all trios of five loci in the FBI database, there was only a single match observed out of more than 7.6 million comparisons. If independence is assumed, the probability of a five locus match ranged from 1.32 X 10 ^ -12 th in southeast Hispanics to 5.59 X 10 ^ -14th in Blacks, implying that the minimum number of possible patterns for each ethnic group is several orders of magnitude greater than their corresponding population sizes in the United States. (4)



Definitive blood grouping is now possible using DNA analysis methods. Previously, a battery of polymorphic protein and blood group marker systems were used to assess blood groups. (84) This created a problem in matters such as rape where bodily fluids of victim and suspect may be mixed. (84)

Initially, fragments from a particular DNA region can be identified by probing size-separated and fixed DNA with specific radiolabelled DNA probes. The pattern of fragments on electrophoresis can then be observed on radiographic film. (83) Differences detected using this electrophoretic technique are termed restriction fragment length polymorphisms (RFLP's). (83) Following the advent of RFLP's came the discovery of gene amplification using *thermus aquaticus* polymerase chain reaction (PCR). (83) Polymerase chain reaction involves dissociating the DNA into single strands by incubation at temperatures near 94 degrees Celsius. The temperature is then lowered to allow oligonucleotide primers to bind to their complementary sequences. After this, a DNA polymerase extends the primers across the region between two primer-binding sites using the target sequence as the template. (85) This allows exceedingly small amounts of DNA to be used for analysis. (83) The whole procedure has also been streamlined with the use of automated real-time analysis and DNA profile bank systems. (80) Furthermore, PCR has made it possible to evaluate identity from hair bulbs, white blood cells, dental pulp, or semen.(82, 86) The use of PCR has allowed for definitive kinship to be established (or more readily ruled-out) in cases involving paternity, immigration, human forensic science, and family relationship analysis. (81, 82) It has also been used in diagnostic medicine, animal and plant science and wildlife forensic science including the prevention of poaching. (82)

The advantages of using DNA for identification are clear and include: its application to all body tissues, its greater discriminatory potential, high sensitivity and specificity, long life of samples, and application to commingled specimens. (87) Weedn and Roby (1993) reported that DNA based evidence had been accepted in 756 cases in the United States prior to August 15, 1992 and in addition was used as an investigative tool in 10,000 cases. (87)

One might ask the reason for using any other technique (other than DNA) to prove identity. Probably the most important problem in using DNA as a sole source of identification is the veracity of the collection methods of the substance. Just because a body fluid is present does not mean that the person was present. (88)

What are the problems with DNA analysis ? The first problems are logistical and not related to the technique itself. They include cost and time for the procedure to be undertaken. The age and state of the sample may not contain usable DNA and the technique requires a high level of expertise. (81) Incinerated and buried remains may not contain adequate DNA for analysis as may the condition of a tooth if dental pulp is to be used. (81, 89).

Secondary problems may also render DNA analysis problematic and include preservation, transportation, correct use of statistics, sample mixing in the field, introduction of operator DNA into the field or contamination of other PCR products or other amplification sources. (85, 90) Most of these can be easily overcome by solid laboratory practice. (85)

A competent defence attorney may also attempt to have the DNA "chain of evidence" examined or attempt to cast doubt on the objectivity of the laboratory system. (90)



Although DNA analysis is, at the time of writing on the leading edge of identification procedures, in the authors opinion it seems unlikely to completely replace dental identification because the latter technique is easier, cheaper and gives an absolute yes or no in cases of identification rather than a probability of identification.

**Facial reconstruction /comparison for identification.**

On occasion, skeletal remains are found in which there are no clues which may lead investigators to a possible identity. If there is no antemortem material available for an antemortem to postmortem comparative identification, one may have to use reconstructive methods. One of these reconstructive methods is facial reconstruction. In using facial reconstructive methods, the forensic scientist is not attempting to make an identification per se but rather elicit "possibles" via presentation of the reconstruction to the public. (91) At times it has been quite useless in the identification process (92) and in other cases has been remarkably efficacious in the identification procedures.(93) Perper (1988) noted that "there is always a lingering doubt that the portrait or photograph may correspond to more than a single matching skull and vice versa." (94)

According to Brown (1983) the principle of identification of skulls by reference to portraits of known persons was used in Germany by Hermann Welcker.(95) Since then, reconstruction of facial features on the human skull for identification purposes has taken one of two forms. The premise of all facial reconstruction was best delineated by Dong-Sheng (1989) who stated that "the skull is the parent of the face and there exists a close relationship of identity and exclusiveness between the face and skull."(96) Facial reconstruction has been either two-dimensional, utilising photographic or artistic rendering, or three-dimensional sculpting techniques. (97) Many others have used two- or three-dimensional image production in conjunction with computer assisted image manipulation. (97, 98) Superimposition, defined as "to lay or impose on something else"(99) between various antemortem and postmortem media may be used for facial reconstruction. Such superimpositions may use radiographs, photographs, direct anthropomorphic comparisons, video-captured images, digital images, computer-generated "wire mesh" images or projected images. (31, 91, 93, 94, 97, 99-104)

If a skull is found and cranial superimposition is contemplated it is prudent to remove the soft tissue from the skull should any remain. (94) This may be accomplished by boiling the skull in a 2 to 1 ratio of water and chlorine bleach for 1 to 2 hours or until the tissue is sufficiently friable to allow its removal. (94) If radiographs are to be exposed they are done after the cleaning procedure. Radiographs which may prove useful include antero-posterior, lateral and occipito-mental projections. (94)

Thomas (1986) described a case in which a simple method of superimposing a black and white passport photograph onto a skull was used. (102) They obtained the passport photograph and made a life size print of it. The mandible was fixed to the cranium and the eye sockets were whited out so that shadows of the eye sockets would not mask the images of the eyes. They photographed the skull on transparency film from six different angles in accordance with the observed angles on the passport photographs. Following this, the print of the skull was fixed to a vertical surface and the facial photograph was projected onto the print of the skull. (102) Although the technique was simple it allowed comparisons of hard and soft tissue relationships. (102) Other simple methods include those of Brown (1983) who superimposed tracing overlays of life-sized photographic enlargements from selected photographic portraits onto outlines of the skull. (95) Tracings of dental landmarks may also be used to assist in comparison of antemortem and postmortem photographs. (100) The image of teeth in smiling portrait photographs may be used to provide the appropriate scale for proper scaling of the antemortem image since they are dimensionally stable in de-fleshed remains. (101) If they are used they must be in a similar orientation between antemortem and postmortem with respect to angle of view.(101) Antemortem and postmortem photographs may also be superimposed using video-camera split-screen techniques. (31) Evenhouse (1992) described a technique in which an image of a person with "average facial features" was superimposed onto a skull in the hopes that the skull would have enough influence on the facial features to yield a useful outcome. (97) These routines allowed generalised facial features to be manipulated to conform to the size and shape of a specific skull. Subtle alterations of the surface form, texture and colour based on age gender and race enhance the individuality of the generated facial form.(97)

McKenna (1985) listed six different levels of confidence in analysing the degree of matching between antemortem and postmortem photograph /skull superimpositions. They are as follows: 1. unequivocal identification, 2. definite exclusion, 3. highly probable identification, 4. consistent but equivocal, 5. inconsistent with but equivocal, and 6. impossible to identify. (101)

It is very important that persons undertaking photographic superimposition realise that it is not a form of scientific identification. There are numerous problems inherent in the technique and the means by which it is carried out. These are listed in table II.

**Table II Problems associated with using facial photographic superimposition as a means of body identification** (81, 94, 99)

1. Angular positioning of the skull and facial regions
2. Scaling factors between antemortem and postmortem images.
3. Camera distortion for both antemortem and postmortem images
4. Projector distortion for antemortem and postmortem images
5. Poor quality of the antemortem photographs.
6. Variance in depths of the facial soft tissues.
7. Inherent biases which may be present in the viewer.
8. Degree of experience of the operator.
9. Differences in head posture between antemortem and postmortem.
10. Differences in the size of the film negative.
11. Conversion of the negative image to print form
12. Exposure factors from negative to print copies.
13. Subject factors such as expression, flexion, torsion etcetera.
14. Time interval changes between antemortem and postmortem.
15. Postmortem changes or damage to the skull.

Systematic approaches with standardised photographic equipment and attempts at standardised head positioning have been published.(30, 104) Despite these efforts, photographic identification via superimposition has resulted in misidentification (99)

Computers have proven useful in aiding facial superimposition techniques. The use of computer photographic software has many advantages over the use of actual photographs including the following:1 . It eliminates the need for photography prior to reproduction; 2. It allows components to be added directly to cranial features; 3. It increases interaction and communication between the artist and the anthropologist in adding facial components; 4. "Cutaway" features allow the underlying skeletal structure to be viewed below the soft tissue reproduction to check its accuracy; 5. The size and proportion of the reproduction can quickly be adjusted electronically.; 6. Various versions can easily be stored and reproduced for comparison; and 7. The soft tissue reproduction can be partially removed at various points to view its matching with the skeletal structure. (91) There are highly sophisticated computer assisted software programs available for forensic analysis cited in the literature but a full description of these techniques is beyond the scope of this thesis. (31, 91, 103) A typical example of a computer set-up for facial or other soft tissue superimpositions is visible in Figure 8.

One area in which photographic superimposition in conjunction with computer assistance has showed promise is the area of erasure of mutilating injuries for presentation of cases to the public. Perper (1992) described a case in which a computer paint program was used to "clean up" a mutilated case to a degree that would be acceptable for public view. The process took one and one half hours and led to a search for antemortem materials and subsequent identification of the individual via comparison of antemortem and postmortem dental data. (93)

Figure 8. Photograph of a digitising set-up At right is the x-ray scanner, at the left the monitor and the keyboard and the CPU and output device are between these two. The example on the computer video display terminal (VDT) is that of a human bite mark on a thumb.



**<u>Dental methods of identification:</u>**

**Historical aspects of dental identification**

In 1897 Amoedo (1897) assisted in the identification of 126 victims of a fire in a Paris bazaar. The victims were incinerated beyond recognition in less than 10 minutes. (105) At that time in France it took 30 years absence before complete control of the estate could be exercised by the heirs, so identification of the deceased was of paramount importance. Amoedo used dental means to identify many of the deceased. He also noted that a misidentification of a Madame Haussman had occurred which may have been avoided had dental information been utilised. (105) In undertaking this task, Amoedo became the first to apply comparative identification techniques using dental means to mass disaster identification. (105) Amoedo suggested that "in necessary cases an expert dentist shall be named for the examination of the dental system." (105)

While Amoedo (1897) is frequently credited with being the first to use comparative dental techniques for positive identification he was preceded in this effort by Reid in 1884 who stated that " ... in several instances the medico-legal evidence has been at fault, and a verdict of mistaken identity followed a lengthened and carefully conducted trial, I have failed in finding a record of any instance where the proof of identity, as brought out by the aid of dental science has been set at naught." (106) It is interesting to note that both Amoedo in 1897 and Reid in 1884 undertook comparisons before the advent of routine dental radiographic techniques. (105, 106) Indeed if we examine the literature carefully we can find the rudiments of dental identification dating back to the fifteenth century. Claxton (1989) reports on the identification of the death of the Earl of Shrewsbury by virtue of a missing tooth and the death of the Duke of Burgundy ( on the basis of two lost teeth). (107) Baker (1982) predates Claxton's documentation of dental identification in his description of the identification of the slain mistress of Emperor Claudius of Rome. (108)

In Canada, the Noronic disaster marked the first time that dental means were utilised in an attempt to identify the deceased. In the Noronic disaster 118 bodies were found and only 1 body (with the exception of those who drowned) had identifiable facial features. Over forty dentists took part in the process which had good results. Twenty persons were identified using dental records alone and a further 39 person identifications was assisted using dental comparative means. (29) Unfortunately, in 47 cases, insufficient antemortem charting evidence or postmortem materials did not allow comparative identification techniques to be undertaken. (29)

**Dental identification using chart and clinical evaluations**

Dental identification of the infamous and noteworthy based on analysis of antemortem charting and clinical evaluation has been described previously. Adolf Hitler, Josef Mengele and Martin Borrman were all identified based on analysis of dental records and examinations. (109, 110) Beale (1991) noted that when antemortem and postmortem records are available, identification rates exceeding 65 per cent are not uncommon in cases of mass disaster. (26)

Assuming antemortem and postmortem dental chart records are available, careful comparison must be made with special reference to the differences between the two records. A decision must then be made as to whether an identification may be made. (111) Dental characteristics form an excellent basis for identification because teeth and jaws provide a vast number of individualising or “accidental” characteristics and are highly resistant to postmortem change. (11,13)

The decision as to whether to assign identity is based on the uniqueness of the particular dental profile of that individual.(11)

Keiser-Nielsen (1980) described the mathematical combinations possible in a given dentition based on the number of missing teeth from a compliment of 32 teeth. (47) As the number of missing and decayed teeth increases so does the number of possible combinations and hence the likelihood of individuality. (47). Fellingham (1984) pointed out the inherent problem with the logic of a mathematical description of missing teeth as a basis for identity. (24) Keiser-Nielsen's logic in this regard assumes that dental characteristics are uniformly distributed through a population. (24) Any general dental practitioner intuitively knows that this is not the case in a clinical situation. Some teeth such as third molar teeth are more likely to be missing than lower cuspid teeth. In addition some people purposefully extract teeth for adornment or functional purposes. (38) The second reason that a mathematical approach to the concept of dental individuality is flawed is that it assumes that events relating to a particular tooth (as in for example interproximal caries) occur independent of those relating to any other tooth. (24)



In Fellingham's (1984) investigation of actual cases 2 identical pairs and 1 identical triplet were present in an examination of the charts of 178 adolescents aged 15 - 19 years. (24) Other similar investigations revealed about 4 per cent of dental records may have duplicates. (24)

Charts may be particularly useful for exclusion of possibles. For instance if a tooth is present in the post mortem chart but absent in the antemortem chart then there is an exclusion.(28) Similarly if a restoration is present antemortem and a tooth is unrestored post mortem an exclusion may be made with certainty. (28) Generally if a feature is absent in both antemortem and postmortem records this is a match but not as good a match as if a feature is present in both antemortem and postmortem. (28)

With respect to obtaining records, it is not the usual responsibility of the forensic dentist to obtain antemortem dental records. (19) The forensic dentist may, however, assist the authorities in providing means for the search for records however. (19) In this search for antemortem records, one should consider such things as former military service, known previous dentists, hospital admissions, attendance as a patient at a dental school, insurance or welfare records, or incarceration in an orphanage, or prison. (19) It is the responsibility of the forensic dentist to accurately chart the postmortem dentition and this may necessitate the removal of the jaws. (112) This should only be done with the authority of the Coroner and examining forensic pathologist. (26) It is also the responsibility of the forensic dentist to interpret the antemortem records which may be daunting in light of the huge number of notation systems currently in use. (19) Once the antemortem and postmortem records are obtained and interpreted, it is prudent to record their findings on colour-coded antemortem and postmortem charts. (113) If there are a large number of cadavers to chart, some have used 3 man teams who rotate their responsibilities and check each others work. (114)

With regards to the contents of the chart the question may be asked what kinds of things should be examined and recorded in the antemortem record? The answer is clear. Everything which may be pertinent or helpful in an identification situation should be provided. Frequently clinical features without relevance are not recorded in a routine dental chart but some of the features which may be of assistance are summarised in Table III.

**Table III Clinical features found in the oral cavity which may be of assistance in dental identification** (3, 26, 27, 41, 115-117)

- Number of teeth present
- Shape of teeth present
- Class or type of occlusion / malocclusion
- Presence of diastemas
- Shape and number of roots
- Sites of fluorosis
- Sites of subsurface decalcification
- Peculiarities of jaw anatomy
- Shape and position of restorations and materials used
- Location of carious lesions
- Unerupted and impacted teeth
- Retained root fragments
- Evidence of endodontic treatment
- Areas of bone pathoses
- Intrinsic staining
- Dental anomalies
- Fragments of restorations
- Overhanging or deficient margins
- Periodontal bone loss
- Pattern of restorations themselves
- Rotations and tipped teeth
- Foreign bodies
- Dentures, denture materials and moulds
- Orthodontic treatment records including models
- Photography of the dentition
- Special features of restorations which may establish ethnicity



Generally, the more information recorded on antemortem dental charts the greater the probability of identifying remains which may share similar characteristics. (116) As early as 1952 Grant and coworkers stated that "it is important for dentists to chart missing, malplaced and rotated teeth, under or unerupted teeth and other features at the first visit." (29) Rarely have forensic workers described antemortem records assembled for the purpose of identification as being of good quality although this has been reported. (118) Levine (1991) noted that accurate charting by dental personnel can be one of the most important tools in proper identification of an individual. (27) This is important since in cases where bodies need to be identified using scientific comparative methods, dental charts constitute the most readily available records. (26)

Samis (1975) pointed out several potential problems in the dental identification of deceased using chart comparison methods. (119) Securing antemortem records may prove difficult as may interpreting the multiplicity of charting systems. (119) Antemortem records are frequently inaccurate and not current. (119) Blair (1964) noted that antemortem dental records received from practitioners were appallingly incomplete and that some practitioners provided only a synopsis of their treatment rather than full records. (44) Most failed to record the clinical dental features at the time of presentation and subsequently failed to record their own work. (44) It seems that charting errors still remain a common problem today. (25) Some patients are charted under an incorrect name while others have more than one chart. (120) Even when complete dental records are located, they may be years out of date.(92) The transmission of these records may be time-consuming and personal mobility in today's society may lead to difficulties in securing antemortem records. (119) A simple error consisting of failing to label right and left in copies of radiographs can render radiographic identification impossible. (92) In some cases even when dental records are present, their compilation was undertaken by police personnel and not dentists. (92)

On the post mortem side, the preparation of port mortem records is unpleasant and difficult, this being particularly complicated in macerated or decayed remains. (119) In an examination of serial murder victims if more than one record existed, there was a tendency for investigative agencies to acquire only one of several sets of records. (92)

Errors in charting, in either incoming antemortem data or post mortem data obtained from examination of the deceased are common. In a study undertaken by Sand (1994) examination of the accuracy of dental registrations in forensic odontology among dental students and dentists was undertaken. (121) They found that the most common error in registration for dentists was incorrect charting of restorations whereas students erred more frequently in charting missing teeth correctly. (121) They suggested that forensic dental work be undertaken by specialists in the field. (121)

Frequently family members and police services wish to circulate copies of the dental chart of a missing person or a recovered unknown body. In the authors experience this rarely results in a identification. According to Siegel et al (1977) "the circularisation of records is almost always futile". Equally useless in terms of its identifying "power" is the idea that dentists can recognise their own work. In a study undertaken by Ireland and Carr (1990) dental students and dentists were assessed for their ability to recognise their own work. (122) In their study, identical teeth and manikins were used with the only difference being restoration patterns. They postulated that the length of time spent placing the work and its difficulty as well as the interval of time between viewings were important variables to consider.

(122) They concluded that the reliability of this as a means of identification was quite low. (122)

## Charting notation and methodology

In 1883 Cunningham suggested a method of dental notation be adopted to facilitate communication. (123) Early systems of dental notation included those of Haderup (1902) (124) and Palmer (1870) (125). Since then, over 150 charting methods have been in regular use in the United States alone. (19) Some of these nomenclature systems are adaptable to forensic dental situations and some are so complex as to render them, in the authors opinion, practically useless. (126) Interestingly the "Universal" system currently used in the United States is not universal. (19) In 1932 the Federation Dentaire International (F.D.I.) promoted the use of the two digit system in the description of the dentition. (127) Sandham (1983) reported that the F.D.I. notation system has been adopted by the World Health Organisation, INTERPOL, the International Association of Dental Research, the International Organisation for Standardisation I.S.O., and the American Dental Association (A.D.A.). It is currently used in both the Republic of South Africa and Canada. (128) Despite this apparent wide acceptance of common notation systems Mertz (1977) thought that is was unlikely that the world dental profession and various police forces would ever agree on the use of a universal forensic dental chart. The forensic dental community must however strive to reach the aspirations of Amoedo who in 1897 stated "... ultimate goal it is therefore necessary that the charts taken by any dentist should be understood by all the dental confraternity. These desirable results can only be obtained when a uniform nomenclature is adopted by the dentists of all countries." (105)

Compounding the problem of a lack of uniformity in nomenclature systems is the problem of charting accuracy. Mertz stated in 1977 that "only rarely does one find a perfect match of the antemortem and postmortem records, simply because dentists may overlook some restoration or structure, or most commonly only chart the existing caries and those restorations which they personally perform." (19)

Cottone (1982) noted that many dental charts are simply financial records and are both incomplete and lacking in objective evidence which might be found in radiographic records. (46) Hampl (1991) described the maintenance of dental charts in the United States as poor. (129) He noted that dates, teeth and tooth surfaces are often inaccurately charted with abbreviation systems being used which may be peculiar to individual offices. (129) In analyses of chart errors in Great Britain Prinz (1993) noted that errors were found in 45 per cent of a sample of 50 records. (28) He proposed an error-tolerant algorithm to allow some of the more common errors to be taken into account when undertaking identification. (28) From the lack of common nomenclature and the inadequate accuracy of dental chart records (should they exist) it may be inferred that dental charts may not be the most reliable method of dental identification.

**Computer assisted dental identification**

The United States National centre for missing and exploited children estimated that 1,500,000 children are missing from their homes each year in the United States. (76) Fierro (1984) also noted that 1,450 to

2,000 decedents remained unidentified in Coroner's and Medical examiners offices in the US in 1978 (76) The magnitude of this problem begs for a solution and a national or even international computerised identification data bank becomes an attractive possibility.

Whittaker (1990) noted that it is very important that the postmortem data acquired from a body or bodies and the antemortem data must be compared systematically by an experienced forensic dentist. (111) He also offered a caveat with respect to computer search programs making it quite clear that computer comparisons should not result in identification but only provide the forensic dentist with candidates for specific comparative identification. (111)

Kogon et al (1974) listed eleven "rules" for use of computers in the dental identification process in mass disasters. These are listed below in table IV. (12)

**Table IV Guidelines for use of computer-assisted dental identification in cases of mass disaster.(12)**

1. The computer should store antemortem dental information concerning missing and filled teeth.

2. The computer should store additional information which might subsequently be used for comparison : age, gender, presence of endodontic treatment, gold restorations, replacement of missing teeth, and any unusual abnormalities.

3. The program should allow for quick retrieval of this information in a form which can be used by a dentist.

4. The program should allow for the reception of postmortem dental data and comparison of this information with all antemortem records on the basis of teeth present and teeth filled.

5. A list should be printed which would contain all the possible matches after eliminating all antemortem records that did not match.

6. The program should be able to recognise that dental treatment might have been carried out after the last available antemortem record was established.

7. The program should be able to search all antemortem records for any combination of characteristics that the dental investigator might desire.

8. The program should reject the possibility of any two specimens being from the same person if the two overlap in the description of the teeth which are found.

9. The program should be user oriented.

10. The hardware should be sufficiently portable so that the system could be used in remote locations.

11. The use of the program should result in considerable saving of time spent in comparison and an increase in the efficiency of storage and retrieval of information.

Computers are not always useful in mass disaster identification and are useless in some cases. (92) In a comparison of computer versus non-computer identification in an actual mass disaster situation, the computer-assisted method assisted identification in 79 specimen identifications as compared to 64 identifications and reduced the man-hours required for the identification from 492 to 310. (12)

Another problem with computer-assisted identification is the presence of errors in the antemortem records. (28) Allowing for error-tolerant algorithms presents a major problem for computer programs. (28) Additional errors may also be introduced in the transposition of the antemortem records obtained from the dentist onto the antemortem mass disaster form. (28)

There are many computer programs currently in use for both screening as well as in cases of mass disasters. Solheim (1982) described a computer system for use in dental identification (Nova*status) which, although not as specific as the CAPMI system has proven useful. (130) Keiser-Nielsen (1983) designed a comparison system using computer comparisons which used a multiple digit system coding for dental units and restorations. (131)

The United States military has developed a sophisticated, highly detailed computer assisted post mortem identification system (CAPMI) which allows 35 combinations of restored surfaces for 32 possible teeth. Each comparison made is either a match, mismatch or a possible match. (132) The system allows for the recording of unique or near singular anatomic features as well as tooth orientation. (132) A serious problem with CAPMI is that there is an inordinate amount of coding data which must be entered for each tooth. (25) CAPMI has 3 possible applications including analysis of a large ante mortem population of records and a small or large number of post mortem remains (a typical mass disaster situation); in cases where there is a large antemortem database and few post mortem remains (as for in example Vietnam veteran remains recovery); and where there is a small antemortem database and a large number of post mortem remains. (132)

CAPMI has its limitations in that it requires antemortem data which is accurate; it must be applied accurately, and computer capability must be available. (132) In addition CAPMI is not useful if an accident is small or only a few people are involved. (132) It must be recognised that although CAPMI has proven useful in mass disaster situations. (132, 133)

**Dental identification in mass disasters**

The first use of dental identification by Amoedo (1897) is described above and represents the first mass disaster in which dental identification was vital to victim identification. (105) In the time period 1966 to 1986, 600 air crashes occurred resulting in the loss of life of 18,000 lives. (10) Dental identification in such instances removes the need for en masse burial of people of different religions, and avoids the need visual identification which, as described above is difficult, unreliable and upsetting to relatives. (40) Kogon (1995) provided a summary of mass disaster identification results in many recent and non-recent aircraft and non-aircraft accidents. The result of this communication is represented in Table V .

**Table V Mass disasters and per cent dental identification. (134)**

| | |
|---|---|
| Chicago DC-10 | 80% |
| San Diego PSA | 90% |
| Polish Airline LOT | 98% |
| Canary Island | 75% |
| Tenerife (U.S. Citizens) | 68% |
| Guyana (Jim Jones) | 73% |
| Big Thompson Canyon Flood | 96% |
| New Orleans - Pan Am | 75% |
| NorthWest # 255 - Detroit | 83% |
| Waco Texas | 87% |
| J.F.K., 1975 | 48% |
| Bechman, 1974 | 59% |
| Hafnia, 1973 | 13% |
| Luntz and Luntz, 1972 | 89% |
| Ashley, 1972 | 70% |
| Ashley, 1972 | 10% |
| Waaler, 1972 | 6% |
| Petersen & Kogon, 1971 | 49% |
| van Wyk, 1967 | 58% |
| Boone Ky, 1967 | 28% |
| Harmeling, 1966 | 78% |
| Stevens and Tarleton, 1966 | 10% |
| Fisher, 1963 | 4% |
| Salley (2), 1963 | 49% |
| Keiser-Neilsen - 1963 | 24% |
| Honolulu - 1962 | 52% |
| Moose Jaw, 1954 | 7% |
| Teare, 1951 | 11% |
| Noronic Disaster | 20% |



If dental identification is used in mass disaster situations, extreme thoroughness is an absolute necessity. (45) Mass disasters often occur in unusual physical situations. Examinations made under difficult or primitive conditions must, if anything be thorough. (45) Morlang (1986) who has personally participated in numerous mass disaster situations associated with large numbers of victims states, with respect to mass disaster dental identification, that " success equals teamwork." (135) He proposed that a multi-disciplinary disaster identification centre with a forensic sciences processing line is an effective means of identification of large numbers of human remains. (135) Morlang (1986) describes the typical prototype dental identification section and lists the equipment necessary for identification to be carried out. (135) Solheim (1982) strongly suggested that every country have a disaster identification team with experts placed under the direction of one team leader with each member empowered to ask for the cooperation of experts as they see fit. (130)

At the site of an actual mass disaster, the processing of remains most often takes on a multi-station, assembly-line approach. (43, 135) Full autopsies may be performed and forensic dentists may be expected to undertake complete clinical and radiographic examinations in addition to excising the jaws for examination. (43) In one mass disaster a set of radiographs for an entire body took approximately 30 minutes, (43) whereas in another, the radiologist lagged behind the oral autopsies because of difficultly in obtaining adequate views. (136) Jakobsen (1974) estimated that one complete oral autopsy required approximately 3 man-hours of direct clinical examination and 2 further man-hours for a total of 5 man-hours per body. (136) In another study 12 dentists contributed 492 man-hours in the identification of a moderate-sized air crash involving 109 deceased. (137) Most often identification is made by direct comparative dental identification although age and race determination has been used in numerous cases as a means of identification, most often by exclusion. (138)

Numerous site-related and non site-related problems have arose during mass disaster dental identification procedures. At times there is insufficient amounts of post mortem material available for comparison purposes as in the Helderberg air crash reported by Ligthelm (1994). (139) Even if material is found for comparison to antemortem records, younger victims in one recent disaster had few restorations and it was difficult for forensic dentists to visualise cosmetic dental restorations. (140) In other cases such as the Lockerbie Pan Am crash, remains were spread over a large area, impacted into the earth, and associated with poor lighting. (140) Additional problems incurred at Lockerbie included harassment from the press, and the presence of aviation fuel which affected cadaver-locating tracker dogs. (140) High speed impact air crashes almost always cause commingling and in such cases some teeth may be lost from their sockets and found in the mouth or elsewhere. These teeth may have to be individually identified morphologically (44)

Other site-related problems include high temperatures at crash sites (52 degrees Celsius at one site) and the lack of good portable radiographic equipment. (141) Radiographic facilities at mass disaster sites may, of necessity be primitive as described by Frykholm (1973) in radiographic work at the Dubai air disaster which involved the use of a radio-isotope generator for x-ray production, self-contained film developing and the novel use of buckets for rinse water and string for the drying of radiographic films. (141)

In an ideal setting, antemortem records should be complete, accurate and contain enough quality dental radiographs to allow for proper identification. In practice this is not the case. Blair (1974), who analysed dental identification in the Kaimai air disaster stated that "without bitewing radiographs, many of the charts would have been useless." He also recognised the lack of denture markings and the difficulty dentists had in recognising their own work. (44) The importance of clear antemortem records cannot be overemphasised. (44) Even simple details such as transposition of first and last names as written on the chart can grossly interfere with the identification procedures. This is especially important in cases where individuals from other geographic areas and cultures are involved in an air crash. (142)

## Age/Gender/Race determination from the dentition

Age, gender, and race determination from the dentition must be considered as a reconstructive method of identification rather than a comparative one. Despite this limitation, age and gender assessment has been used in cases of mass disaster as described in the 6 cases reported by Haines (1973). (138) In such cases, age determination in particular may help to identify a subject by means of exclusion, especially in closed populations. (138) Ashley (1970) demonstrated the use of age determination in reconstructive identification in an air disaster involving Asian children.(42) Ashley (1970) suggested that removal of teeth which are commencing calcification or in which root formation is nearing completion provides the most rapid method of estimating dental age.(42)

The presence of a clinically evident neonatal line in the dentin may provide a means of age determination in the very young. This is done by assessing the amount of dentin visible in ground sections of deciduous teeth and assuming a rate of deposition of 4 microns per day. (143)

Later in childhood, tooth formation, emergence, and staging may be used to estimate the chronological age. Emergence is said to be influenced by environmental factors and may not be as useful as tooth development staging.(144) Miles stated that up to age 14 years, evaluation of tooth maturity may allow determination of age to within one year. Between age 14 and 20 the accuracy of such techniques diminishes and more reliance has to placed on third molar which is more variable in its time of development than other teeth (143) Moorrees (1963) described 6 stages of crown development, 6 stages of root development and 2 stages of apical development for multi-rooted teeth. (144) Moorrees (1963) and later Cottone (1982) developed tooth stage charts which are useful in the determination of chronological age from dental developmental features. (46, 144) After age 20 years the ability to use tooth stage of maturation is lost and forensic dentists frequently rely on other methods of age assessment based on regressive changes to the teeth associated with age. When intuitive methods of age determination was used in adults one author underestimated the age of skulls in persons over the age of 60-70 years. (143) Miles (1958) also noted that if the estimated dental and skeletal age matches closely then the subject is likely male whereas if the skeletal maturation exceeds the dental maturation then the subject is likely female. (143)

Gustafson (1950) examined the regressive changes to the dentition associated with age and deduced a formulation for age determination in the adult dentition which is still used. (145) The six main regressive changes he noted were attrition, periodontosis, secondary dentin formation, cementum deposition, presence of apical root resorption and root translucency. (145) The scores for assessment of ground sections of lower incisor teeth are depicted in table VI.

**Table VI Scoring method for age determination from ground sections of lower incisor teeth.** (145)

| | |
|---|---|
| Attrition | Ao no attrition,<br>A1 attrition in enamel,<br>A2 attrition reaching dentin,<br>A3 attrition reaching pulp |
| Periodontosis | Po no periodontosis,<br>P1 periodontosis just begun<br>P2 periodontosis past first one third of root,<br>P3 periodontosis past 2/3 of root. |
| Secondary dentin | So no secondary dentin visible<br>S1 secondary dentin in upper pulp cavity<br>S2 pulp cavity half filled with dentin<br>S3 pulp cavity nearly or wholly filled with dentin |
| Cementum | Co denotes normal layer of cementum<br>C1 is a little greater than normal<br>C2 denotes a great layer<br>C3 denotes a heavy layer of cementum |
| Resorption | Ro indicates no root resorption<br>R1 resorption in isolated spots<br>R2 resorption with a greater loss of substance<br>R3 resorption including cementum and dentin |
| Transparency | To transparency not present<br>T1 transparency noticeable<br>T2 transparency extending over apical 1/3 of root<br>T3 transparency extending over the apical 2/3 |



Bang and Ramm (1970) also observed that root dentin appeared to become transparent as age progressed and further noted that this transparency progressed from the apex of the tooth coronally. (146) Their study of 926 teeth harvested from persons of various age provided evidence that there were no gender differences, that the observation could be made without tooth sectioning and that the process was not altered by formalin storage. (146) Solheim (1984) simplified the ground-sectioning process by only grinding the teeth in half from either the buccal or lingual side stopping in the midpulpal area. (147) He found no real difference between the "half tooth technique" and thin sections advocated by others. (147) A disadvantage of relying on root translucency as the only criteria for age determination was the tendency to underestimate the age of older individuals and in 16 % of cases the roots were not evaluable. (146)

Kvaal (1994) utilised a non-destructive method of investigation of extracted human teeth for the purpose of age determination. (148) They measured the length of the apical translucent zone and the extent of periodontal retraction on teeth as well as the pulp length, pulp width, root length and root width They calculated the ratios between the root and pulp measurements. For all types of teeth, significant negative Pearson's correlation coefficients were found between the age and the ratios between the pulp and root width. The correlation between age and the length of the apical translucent zone was weaker than expected. The periodontal retraction was significantly correlated with age in maxillary premolars alone. Multiple regression analysis showed inclusion of the ratio between the measurements of the pulp and the root on the radiographs for all teeth; the length of the apical translucent zone in five types of teeth and periodontal retraction in only three types of teeth. The correlation coefficients ranged from r=0.48 to r= 0.90 between the chronological and the calculated age using the formulae from this multiple regression study. The strongest correlation coefficients were for premolars. (148)

The pathogenesis of the clinical appearance of translucency was elucidated by Moore (1974) who also noted that the translucency of dentin progresses apico-coronally. (149) In the translucent zones they found a higher concentration of lysine and hydroxylysine, less mineralisation, and progressive filling of the dentinal tubules with organic matter. (149)

Another change in the teeth which may allow aging of the individual was first observed in animal teeth. In many animal studies, paired dark and light bands occur in the cementum. The occurrence of these has been attributed to seasonal effects of nutrition, hormones, and growth status of the animal population.(150) Stott (1982) described three cases in which he said he could determine the age by counting the cemental annulations as viewed on the contact surfaces of the teeth.(151) They postulated that a determination of the number of cemental annulations in tandem with an accounting for the age at tooth eruption allowed for aging of a person. (151) Miller (1988) described the 350 micron thick cemental angulation present at the midpoint of the root and admitted they could be of use in age determination of wild animals. (152) In their comprehensive study of human teeth they noted that only 5.7 % of specimens of polished cross-sections through the midroot of undecalcified teeth allowed correct prediction of the chronological age (within 5 years).(152) Analysis of their data led them to conclude that determination of chronological age in humans from cemental annulation was not possible. (152) Prior to the publication by Miller (1988) (152) Lipsinic (1986) stated, with respect to age determination from cemental annulation that "one must seriously question their regular occurrence in the human population ..... considering the lack of seasonal variations in nutrition and the lack of active growth past the approximate age of 25."(150)

Evaluation of the extent of racemization of amino acids in proteins has also been postulated as a means of age determination from the teeth. (153)

Racemization of amino acids in proteins commences after protein metabolism ceases. Racemization of aspartic acid in bone is generally faster than other amino acids and plots of racemization versus time are linear. (153) Ogino (1985) in his study on racemization as an age-determinant, performed in-vitro studies and cautioned that the work does not take into account environmental stresses. (153) This area requires further exploration through scientific experimentation in order to determine its potential.

Gender differences in the dentition are not, in the authors opinion easy to determine in individual cases. It is generally appreciated by most dental practitioners that females tend to have a more "feminine" appearance to the dentition with smaller jaws, more rounded and curved dental line angles and smaller maxillary cuspid teeth. Unfortunately there seems to be a great deal of overlap between female and male dental traits. Anderson (1976) noted that the sexes differed substantially in the ages of mineralisation of teeth except with third molars at their latest stages of development. Female teeth tended to develop more rapidly. (154) In addition both genders showed high variability in the age of dental mineralisation making this possible determinant of gender impractical. (154) It has been stated that age determination is more accurate when gender is known.

With respect to race it must be stated that in some geographic locations race is an artificial societal construct with the boundaries between biological racial groups blurred through intermarriage as well as through changes in the semantics of racial classification. Despite this, Lasker (1957) did an extensive review of the various racial features present in the human dentition and concluded that there were marked differences in the frequency of numerous physical dental features between different racial groups. (155) Superimposed on the differences between major racial groups however, are significant differences between individuals and between local populations. (155) Furthermore the lack of distinct racial boundaries, large number of intermediate groups and increased rate of intermating, limit the value of forensic dental or any other kind of race classification.(155) Complicating things further is the statement by Dahlberg (1985) " unfortunately as far as we know, dental traits never come as a single gene trait- they are polygenic." (156)

Examination of the dentition for evaluation of dental traits should include an assessment of the following physical dental features: cusp size, cusp number and location; occlusal cusp-groove surface patterns; root systems; number and arrangements of teeth; individual tooth measurements; dimensional proportions between kinds of teeth; occlusal and bony relationships; nature of pulp chambers and canals; and microscopic tooth-surface characteristics. (156)

There are marked differences in frequency of various features between different racial groups. (155) Those of European descent show the highest frequencies of chisel-shaped incisors, Carabelli's cusp, reduced number of molar cusps and cynodont molars with bent and splayed roots. (155) Mongoloids show a high frequency and marked degree of shovel-shaped teeth, enamel extensions onto roots, enamel pearls, taurodont molars, wrinkled molar crowns, fused roots, and extra distolingual roots of mandibular molars. (155, 156) Negroes, Australians, and Melanesians show the least reduction in size and number of molar teeth. (155) American Indians and Eskimos are essentially like Asiatic Mongoloids in dental traits; (155) East Indian, Mediterranean, European, and American populations have smaller rounded incisors with smooth surfaces. (156)

The use of age, gender and race determination can at best be used as a reconstructive springboard in a search for dental or other records which may allow identification by scientific comparative means.

## Dental appliances in dental identification

Fixed and removable appliances can both be purposefully labelled at the time of their fabrication in a manner to facilitate post mortem identification. (157, 158)

Dimashkieh (1993) described a simple engraving instrument which could be used to write the surname, year of birth and gender of the patient on the metallic portion of a fixed appliance. He used a "+" plus sign as a symbol for women and an arrow for men. He also suggested using the mother tongue of the patient to assist in determining the country of origin. (158) Fixed appliances may be used in conjunction with either radiographic or chart-based dental identification in that they are a "fixed" part of the patient. Removable appliances however infrequently be demonstrated on dental radiographs or other permanent records. Denture-based identification is less likely than identification based on the dentition.(111) Partial dentures, and especially cast partial dentures contain more useful information about the putative identification in that they provide indirect evidence of the existing dentition at the time of death. (111) Orthodontic appliances such as retainers may also be used for the purpose of identification. (111)

Purposeful denture identification marking was mandatory in 9 states of the United States of America as of 1985 and is mandatory in Sweden. (51, 157) Haines (1967) reported both partial dentures and full dentures assisting in the identification of unknown deceased. These identifications were based on markings and characteristic laboratory techniques. (40) Others have been less enthusiastic about the utility of dentures and denture marking for identification. (137,157) Of eight air disasters involving 380 victims, 50 had complete dentures and 47 had partial dentures but only seven (7.2 %) of the dentures were marked with the victims name (157) The identification method may involve scratching the tissue surface of the denture with an identification number or name, processing with indelible ink, or placing the name of the denture on shimstock or tissue paper and processing it into the denture. (111, 119) If denture marking is contemplated it is important that the method obey the following criteria : it must not influence the strength of the denture, it must be simple, it must be protected, its bulk shouldn't interfere with denture construction, it should be readily visible and identifiable after long periods of time and it should be uncomplicated. (119, 159) In the authors opinion, it is unlikely that any denture marking system manages to obey all these important rules.

Others have suggested incorporating radio-opaque materials into denture base materials to render them visible on radiographs. It is also possible to analyse denture base material itself to get an idea of the age of a material or to spot repairs which may have been made to the denture thereby providing more individualising characteristics. (111) If the corpse is available the denture may be "tried in" to see if it fits or alternately a study model may be prepared from the corpse and the denture tried onto it. (111) Even the examination of the denture wear facets may yield information about the opposing dentition. (111) Conversely examination of the perikymata of the teeth may lead one to suspect that the unknown corpse was a denture wearer. (39)

The intrinsic properties of dentures may provide clues which, while not absolute means of comparative identification can yield important circumstantial information. Artificial teeth may have markings which can reveal their origin of manufacture. (157) Such trademarks, shade numbers, mould numbers and anatomical configurations can provide information about the manufacturer of a particular synthetic tooth. (160) Dorion (1975) described the different inscriptions on prosthetic teeth of different manufacture and also discusses the clinical and radiographic differences between porcelain and acrylic teeth. (160) He noted that acrylic teeth do not fluoresce under ultraviolet light whereas porcelain and vinyl teeth do. Porcelain is also harder and has a more "lively" colour. (160) Furthermore, the surface of porcelain teeth is granular when a small surface layer is removed. (160) Denture materials may also be used to deduce the temperature of fires as reported by Ligthelm (1984). (161) This is discussed further in the following section.



**Dental materials and tissues in fire victims.**

Fire is a silent killer that may expose the dentition and dental materials to temperatures at which their dimensional stability is lost. Purves (1975) describes an experimental house fire in which a two story house was consumed by fire in only 42 minutes. During this experiment the maximum temperature on the main floor was 1274 degrees C. and 232 degrees C. on the second floor. When the second floor collapsed onto the first floor the temperature within peaked at 1004 degrees C but dropped to 870 degrees C. 3 minutes later. (112) Purves (1975) postulated that one could determine the temperature of the fire based on what happens to the dentition and dental materials. (112)

Human teeth may become brittle at temperatures as low as 200 to 300 degrees C and become completely ashed at temperatures ranging from 500 to 600 degrees C. (162) The intensity of the heating and the rapidity of its application may influence the deleterious effects of heat on teeth. (161) If teeth are exposed to a gradual rise in temperature they remain intact up to a temperature of 1100 dg C. (161) Conversely if teeth are subjected to intense rapid heating they disintegrate immediately (161) Prior to ashing, they frequently develop cracks and may fragment partially or totally. (162) In actual fire situations however the dentition may remain largely intact due to the protective thick facial muscles, saliva, and tongue which act to insulate the teeth from fire damage. (112, 161) It follows that the teeth most frequently and severely damaged in high temperature fires are anterior teeth. (112) Maxillary and mandibular bone in the anterior and facial aspects of the arch are also destroyed prior to destruction of palatal or lingual aspects of the bone. (112)

Damage to enamel is mediated through heating of the dentin core, which, as it loses its water content may fragment or "pop" the enamel off. (10) Dentin is usually protected by enamel or bone but may develop multidirectional cracks, almost to the pulp at temperatures in excess of 400 degrees C. (10) In the authors experience, remains exposed to intense fire are likely to lose their coronal portions and therefore the restorations which would aid in their dental identification.

Amalgam restorations, which normally demonstrate excellent individualising characteristics for comparative dental identification are subject to heat damage which may render them forensically useless. Mercury is released from amalgam at 100 degrees C and boils at 356 degrees C. (10) The alloy powders into silver, tin, and copper-zinc complexes following the loss of mercury. (10) If mercury droplets are lost from amalgam and come to rest on gold-containing structures, these gold structures may be discoloured by the mercury, replacing the gold colouration with a silver one. (10) Between the temperatures of 500 and 1000 degrees C amalgam loses its dimensional integrity and colour. (10) Silver metal melts at 500 degrees C and tin melts at 231 degrees C. In essence, silver amalgam restorations are highly susceptible to moderate to severe heat damage. (10, 112) It must be noted however that even when the amalgam material is lost, the tooth may retain the cavity preparation form which may act as a clue to body identification. (112)



Other common metals used in dental restorative and prosthetic work generally withstand temperatures in excess of those that destroy amalgam.(112) Gold restorations and gold prostheses may melt at temperatures of 870 to 1070 degrees C. (10) Other denture metals endure temperatures over 1100 degrees C. (112) Botha (1986) noted that partial denture base metal alloys melted between 1275 and 1500 degrees C but exhibited tarnishing when exposed to 900 degree C. heat for 1.5 hours. (10) Metals used for ceramic fused to metal fixed prostheses or crowns have been used to calculate the temperature of fires. In one case described by Purves (1975), porcelain was lost from the restoration but the dental gold remained. Since porcelain melts at

1024 degrees C and dental ceramic gold at 1221 degrees C. the fire temperature would have been between these two temperatures. (112)

The fire resistance of other dental restorative materials have not been completely studied. Root canal restorations when heated, show filling defects when examined radiographically. These appear as radiolucent zones in the root. (10) Silver point endodontic filling material has a melting point of 960.5 deg C. (10) Retentive steel posts showed no change after heating to 815 degrees C for 1.5 hours. (10)

The stability of acrylic resins in fire is poor with melting taking place as low as 200 to 300 degrees C. (112) Polymethyl methacrylate denture bases and prosthetic teeth depolymerize to monomer at 450 deg. C. Such resins may burn at even lower temperatures if in direct contact with flame. (10) Porcelain denture teeth, in contradistinction to plastic ones did not suffer any damage when replaced into a crematorium furnace at 900 deg C for 1.5 hours(10)

The fire-resistance of composite resin restorative material is not well studied although Botha (1986) noted that some are very heat resistant. (10) In the authors opinion, studies should be undertaken analysing the heat resistance of aesthetic restorative materials at temperatures commonly found in various fire situations.

Handling of fire-victim remains must be undertaken in a systematic and delicate manner. (163) Great care must be taken not to destroy fragile portions of the teeth and jaws prior to their removal and examination. Small fragments are brittle and make reconstruction of the whole tooth difficult. (162)

It is, in the authors experience, easier and quicker to remove the stabilised jaws for examination and radiography. Purves (1975) has stated that "removal of the jaws is essential for accurate charting, radiographs, and photographs. (112) Mincer (1990) described the most popular methods of specimen stabilisation in a survey of stabilisation techniques in current use. These included impregnation with a solution of polyvinyl acetate and application of cyanoacrylate cement, respectively. Experimental investigation in vitro on incinerated extracted human teeth with commercially available preparations of cyanoacrylate cement, clear acrylic spray paint, hair spray, furniture varnish, clear fingernail polish, quick setting epoxy cement, Duco® household cement, polyvinyl acetate polymer in acetone, or self curing clear dental acrylic resin revealed that any of the aforementioned substances provided adequate stabilisation. Of these materials. (163) Mincer (1990) favoured clear acrylic spray paint as the most efficacious overall because of its handling characteristics and low cost. (163) Griffiths and Bellamy (1993) used cyanoacrylate for stabilisation of ashed remains. Bonding was achieved in 2 minutes and maximum strength was reached in 12 hours. (162) In instances where remains must be transported, they advocated placing the cyanoacrylate-stabilized dentition within a layer of bubble plastic within a soft cardboard packing material. (162) If the dentition was to be transported as part of the skull they recommended an additional foam band layer around the skull itself. (162)

**Special dental identification devices**

Numerous authors have suggested placement of some form of permanent record in the dentition which would assist in cases in which identification is an issue. Such materials encode some form of information about the bearer that would assist in identification.

Muhlemann in 1979 described a technique in which a gold disk is scribed with up to 13 characters which are readable with an 8 X hand lens. (164) This gold disk, which has a melting temperature of 1360 to 1480 degrees Celsius is placed within a tooth beneath a red glass filling material. (164) Muhlemann (1977) himself identified one problem with this system noting that dentists would have to retain a quantity of the red glass restorative material in order to place the encoded chip in a manner to make it visible to a postmortem viewer. (164) There are two other problems with this system which Muhlemann did not note. Firstly it would, in the authors opinion, be difficult to convince persons with sound teeth to have restorations placed solely for the purpose of postmortem identification. In addition, although the chip may not melt until a temperature of 1360 degrees Celsius is reached the teeth themselves may be damaged by temperatures as low as 400 degrees Celsius. (10) Finally, misplacement of a tooth due to commingling from high impact mass disaster type incidents (12) or accidental or purposeful actions of others (165) would not allow for identification of the body - only the single tooth in which the chip rests.



Prior to Muhlemann's work, Samis (1975) described a similar system in which an identifier pin was used to signal the presence of an identification plate in a tooth. The brass indicator indicates to the postmortem examiner the presence of the plate which lay beneath the restoration. (119) Again the pin is robust, being made of brass with a melting temperature of 1000 to 1110 degrees Fahrenheit and since it is placed within dentin itself it would be less likely to be lost as the enamel caps popped off of the underlying dentin. (119) However it could conceivably be mistaken for a retentive pin rendering its indicator value useless.

With regards to the incineration of indicator devices, Wilson (1982 & 1983) described a ceramic identification chip which allowed recording of personal data in a "Dentify" chip. This information was decipherable after *in-vitro* heat exposures as great as 1,000 degrees Celsius. (166, 167) The indicator pins used in this study were similar to those in the study undertaken by Samis (1975) (119) and were less resistant to heat damage. (166)

Gladfelter (1989) reported a less invasive method of attaching identification microdisks to the teeth in the form of acid etched, bonded microdisks. (168) After a 2 week period only 2 of the disks placed were legible. The remainder of the disks showed varying amounts of crazing, cracking or dissolution of the covering sealant. (168) In doing this work Gladfelter (1989) described the ideal properties of identification microdisks (Table VII).

**Table VII Ideal characteristics of identification microdisks** (168)



1. Small enough to be easily placed onto a tooth surface
2. Capable of withstanding an aviation fire for 1 hour.
3. Must remain in place for at least 4 years
4. Must be bonded in a standard location on a standard tooth
5. Should be tinted to facilitate postmortem recognition
6. Must be made from non-toxic materials.
7. Should be easy to place using standard bonding agents
8. Should be difficult to remove except by dentist
9. Should allow easy professional removal
10. Must not promote caries or periodontal disease
11. Must carry enough information to identify the wearer
12. Should be readable when in place in the mouth
13. Should be legible at 30 X magnification or less
14. Should withstand a pH range of 4 to 8 for extended periods

**Other means of dental identification:**

The science of cheiloscopy has been put forth as a means of comparative identification. (3, 157) It involves the evaluation of labial wrinkles and grooves (sulci laborium) which can be subdivided into eight different types. In a study of 1364 Japanese subjects Tsuchihashi (1974) noted that no two pairs of lip prints were the same. (5) He subdivided the types of lip prints into eight sub types for the purposes of classification but noted that even identical twins had different lip prints under careful examination. (5)

Examination of the rugae pattern of the palate has also been proposed as a possible means of identification. (157)

Kogon (1973) stated that men had greater development of the rugae pattern than women but each pattern was highly individualised. (169) Furthermore, rugae pattern, appears to be established early in life and the features return following surgery or trauma. (169) A photographic superimposition technique has been proposed to facilitate comparison between rugae patterns antemortem and postmortem. (169) Jacob in 1987 used palatal rugae pattern from dentures to evaluate the degree of matching and found that in a series of 14 trials the pattern could be evaluated correctly with 79 % accuracy. (170) Despite these findings he did not support "the effective use of maxillary dentures as a means of edentulous forensic science identification when the entire internal aspect of the denture is reproduced by means of a dental stone cast." (170) He noted five potential problems with using rugae as a means of identification. (170) These are depicted in Table VIII below.

**Table VIII Problems inherent in using palatal rugae comparison for identification purposes.** (170)

1. Evaluator inconsistency
2. Distortion during impression techniques
3. Post -fabrication denture adjustments
4. Use of palatal relief chambers
5. Variation from trauma and disease

So called "accidental" characteristics (unique and usually acquired individualising characteristics) of both the dental hard and oral soft tissues can be utilised for both reconstructive and comparative methods of undertaking identification. Thorough examination of the dentition of an unknown person may yield clues as to their occupation or habits during life. (Table IX) (38, 111).

**Table IX Dental and Oral characteristics which suggest antemortem acquired conditions of the teeth (38, 39, 111).**

| | |
|---|---|
| Straight pins | notching of anterior teeth |
| Thread biting | chipping of anterior teeth |
| Bobby-pin | notching of anterior teeth |
| Oral hygiene excesses | abrasion anterior surfaces of the front teeth in rural South African Blacks.-characteristic cervical abrasions along the buccal surfaces of teeth |
| Fluoride excess | fluorosis and mottling of enamel |
| Pipe smoking | notching of teeth in which pipe fits |
| Erosion | battery workers anterior teeth |
| Purposeful mutilation | maxillary incisor teeth in Cape Coloureds |
| Snuff dipping | mucosal recession |
| Smoking | hyperkeratosis, lip burning (in poor) |
| Betel quid | discolouration, fibrosis, carcinoma |
| Mental patients | chronic cheek and lip biting |
| Dilantin | gingival hyperplasia |
| Lead exposure | lead line in gingiva |
| Intraoral tattoos | may be intraoral |
| Racial pigmentation | may be intraoral |
| Amalgam | may be visible clinically or on radiographs |
| Perikymata change | may indicate prosthetic dental treatment |
| Neonatal changes | visible in enamel of developing teeth |
| Tetracycline use | visible in enamel of developing teeth |
| Nutritional deficiency | visible in enamel of developing teeth |
| Childhood fever | visible in developing teeth |

The timing of extractions may also be assessed using radiographic or histologic examination. van Wyk(1976) has proposed sectioning and microscopic examination of alveolar process bone as a means of evaluating the extent of socket repair and replacement by woven bone.(38)

Two other comparative / reconstructive methods of potential identification have been proposed in the literature. The physioprint and Sassouni analysis are methods in which the contours of the face at each level of depth are recorded. It is made by projecting a grid onto a face. The grid is projected from the front and photographed from the side. (37) "Sassouni analysis", not surprisingly named after its proponent, involves the recording of planes, arcs, vertical balance and teeth axes. By its very nature it is a proportional analysis and not a metric analysis. (37)

## Dental radiographic identification

Teeth and dental restorations are resistant to destruction by fire and maceration and are therefore very important in identification.(171) The process by which dental radiographs are used is simple.

The forensic odontologist utilises dental radiographs of the victim exposed before death and compares them to dental radiographic data from the remains to assist in body identification.(171)

In previous portions of this literature review we have seen how chart-recorded aspects of the dentition may be used, on their own to make a dental identification. This is particularly important in closed population dental identifications such as are seen in airline crashes. Chart similarities in and of themselves however may not be as unique as hypothesised. In 1963 Gustafson examined 775 children and discovered that 164 of these showed identical filling patterns when only tooth surfaces were considered. (172)

Radiographs do not lie. Nortjé (1986) stated that "the radiographic appearance of the teeth and of the bone of the face is a permanent record of these tissues, even when the teeth and sections of bone have to be removed for histopathologic examination." (18) Radiology can serve as one of the most objective types of information for evaluation of clinical treatment data and is considered definitive evidence in both malpractice litigation and cases of identification. (18,33) The use of dental radiographic evidence as a means of identification is also advantageous when compared to other identification methods because of the greater likelihood that objective antemortem dental evidence may be found. (33) Postmortem dental radiographic evidence may also be more readily obtained since even minute fragments that may be present from burned victims can be saved for radiologic examination. (157)

Radiographs showing the dentition aided in the identification of the remains of Adolf Hitler. Following the 1944 assassination attempt, X-ray plates of Hitler's head were found which revealed several characteristic dental conditions including a maxillary left central incisor with a radiopaque metallic restoration, a dental bridge in the right mandible and periodontal bone loss about the mandibular incisors. (173) Identification using restorative means is common. (40) There exist however numerous features evident on intraoral radiographs which should be assessed in the process of radiographic evaluation. These include bone marrow spaces, nutrient canals, incisive canals, median sutures, retained roots, impacted teeth, bony sclerosis, anatomic and non-anatomic radiolucencies and alveolar bone resorption. (174) The variability of this evidence with time must also be considered and the appropriate weight for each identification must take into account the amount of evidence available, the quality of the evidence, and the experience of the forensic scientist undertaking the effort. (165) In addition, the post mortem dental radiographs should be exposed in a manner which mimics the positioning and angulation of the antemortem ones as closely as possible if comparisons are to be made. (157) For example, the degree of periodontal bone resorption may be rendered difficult in intraoral radiographs if the antemortem and postmortem radiographs were exposed with different image geometry. (174) Borrman (1992) also noted that radiologists were "significantly superior to other specialists" and were "better able to evaluate the effect of projections differences and changes over time." (174)

Some have considered that dental radiographic comparison is of such value that mass screening radiography of patients be undertaken to provide a source of antemortem dental radiographic material. (175) Thorne (1953) proposed that children aged 1 to 6 and adults in dangerous occupations have cephalometric radiographs exposed to serve in a potential repository of antemortem radiographs. (176) In a study of 100 subjects with cephalometric skull radiographs exposed one month apart he was able to match the appropriate putative antemortem to the putative postmortem radiograph 100 per cent of the time. (176) Although the comparison between antemortem and postmortem radiographs does constitute an important basis for victim identification, (177) it is not appropriate to undertake any radiographic procedure unless there is measurable diagnostic benefit for the live patient. Despite the lack of antemortem radiographic data, if antemortem radiographs are available, the comparison between antemortem and postmortem dental radiographs constitute an important basis for victim identification. (177) Wenzel (1994) examined bitewings randomly sampled from a large population of adolescents. Subtraction images were performed of pairs of bitewings originating from the same individual (identical images) and from different individuals (non-identical images). The distribution of grey shades in subtraction images was used as the parameter for evaluation of homogeneity in the images. Subtraction images derived from highly similar radiographs were significantly more homogeneous than those derived from dissimilar images ($p < 0.001$) in both the group with and without restorations. (177) The time period between the putative antemortem and putative postmortem radiographs was 2 to 3 years and the authors digitally subtracted the "antemortem" and "postmortem" and examined a histogram of the grey scale distribution to see if there was homogeneity or not. (177) The technique is quantitative if one can hold the exposure factors of each radiograph the same and ensure that the radiographs cover the same geographic area.(177) Using this technique did not allow for identification per se since the homogeneity distributions overlapped. (177)

Occasionally postmortem evidence has been altered or damaged rendering dental radiographic identification difficult even in the presence of antemortem data. Smith (1992) described a non-traditional radiographic technique in which postmortem loss of teeth could be demonstrated if the bone was well preserved. (178) Smith (1992) stated that the "radiographic comparison of root structures is increasingly becoming a necessity, reflecting a general reduction in the number of victims with dental restorations."(178) Smith's (1992) procedure involved a 6 step procedure as follows: debridement of sockets; sealing of the sockets with cyanoacrylate; mixing of polyvinylsiloxane and barium powder; injection of the mixture into the extraction sites; exposure of radiographs of the specimen; and removal of the impressions of the sockets. (178) He did point out the problems with the technique.

These are the loss of the three-dimensional appearance of the roots, poor periapical sealant with cyanoacrylate; and incomplete root filling with the radiopaque media. (178)

**Reduction in caries rates:**

Despite the large numbers of possible antemortem and postmortem comparators available to the forensic odontologist, the comparison of dental restorations is the most commonly used, comparative scientific method of body identification. Direct, radiographically-visible materials are particularly useful in that they have "accidental characteristics" and may be of unique shape. A problem in identification arises in persons who have few restorations available for antemortem / postmortem comparison.

The decrease in caries rates is graphically illustrated in analyses of military and non-military persons in the United States of America. Graves (1985) noted that in the years 1863-64, loss of teeth was the fourth most frequent cause for rejection of young men for draft into the Union Army during the American civil war. (179) The problem of caries continued to improve with the advent of modern dentistry although by the 1920's more than half of teeth of males in the 20 to 24 years old age group had been affected by caries with this proportion increasing in the older age groups. (179) Alexander (1991) examined dental charting practices in the American Navy and found that the majority of military personnel "had no or very few restorations upon entry into active duty" (25) This reduction in caries was significant even when compared to similar studies of the same population in the time period 1969-1970. (25) Alexander (1991) suggested that this lack of restorations might simplify charting and reduce charting errors but would also render dental identification more difficult. (25)

The problem may be larger than that indicated by Alexander (1991) in that children in Western countries have experienced a dramatic reduction in caries levels (and therefore numbers of restorations) over the past 20 years. (180) In a study by Graves (1985) the diseased missing filled surfaces score (DMFS), an indicator of the uniqueness of the dentition had dropped from 7.06 to 4.77 between 1974 and 1980. (179) In addition, composite and glass ionomer dental materials are being used more frequently and they cast little or no radiographic shadow which presents a problem in identification. (181)

Graves (1985) stated that this would lead to "a much simpler restorative pattern than at present." (179) This is the exact opposite of what the forensic dentist needs in order to facilitate dental identification. Wenzel (1994) specifically noted that this lack of dental intervention would impede the successful identification of victims in the future. (177) In a population with an almost non-existent caries rate, dental identification will be of limited application in that postmortem identification can only be as good as the antemortem records. (142)

This impedance of identification has been reported in attempted postmortem identification. Even with the aid of posterior bitewing radiographs purposefully exposed in a manner so as to duplicate the antemortem ones it was impossible to state with certainty that a match had been made. (51) In this case, similarities could be seen with respect to the anatomic features but a conclusive match could not be made. (51) In laboratory investigations using groups of patients with and without restorations; difficulties in correct identification occurred in with greater frequency in the non-restored group. (181) Borrman (1990) did not use anatomical features but did suggest that comparison of structures such as pulp, root, spacing between teeth and bone marrow cavities might have reduced the number of errors. (181)

## Statement of the Purpose

Brown noted that "all research is costly and financial support for research in forensic odontology is not forthcoming because forensic odontology is not a lucrative, commercially-viable commodity but rather a community function with little, if any electoral significance." (182) Brown (1988) identified the need for two areas of research in forensic dentistry. The first was research aimed at developing and applying new and advanced technologies. The second area was research of a nature that will confirm existing data or produce new information that is valid within local, national or geographic areas. (182) It is hoped that this thesis will partially fulfil these two important concepts.

The purpose of this thesis is to develop and refine a method in which anatomic features viewed on antemortem and postmortem dental radiographs can be compared using digitally stored and enhanced images. Comparisons will be done independent of any dental restorative feature. Secondary purposes include the definition of the valid clinical limits of its usefulness and to design the optimum instrumentation to successfully implement this procedure. Cases in which this method has been used have been included in the last portion of the thesis. The individual hypotheses will immediately follow the individual experiments in the following materials and methods section.

## Materials and Methods:

### Experiment 1: Basic experimental methodology.

Thirty-nine mandibular anatomic specimens with permanent dentitions were obtained from an anatomic specimen supply at the authors institution. Most of the mandibles had missing teeth but all the specimens possessed one or more teeth. Many specimens had missing teeth with unhealed root sockets. This was present due to the loss of teeth which occurred in these specimens from repeated handling over a long period of time and did not represent teeth extracted while the subject was alive. Inclusion criteria for each hemi-mandible in this experiment were: the specimen had to have teeth or tooth sockets numbering at least 4; no restorations could be present; the specimens had to have permanent dentition only; the specimens had to be free of soft tissue; the specimens had to be free of radiographically-demonstrable bone pathology other than periodontal disease; and the teeth had to be firm in their sockets. The mandibles were numbered randomly and 1 mandible with all its teeth intact was selected to represent a typical or control specimen for the first two parts of the comparison procedure undertaken in experiment 1.

Two radiographers participated in experiment 1. A test radiograph was performed by each radiographer prior to exposing dental radiographs of the specimens. This was to ensure adequate density of the image. The test radiograph was exposed only at the initiation of the experiment and not for every mandible since it was assumed that all mandibles were of roughly the same atomic weight and subject contrast. Radiographer A used a standard intraoral dental X-ray generator[1] (10 mA, 70 kVp, 24/60 sec). These radiographs represented the "antemortem" radiographs. Radiographer B used a different intraoral dental X-ray generator[2] (10mA, 70 kVp, 24/60 sec). This second set of radiographs represented the "postmortem" radiographs. The x-ray generators had different focal spot to film distances and were made by different manufacturers. Each radiographer was instructed to expose one posterior and one anterior periapical radiograph of each mandible. No attempt to standardise these views by using film holders or aligning devices was undertaken. The purpose of this was to mimic a typical clinical situation in which radiographs would be exposed. As a deceit, radiographs of 2 mandibles were exposed from the medial to the lateral by one of the radiographers to see if the examiner manipulating the images would be able to determine this during computer-image comparisons. Such orientation of radiographs is opposite to the way periapical radiographs are normally exposed in a clinical situation.



In order to eliminate one source of bias, labels of the mandibles were changed between radiographers to ensure that the operators were not aware of the identity of the mandibles. This allowed the comparison of "antemortem" and "postmortem" radiographs to be done "blind." The radiographs were developed in a darkroom using an automatic X-ray film processor[3] with automatic replenisher (30°C, 4 1/2 min.) by an x-ray technician who did not know the purpose of the experiment. The radiographs were then digitised on a Macintosh® IIci computer[4] with a flat field X-ray scanner[5].

[1] Pennwalt, Spacemaker®, model # 90W, serial #24728, Philadelphia P.A.19102.
[2] Belmont Equipment Corp., model 907, serial #508043, 1 Belmont Dr. , Somerset, N.J.
[3] Phillips 810 XL, AFP Imaging Corp., serial #24071-1005, Elmsford, NY,10523.
[4] Apple Computer Inc., 20525 Mariani Avenue, Cupertino, CA, 95014-6299.
[5] model 3CX, XRS Corp., 4030 Spencer Street, Torrance, CA, 90503

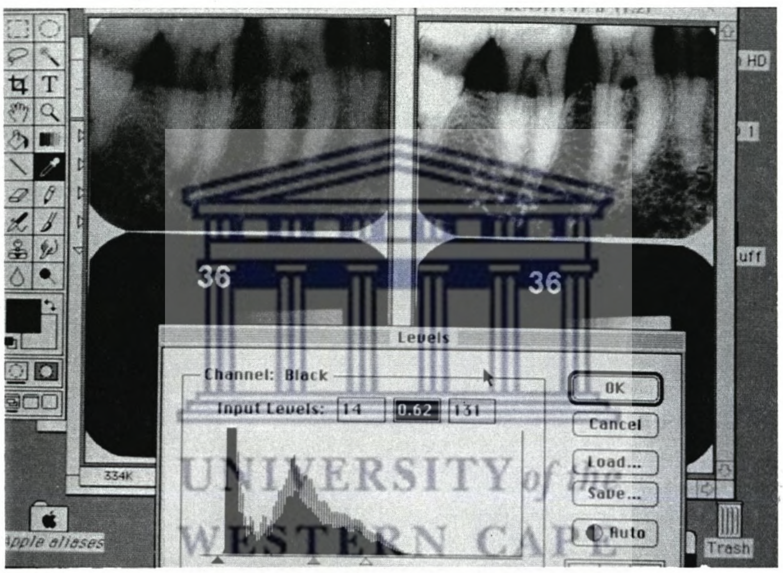
Adobe Photoshop image editing software[6] was used to manipulate the digitised radiographic images. This program is an inexpensive, commercially available, program which may be run on a personal computer. Each mandibular image was labelled with the appropriate corresponding code number or letter using the "text" function in the image editing software. "Antemortem" images were labelled and numbered, Postmortem images were also labelled and lettered. The brightness and contrast of each image was adjusted by the authors using the " output levels" and "brightness/contrast" command of the image editing software until the images were clinically acceptable. The "output levels" command allows the examiner to select the window of radiographic density he wishes to see on the computer screen.

This is accomplished by selecting the maximum density, minimum density and mean density using sliding "switches" which appear on the screen. (Figure 9) An operator can choose to view only the lightest areas of the film, the darkest, or only the mid-tones.



[6] Adobe Systems Inc., 1585 Charleston Road, Mountain View, CA, 94039-7900

Figure 9. Photography of computer monitor screen illustrating use of out put levels command. As the operator slides the triangular switches at the base of the histogram, the lower, mean and upper limits of densities read change. This is evidenced by comparison of the 2 identical radiographs above the histogram. The radiograph on the right side has been manipulated.



The "brightness" and "contrast" commands allow incremental changes to brightness and contrast to be made by the operator. No alteration in size or shape of the image occurred at any point. The person doing the computer manipulations was not aware of the identity of the mandibles but did know the purpose of the experiment.

A horizontal section of the roots was then randomly selected by one of the authors from the postmortem radiograph and superimposed on the antemortem radiograph using the "cut" and "paste" commands (figures 10 & 11). The horizontal cut consisted of a viewable section across the roots of a group of teeth from anterior to posterior in a mesio-distal direction. The height of the cut was restricted to being between 1/5 to 1/3 of the estimated root height. The matching process involved isolating the best matching root (based on gross morphology) of the horizontal section and fitting it to the corresponding tooth on the antemortem radiograph. The author and research assistant then looked for points of concordance along this horizontal section in an antero-posterior direction. A grade of match , no match , or not visible on film was assigned to the mesial lamina dura, mesial periodontal ligament space, pulp chamber, distal periodontal ligament space, and distal lamina dura in each of the encountered roots or the mesial lamina dura and distal lamina dura of a tooth socket where a tooth was lost postmortem. A structural feature was graded as a match if the antemortem and postmortem images lined up within a width of 0.1 mm (approximately 1/2 a normal radiographic periodontal ligament width space). With their scales equalised a horizontal section across the tooth roots was excised from either the "ante mortem" image and "floated" over its corresponding "post mortem" image in such a manner as to compare the dental landmarks of each root complex structure one to the other. In evaluation of these cases the following was determined:

1. How many anatomic landmarks align when comparing radiographs taken at two different times ?
2. How many anatomic landmarks were available for potential evaluation?
3. How many anatomic landmarks did not align ?
4. What is the degree of concordance (C) of points of identification ?

$$C = \frac{A}{B - V}$$

where C = concordance, A = aligned points, B = points used for examination, and V = points not visible for evaluation on the two sets of films.



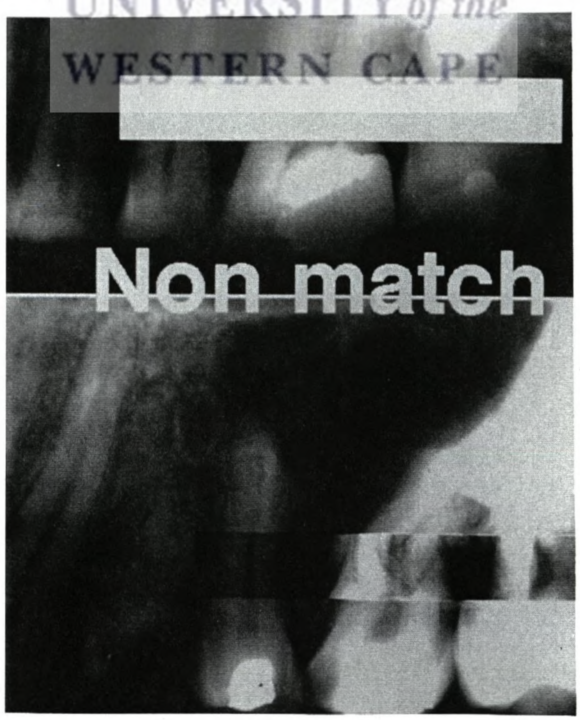
Concordance of 90% was considered to be a match during this *in-vitro* experiment. For an anatomic landmark to be considered a match it had to align with its corresponding structure within one tenth of a millimeter. The anatomic landmarks used were: mesial lamina dura, mesial ligament space(s), root surface, mesial pulp chamber, distal pulp chamber, distal root surface, distal ligament space(s), and distal lamina dura.

The computer software allows or intense magnification of the image on screen to assess these minor differences. During this and the following experiments the magnification on screen was 1:1 with the images being viewed on a high resolution computer monitor with very low ambient room lighting. The concordance for each of the antemortem and postmortem radiographs was equivalent to the total number of matched points divided by the (total number of points examined - total number of points "not visible").

A point of match was present when the antemortem anatomic structure directly overlaid the image of the same structure on the postmortem radiograph. "Not visible" points were points that were not present or visible on one or the other of the "antemortem" or "postmortem" films. This occurred because of the purposeful lack of radiograph exposure standardisation by the two radiographers which was done in order to mimic a typical clinical situation. Two operators examined the radiographs to assess whether a point was indeed missing from the film. If 90 percent or more of the radiographic features examined in this *in-vitro* portion of the experiment were in concordance, then the two images were (arbitrarily) considered to be from the same jaw (Figure 10), otherwise the images would be considered as a non-match (Figure 11).

Figure 10. Image exhibiting horizontal-cut technique in which concordance allowed a positive match to be made.


Figure 11. Image exhibiting lack of concordance between the horizontal cut from the "antemortem" and the postmortem image.



**Experiment 1.1 Simulated identification of an individual case**

An attempt to superimpose "antemortem" and "postmortem" radiographs of the randomly selected control was made using the criteria specified above. Based on the assumption that the radiographs were from the same hemi-mandible, a positive identification was expected. The hypothesis for this part of the experiment was as follows:

1.1 "It is possible to match a known "antemortem" to its corresponding known "postmortem" image using the horizontal slice technique.

**Experiment 1.2 Testing the Individuality of the antemortem radiographs.**

The antemortem radiographs of the control specimen were superimposed on the antemortem radiographs of 38 other mandibles. The authors attempted to establish a positive physical match using the landmarks described to evaluate the possibility of false identification. In each case the best possible match was made between the control and the other radiographic views. The hypothesis for this part of the experiment was:

1.2 "It is impossible to match an "antemortem" image of one specimen to a "postmortem" image of another specimen in this closed population group.

**Experiment 1.3 A Simulated Mass Disaster with 39 hemi-mandible**

The antemortem radiographs of 39 mandibles were individually compared against 39 postmortem radiographs. The postmortem radiographs representing possible matches were first visually identified and a horizontal section of these radiographs was superimposed on the antemortem radiograph. The criteria specified above were used to determine if there was a positive match. Once the identity of the antemortem radiographs was established, the corresponding postmortem radiograph was taken out of the pool. This experiment was repeated a second time leaving the postmortem radiographs in the pool.

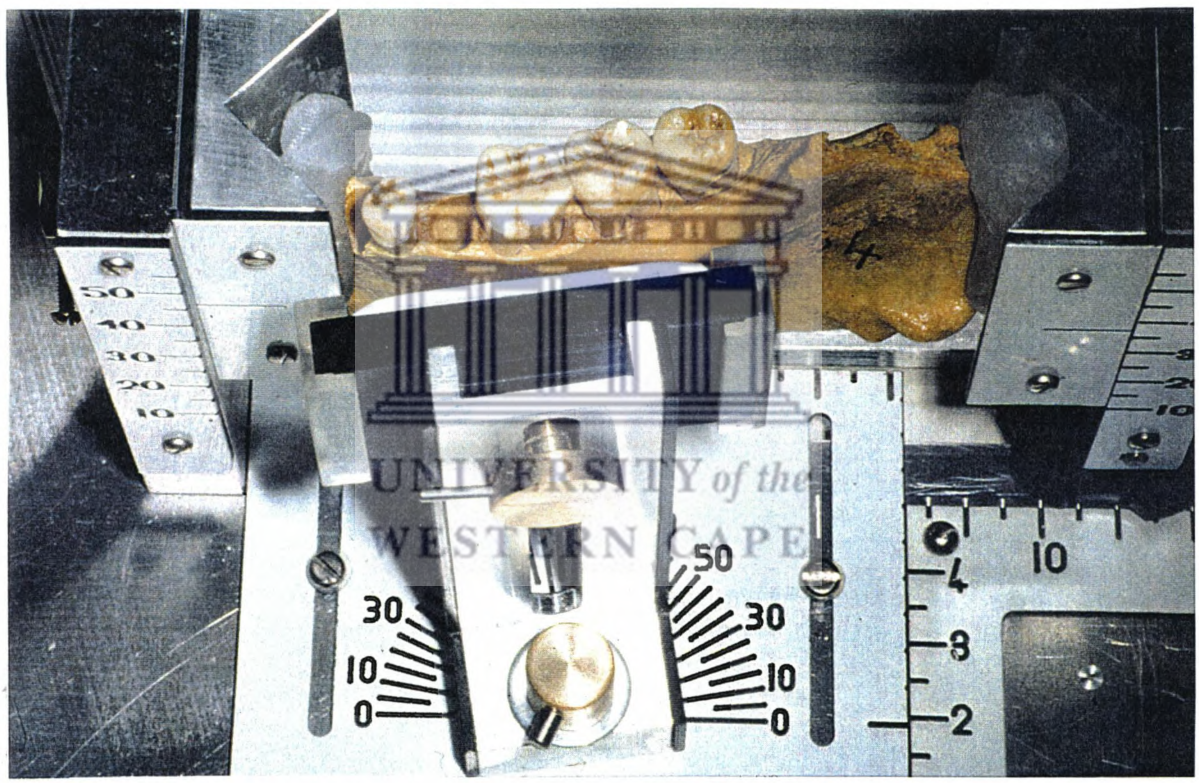
The results between the randomly selected numbers on antemortem and postmortem radiographs were checked to determine whether they were correct . The means of the total number of points compared, number of matching points, non- matching points, structures not visible, and percentage concordance were calculated. The hypothesis for this portion of the experiment was:

<u>1.3 It is possible to use this technique in a closed mock mass-disaster of known size.</u>

The results for this section of the experiment are found in the results section 1 below.

The success of this process has led to the adoption of this technique in dental identification cases at the Coroner's office in the authors jurisdiction. It has proved especially useful for cases where restorations are absent and in incinerated cases where there is loss of coronal tooth structure. A special device has been built to align specimens appropriately (Figure 12).

Figure 12. Photographic depiction of mandibular positioning device ("jig") used to position specimens.



Despite this success, questions remain as to various aspects of its usefulness. These include:

1. What is the stability of the structures used for comparison? Are they stable within each stage of the human dentition (primary, mixed, and permanent dentitions)? Are they stable in the adult dentition and if so what is the greatest time distance between successive radiographic examinations for which the technique may be used?

3. How does radiograph production effect the imaging systems? Do differences in various exposure and positioning methods effect the ability to carry out identification? What are the limits of the system with respect to these parameters?

3. Is there a difference in the use of different scanners and scanner systems ? Do these scanners produce images which are accurate, easily manipulated and stored with a minimum of disk space ? What is the best scanner system to use for this technique and how does one decide on which scanning system is best?

4. Can these digitised images be prepared for and sent via electronic mail or file transfer and recovered for comparison purposes?

5. Can these cases be used with confidence in a clinical situation. In actual cases of dental identification can these methods be used? How many points of identification and what types of error

would be found in analysis of a typical series of cases from a morgue / Coroner's office? Can the technique be used by other operators and is the technique reproducible ?

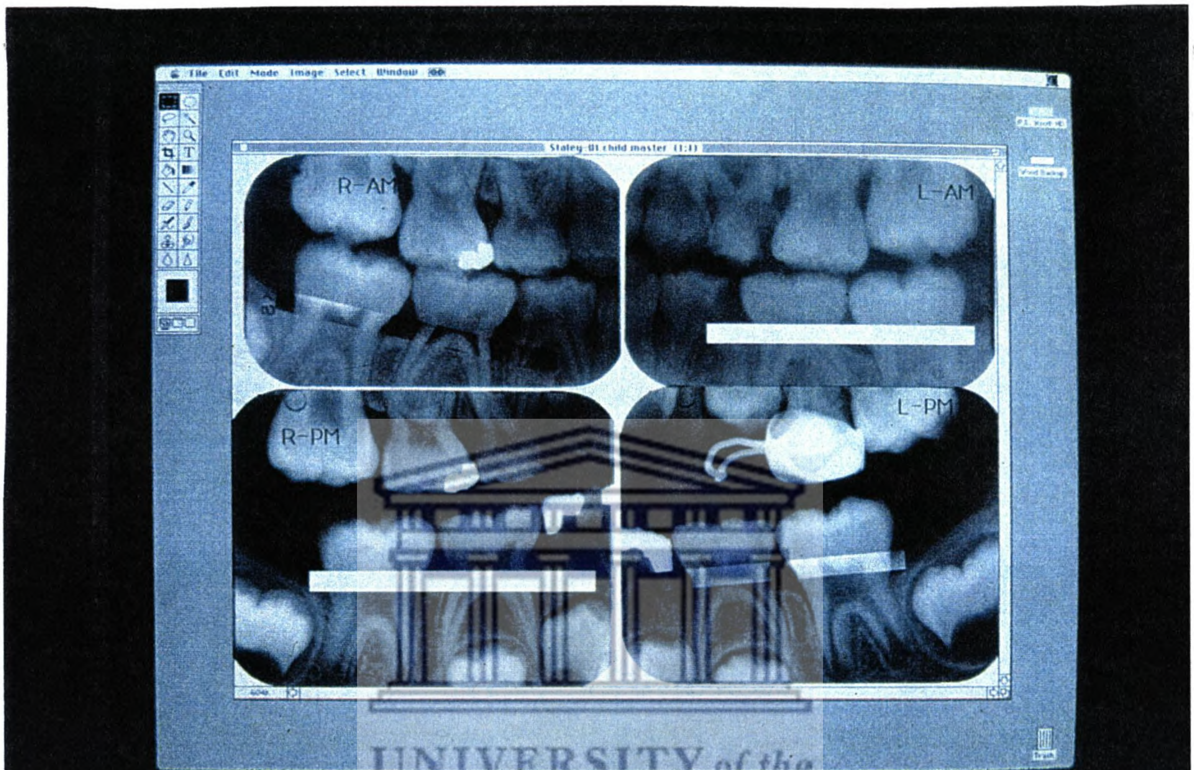
The author will attempt to answer these questions in the following nine experiments.

**Experiment 2 Stability study within the paediatric dentition.**

This study was done using sequential dental radiographs from the Faculty of Dentistry, University of Western Ontario. These were provided by Dr. D. MacLean of the Department of Oral Medicine and Radiology. With regards to the stability of the spatial relationships of teeth as viewed on dental radiographs there are three distinct groups of patients who must be evaluated. These are those in the paediatric dentition, the mixed dentition and the adult population.

The author has used this technique in the paediatric dentition to identify a body of a 6 year-old fire victim. The time span from antemortem to postmortem radiographic examination was only 6 months and there had been little change clinically within that time. (Figure 13)

Figure 13. Photograph of computer monitor exhibiting a paediatric case which is a match.






The paediatric radiographs examined in this thesis contained both matches and non-matches (false matches). The radiographs consisted of paired posterior bitewing radiographs in which both the maxillary and mandibular posterior teeth were visible. The radiographs were exposed by a single dentist in private practice in southern Ontario over a period of many years. He used archival processing and high quality films. The radiographs were coded prior to my receipt of them. The radiographs were mounted as pairs and the author was not aware as to whether the pair was a match or a non-match until the conclusion of the experiments. Some of the radiographs were matches and some were non-matches (ie from different patients but having highly similar features). The pairs of radiographs were digitised, and managed as described in section 1 of the materials and methods section (above). Following their digitisation, the "contrast", "density" and "output levels" of the radiographs were manipulated to yield optimal image quality when viewed on the computer monitor. A horizontal section through the roots of the deciduous teeth, as previously described was cut from the "antemortem" and superimposed over the "postmortem" radiograph. The alignment of the anatomic features was then assessed as per the criteria outlined in section 1 above. The number of aligned points, concordance, and whether the author believed the case to be a match or non-match was recorded. The authors decision of whether the case constituted a match or not was then compared to the key provided by Dr. MacLean. The mean number of aligned points for the true matched group was compared to the true non-matched group using a Student's t test. In addition the sensitivity, specificity and predictive value of the test were deduced and expressed as a percent. The hypothesis in this section was:

<u>2.1 "Identification is possible in the paediatric dentition when there is temporal space between "ante mortem" and "post mortem examinations."</u>

The results of this experiment may be found in section 2 in the results section below.

**Experiment 3 Stability study of subjects in the mixed dentition stage of dental development.**

The analysis of the spatial relationship of the roots of the teeth within the mixed dentition, for forensic purposes is in my opinion the least reliable. At the time of the change in the buccal dental segments from primary to permanent dentition there is significant change in the mesio-distal widths of the buccal segments. The author has had little occasion to use this technique in actual case work. In the single case in which it was attempted, the alignment was markedly off and an identification could not be assisted by using this technique. The subject in question was then subsequently identified using other means. In this section of the experiment, the author defines mixed dentition as subjects in whom the permanent buccal teeth are erupting. Since there is no collection in which the exact chronological spacing in terms of months between "antemortem" and "postmortem" radiographs were taken I have obtained a series of radiographs from Dr. D. MacLean of the University of Western Ontario. This series of 25 pairs of posterior bitewings were also exposed in the office of a single practitioner. The radiographs consisted of some matches and non-matches with both "antemortem" and "postmortem" radiographs temporally spaced but within the mixed dentition. The images were digitised as outlined above. Measurements were made of the number of possible points in the cut section taken from the "antemortem" film, the number of sections for comparison from the "postmortem" film and the concordance. From the concordance data the case was described as a match or non-match and compared to a master list which contained the information as to whether the pair of radiographs were indeed taken from the same patient. The mean number of aligned points for the true matched group was compared to the true non-matched group using a Student's t test. In addition the sensitivity, specificity and predictive value of the test were deduced and expressed as a percent. The hypothesis is:

3.1 "Identification is possible within the mixed dentition when comparing the spatial relationships between "antemortem" and "postmortem"pairs of radiographs.

The results for this section of the experiment are found in the results section and labelled "Results - Experiment 3." Examples of two cases, both non matches are displayed in Figure 14.

Figure 14. Photography of computer monitor showing two cases of mixed dentition cases. Neither could be matched using the technique although one pair of the radiographs were from the same patient.




**Experiment 4: Stability study of subjects in the permanent dentition stage of dental development.**

Permanent dentition is defined as those patients in whom all of the clinically present teeth are permanent. The permanent dentition has been used for identification using this technique in excess of 30 cases by the author with a time span between ante mortem and post mortem radiographs as great as 11 years. They are studied in greater detail in section 10 below. For this reason the time between "ante mortem" and "post mortem" in the study group of radiographs must be extended. Twenty-five patients were used with time differentials between sets of radiographs as long as possible. The minimum cut-off time difference between "antemortem" and "postmortem" images was 60 months (5 years). The images were digitised as outlined above and comparisons were made as previously described. The number of aligned points, concordance, and whether the author believed the case to be a match or non-match was recorded. The authors decision of whether the case constituted a match or not was then compared to the key provided by Dr. MacLean. Once again Dr. D. MacLean supplied the material from a single dentist from whose practice these radiographs were obtained. The mean number of aligned points for the true matched group was compared to the true non-matched group using a Student's t test. In addition the sensitivity, specificity and predictive value of the test were deduced and expressed as a percent. In addition the number of months (maximum, minimum, mean, and mode) was calculated. The hypothesis for this experiment is:



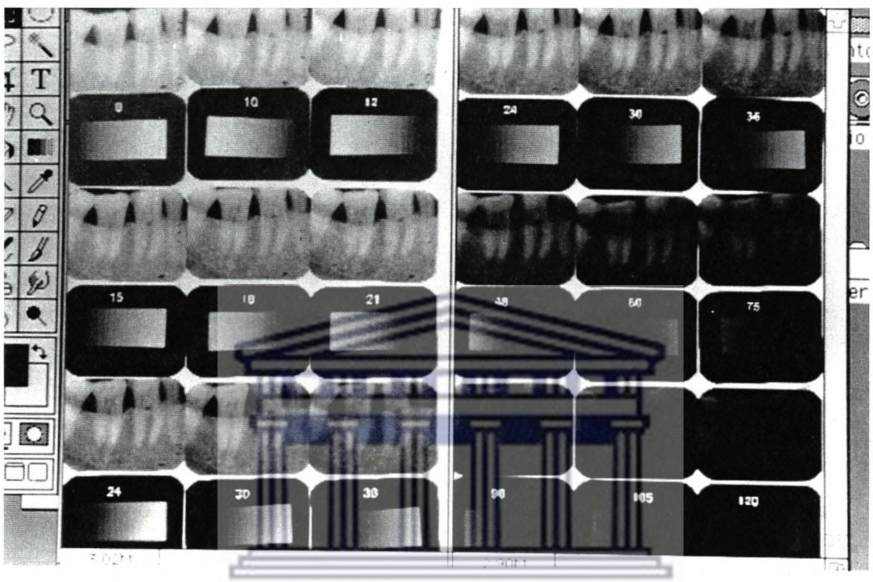
4.1 "Identification is possible in the permanent dentition when the spacing between "ante mortem" and "post mortem" examinations is chronologically protracted "

The results for this section of the experiment are found in the results section and labelled "Results - Experiment 4."

## Experiment 5 Influence of radiographic density on system reliability.

Density is defined as the degree of darkness of a film. (183) Optical density is defined as the log of (the light incident on a film divided by the light transmitted by the film). (183) Although there are numerous ways to increase or decrease density, adjustment of the mA and time of exposure was used in this experiment. Using a single hemi-mandible specimen and a specimen holder device (Appendix B), a series of exposures were made using different mAS (holding kVp constant) so as to give 18 films of varying density ranging from very light (low optical density) to very dark (high optical density) (Figure 15). The design of this positioning device was based on measurements of mandibular anatomic specimens whose dimensions may be found in Appendix D.

Figure 15. Photograph of computer screen showing 18 radiographs of differing density made by altering the mAS during image production.






A range of 18 radiographs was selected because it represented the largest useful range obtainable with the x-ray generator available. The radiographs were developed in a darkroom using an automatic X-ray film processor[7] with automatic replenisher (30°C, 4 1/2 min.) by an x-ray technician who did not know the purpose of the experiment. The 15

7 Phillips 810 XL, AFP Imaging Corp., serial #24071-1005, Elmsford, NY,10523.

films were measured for optical density using a sub program of the Adobe Photoshop imaging program. The radiographs were then digitised on a Macintosh® IIci computer[8] with a flat field X-ray scanner[9]. Adobe Photoshop image editing software[10] was used to manipulate the digitised radiographic image. The 15 different radiographs were digitised but not initially computer-enhanced. They were viewed with the normal computer screen brightness and magnification held constant. Following assessment of the degree of matching between a control radiograph of optimum density the images were computer-enhanced. This consisted of digitally altering the density of the radiographs on screen. The goal of this manipulation was to assess the degree of match of the density enhanced and density non-enhanced films. The degree of matching was assessed by evaluating the alignment of radiologically visible structures as described in Experiment 1 above. The hypotheses for this section of the experiment is:



<u>5.1 "Density of the image has no effect on the ability to adequately visualise the structures of interest for forensic identification."</u>

<u>5.2 "Density of the image can be enhanced to increase the degree of matching of anatomic structures as viewed radiologically."</u>

The results for this section of the experiment are found in the results section and labelled "Results - Experiment 5."

[8] Apple Computer Inc., 20525 Mariani Avenue, Cupertino, CA, 95014-6299.
[9] model 3CX, XRS Corp., 4030 Spencer Street, Torrance, CA, 90503
[10] Adobe Systems Inc., 1585 Charleston Road, Mountain View, CA, 94039-7900

**Experiment 6 Influence of radiographic contrast on system reliability.**

Contrast is not as simple a concept as density. In order to test whether changes in contrast affect the ability to adequately evaluate the image for forensically important information, film density must be held constant. This was done by exposing the specimens with a 14-step, aluminium stepwedge while adjusting the x-ray generator kVp. Tube kilovoltage (kVp) controls contrast where image geometry, subject contrast and film contrast are held constant. However, alterations in kVp also change density. Using a single hemi-mandible specimen and a specimen holder device Figure 12 (Appendix B), a series of exposures were made using different kVp (holding mAS constant) so as to give 11 films of varying contrast (and also density) ranging from a maximum of 13 visible steps on the step wedge (at middle to low kVp) to 4 visible steps on the step wedge at high kVp. This range of 11 radiographs was selected because it represented the largest useful range obtainable with the x-ray generator available. The x-ray generator kVp ranged from 50 kVp to 100 kVp (Figure 16). The time of 36 impulses and 10 mA was held constant throughout the series. The radiographs were developed in a darkroom using an automatic X-ray film processor[11] with automatic replenisher (30°C, 4 1/2 min.) by an x-ray technician who did not know the purpose of the experiment. The 11 films were measured for optical density using a sub program of the Adobe Photoshop imaging program. The radiographs were then digitised on a Macintosh® IIci computer[12] with a flat field X-ray scanner[13]. Adobe Photoshop image editing

[11] Phillips 810 XL, AFP Imaging Corp., serial #24071-1005, Elmsford, NY,10523.
[12] Apple Computer Inc., 20525 Mariani Avenue, Cupertino, CA, 95014-6299.
[13] model 3CX, XRS Corp., 4030 Spencer Street, Torrance, CA, 90503

software[14] was used to manipulate the digitised radiographic image. The 11 different radiographs were digitised but not initially computer-enhanced. They were viewed with the screen brightness and magnification held constant. Following assessment of the degree of matching between a control radiograph of optimum contrast the images were computer-enhanced for contrast. This consisted of digitally altering the contrast of the radiographs on the high resolution monitor. The goal of this manipulation was to assess the degree of match of the contrast enhanced and contrast non-enhanced films. The degree of matching was assessed by evaluating the alignment of radiologically visible structures as described in Experiment 1 above. The hypotheses for this section of the experiment is:

6.1 "Radiographic contrast of the image has no effect on the ability to adequately visualise the structures of interest for forensic identification using horizontal image sections."

6.2 "Contrast of the image can be enhanced to increase the degree of matching of anatomic structures as viewed radiologically."

The results for the evaluation of contrast on the ability to match corresponding points of concordance with respect to alignment of landmarks are found below in the results section 6.

[14] Adobe Systems Inc., 1585 Charleston Road, Mountain View, CA, 94039-7900

Figure 16. Photograph of computer monitor showing 11 digitised radiographs and corresponding step wedges exposed by manipulation KVP.

**Experiment 7 The influence of positioning on the ability to use the system.**

Changes in angulation of the collimator or specimen relative to the film result in grossly altered radiographic images. In this section of the experiment each of the positional components of the radiographic image production was altered and the resultant images compared to a control image. A single specimen was used in the positioning device previously described. Changes in the following components of image geometry were made.

7.1 Horizontal angle changes.

The use of the horizontal section comparison system described above for the analysis of forensically important dental radiologic landmarks relies on their accurate depiction on radiographs. The alignment of numerous anatomic landmarks between antemortem and postmortem radiographs should, in theory, be highly dependent on image geometry. Since horizontal sections are used in this technique it would be logical that changes in horizontal angulation between the putative "antemortem" and putative "postmortem" radiographs would have a great influence on the resultant ability of the operator to align the radiographic landmarks for identification purposes. In this section of the experiment a hemi-mandible was placed into the radiologic alignment device (previously described above) and fixed using a combination of polyvinylsiloxane impression material and cement. A test film was taken with an ANSA group "D" speed film placed in the film holder and the film holder, object and collimator device fixed so the central x-ray was positioned perpendicular to both the hemi-mandible and the film. Following this, ten radiographs were exposed with the film holding device angled (at 5 degree intervals) in 10 different positions ranging from 5 degrees from the central ray to 50 degrees from the central ray. This was done to mimic the clinical situation where the beam would be angled from the anterior to the posterior. An additional 10 radiographs were made using similar angles to the first set but with the beam directed from posterior to anterior. This resulted in a total of 21 radiographs angled in 5 degree increments from the most anteriorly measurable to the most posteriorly-directed angle.

After this the radiographs were digitised as previously described and the image contrast and density were optimised. A horizontal section of the 90 degree (normal) radiograph was then digitally excised and placed over the roots of the other radiographs sequentially to assess the degree of matching as represented by the number of concordant points. The results of this investigation are described in the results section below in section 7-1. The hypotheses concerning the horizontal angulation of the above is as follows:



<u>7.1 "Horizontal angulation of the beam has no effect on the ability to adequately visualise the structures of interest for forensic identification."</u>

7.2 Vertical angle changes

Errors in vertical angulation are common in the clinical practice of intraoral radiology. To test the influence of these factors on the ability to match horizontal anatomic points of identification, elongation and foreshortened images were created from a normal situation where the film plane is perpendicular to the central ray in the vertical plane. These images were made at five degree intervals from a positive vertical angulation equivalent of 30 degrees to a negative vertical angulation of 30 degrees. This represented the maximum achievable vertical shift obtainable with the positioning device. The shift was achieved, not through a change in the position of the collimator (as it is clinically) but through a change in the angle of the fixed mandible on the positioning jig. This resulted in a change identical to that of changing the collimator but could be accomplished with greater precision. Six images representing incremental mild to severe elongation were made as were six additional images representing incremental mild to severe foreshortening. After this, the radiographs were digitised as previously described and the image contrast and density were optimised. A horizontal section from an image of the same mandible was cut and superimposed over each image from the elongation and foreshortened series to assess the degree of matching. The results from this section are depicted in the results section 7. The goal of this experimental section is to decide the following hypothesis:

7.2 "Vertical angulation of the beam has no effect on the ability to adequately visualise the structures of interest for forensic identification."

7.3 Changes in focal film distance

Aside from horizontal and vertical angulation differences there is another factor which governs radiographic images. This is the relative focal spot / object / film positions. The focal spot is the tungsten target in the anode of the x-ray generator. The object in this case is the teeth and the film position is the plane of the dental x-ray film. The relative positions of these three has an influence on the relative magnification of the image size relative to the object size. Specifically, when the object to film distance is large, the image is magnified relative to the actual object size. In practical terms this is not a factor in dental intraoral radiography because it is anatomically difficult to place the film at a great distance from the teeth. It is not however difficult to alter the focal-spot to film distance. In this part of the study I altered the focal-spot to film distance in order to assess the influence of this change in image geometry. This took the form of increasing the focal spot to film distance from 6 cm to 36 cm in increments of 5 cm resulting in 7 films with different focal spot to film distance. Since the inverse square law governs dental x-radiation, doubling the distance (as was done in this portion of the experiment) results in an image with 1/4 the normal density. To compensate for this, the first three images (with short focal spot to film distances) were exposed with 10mA at 70 kVp and 36 impulses. The last four images were exposed with 15 mA at 70 kVp and 36 impulses. While this did not totally compensate for density loss it did result in images which were suitable for comparison. Following development of the images they were digitised and a horizontal section was cut from the short focal spot to film distance image and compared to the other images for anatomic alignment. The hypothesis for this section is:

<u>7.3 "Change in the focal film distance has no effect on the ability to adequately visualise the structures of interest for forensic</u>

identification."

The results for this section of the experiment are found in the results section and labelled "Results - Experiment 7."

**Experiment 8 Use of different scanners in the derivation of digitised images.**

The purpose of this study is not to undertake a detailed comparison of scanner technology. There are currently dozens of manufacturers of flat-field scanners and a detailed comparison of one to the other is a study unto itself. However, since I have access to three different types of scanners which available in my department, a comparison of the three scanner techniques was undertaken to demonstrate whether all (or any) are capable of producing adequate images for forensic comparisons. A synopsis of the speed of scanning, disk space utilised and subjective adequacy of the image and objective measures of contrast (as determined by the number of visible steps on a stepwedge) was recorded. The three scanners are a Microtek slide scanner, [15] (Figure 17) a UMAX 840, [16] (Figure 18) mid range flat field photograph equipped with a transparency accessory and an XRS flat field radiograph scanner (Figure 19). Images were acquired in "normal" mode using the transparency selection and a 256 level grey scale at 300 dpi resolution. Three-hundred dpi resolution is the maximum resolution obtainable with the XRS scanner so it was used as the level of resolution for all scanners. Both the UMAX 840 Max Vision scanner and the Microtek

[15] Microtek Corporation Inc., Taiwan, R.O.C. Model Scanmaster 1850S serial number:S1941011702

[16] UMAX data systems Inc. Taiwan R.O.C., Model 840 serial number:G2E UC840

scanner are capable of much greater resolution but 300 dpi is the level of resolution the author routinely uses for forensic comparisons. The image selected for comparison was exposed using the film holding device and normal image geometry. It was exposed at 10 mA, 36 impulses at 65 kVp. It was developed using strict adherence to proper chemistry and scanned in the scanning system according to manufacturers instructions. It was saved as a "PICT" file with no image compression at 8 bits / pixel. It was examined on a high-resolution screen with low ambient room lighting and magnification to a 1:1 ratio. The hypothesis for this segment of the project is:

8.1 "All three scanning systems are adequate for use in evaluating dental radiographic images for forensic purposes."

The relative merits of each system of scanning will be discussed in the results section 8.

Figure 17. Photograph of the Microtek slide scanner.



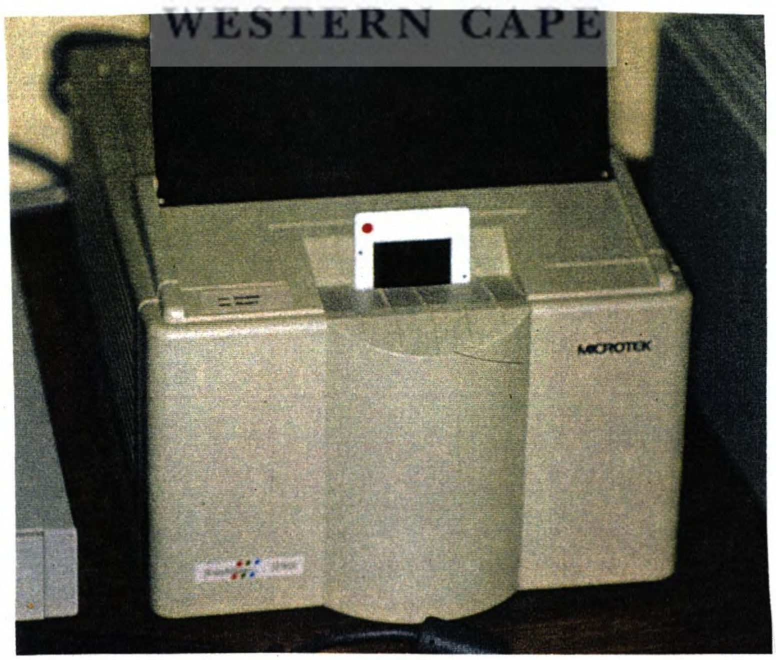
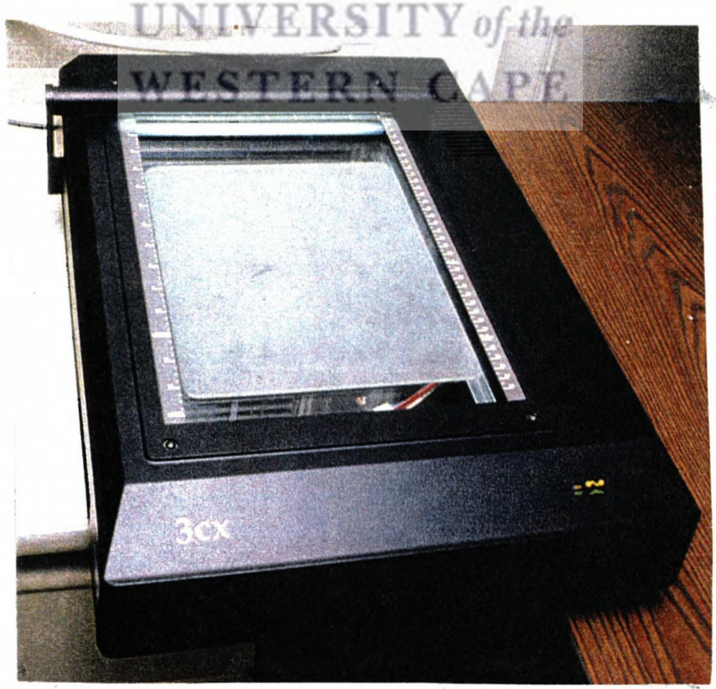


Figure 18. Photograph of the UMAX 840 scanner. The transparency attached is affixed appropriately on this flat bed scanner.


Figure 19. Photograph of the XRS Omniscan x-ray scanner. This scanner was used for the bulk of the scanning in this study.





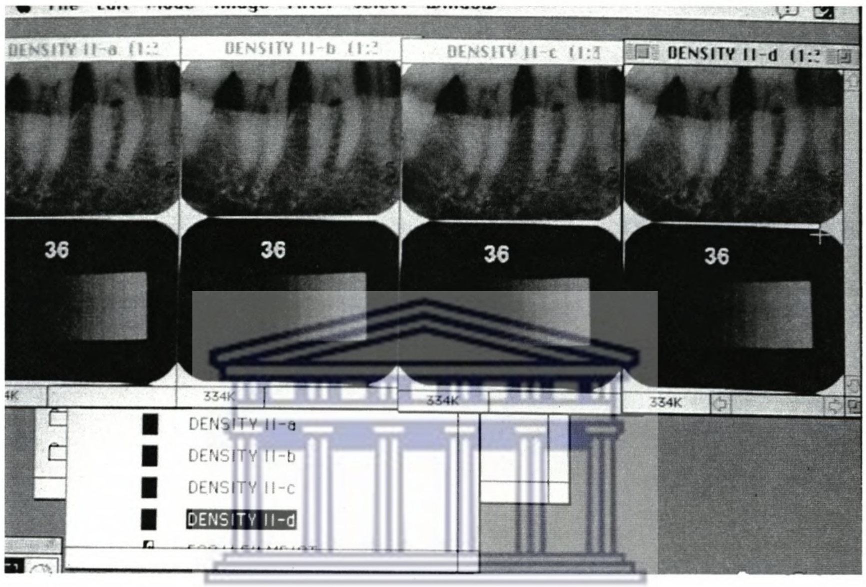
## Experiment 9 Preparation of digital images for transmission

Preparation of digitised images for, and transmission via electronic mail systems. A synopsis of means of data compression and methods of transfer of these images via electronic mail systems and file transfer programs (FTP's) will be given.

Pictorial examples of the results of image compressions will be provided. An attempt will be made to decide how much compression will be allowed before the image is rendered useless for forensic comparison purposes (Figure 20). It is the author's hypothesis that:

9.1 Digital images can be compressed, stored, sent via electronic mail, and re-assembled at a distant site for evaluation.

Figure 20. Photograph of the computer monitor showing (from left to right) 4 varying degrees of image compression from minimally compressed to maximally compressed.






**Experiment 10 Coroner's clinical cases.**

What are the features of a series of actual cases seen in the Coroner's office ? In this section of the experiment actual cases were used in which this technique has been utilised. The cases were analysed in the same manner as described above. Images were acquired using the

XRS Omniscan as previously described. The images were enhanced and comparisons between the antemortem and postmortem images undertaken to determine the alignment of anatomical landmarks. Since these cases were deceased individuals the rules of cost-benefit ratio with respect to radiation dosage were not at issue. Where indicated, numerous postmortem images were exposed to ensure that the antemortem and postmortem images were as close a match as possible with respect to image geometry, density, and contrast. It is important to note this fact when comparing results of the clinical cases described herein to historical cases as seen in experiments 2, 3, and 4 above. This portion of the experiment was undertaken to critically examine the clinical usefulness (or lack thereof) of this technique. In addition an inter-operator and intra operator error calculation was made using 5 of the clinical cases.

The hypothesis of this sections is:

<u>10.1 The analysis of the spatial relationship of the teeth as examined on digitised dental images allows for identification to be made.</u>

<u>10.2 Intra operator error and intra operator error will be within acceptable ranges.</u>

<u>10.3 The system can be learned and used within a reasonable length of time.</u>

## Results

### Experiment 1

In part one, the antemortem radiographs of the control matched with the postmortem radiograph. Out of 30 possible points of comparison, 29 points matched and the other point was not visible in the radiographs due to geographic cut-off from the antemortem image during the radiography procedures. The concordance was 100%.

In part two, the control radiograph could not be superimposed on any of the other radiographs. In a few cases it was possible to match one root complex of the antemortem control radiograph with a root of similar dimension in the postmortem radiographs, however it was evident that adjacent roots differed with respect to the lamina dura (the dental bony socket), root width, periodontal ligament space shadow, and pulp space.

In part three, all 39 sets of antemortem radiographs were identified and paired with the matching set of postmortem radiographs. The results were then verified against the sealed "Master List" containing the correct matches and they proved to be 100 percent correct. The average total number of points of comparison for a pair of radiographs was 18.3 $\pm$5.4 with the maximum and minimum points of 32 and 10 respectively. For each pair of antemortem and postmortem radiographs, the average number of matching points was 17.5 $\pm$ 5.3 and the number of non-corresponding points per pair of radiographs was 0.1 $\pm$ 0.4 . The average percentage concordance was 99.2% $\pm$ 2.5%. Sensitivity and specificity measurements were not made here since the method was specific in 100 % of cases and sensitive for all 100 % of cases.

It seems therefore that the spatial relationship of tooth roots and their surrounding structures is unique and no two persons have the same spatial relationship of their tooth root complexes.

**Experiment 2**

Examination of the radiographs with respect to the spatial relationships of the teeth for identification purposes reveal that in most cases the technique may be used in routine bitewing radiographs in the paediatric dentition. In one case (case # 117) there was a gross difference in the horizontal angulation between the "antemortem" and "postmortem" radiographic examinations. Despite my intuition that these radiographs would match, using the strict criteria of the experimental design they simply did not match clinically with a concordance of only 27%. This error is not critical in that it would not result in a misidentification, (false positive) only an inability to make the identification (false negative). This could conceivably be altered by controlling the horizontal angulation in the process of doing the postmortem examination. This was not possible in the current series since the "postmortem" series of radiographs were culled from live patients. These radiographs are archival and the patients have since aged, negating the possibility of doing a second corrected set of radiographs. Even if the patients were available it would not be ethically responsible to expose an extra or additional set of radiographs for the purposes of this study.

Examination of the results of this group of patients reveals that in all cases identifications were positive in those cases where the "antemortem" and "postmortem" radiographic examinations were from the same patient. In those cases where the "antemortem" and "postmortem" radiographic examinations were similar but from different patients, the technique correctly predicted that they were a non-match even though some cases were highly similar clinically. The largest percentage of matching points in a case where radiographs were taken from different patients was 32%. The smallest percentage of matching points in a case where it was deemed there was a match (negating the false negative described above) was 85 % (Table X).

The sensitivity of the test was 91% and the specificity and predictive value was 100% for both. Examination of the number of aligned points for the true matches to the true non-matches reveals the difference in the aligned points to be significantly different (p<0.0001). This is suspected from examination of the data. It is obvious that there are (with the exception of subject number 117) gross differences in the number of matching points between the two groups indicating they are indeed from two distinct populations.

**Table X Comparison of the points of concordance within the primary dentition for a group of 25 sets of bitewing radiographs.**

| I.D. # | points aligned | concordance ( % ) | match (Y/N) | correct (Y/N) |
|---|---|---|---|---|
| 126 | 6 | 27 % | N | Y |
| 125 | 27 | 87% | Y | Y |
| 124 | 23 | 85% | Y | Y |
| 123 | 3 | 16% | N | Y |
| 122 | 8 | 38% | N | Y |
| 121 | 5 | 23 % | N | Y |
| 120 | 19 | 95% | Y | Y |
| 119 | 6 | 24% | N | Y |
| 117 | 4 | 27% | N | **N** |
| 116 | 3 | 19% | N | Y |
| 115 | 29 | 100% | Y | Y |
| 114 | 3 | 13% | N | Y |
| 113 | 5 | 21% | N | Y |
| 112 | 19 | 90% | Y | Y |
| 111 | 6 | 29% | N | Y |
| 110 | 8 | 31% | N | Y |
| 109 | 21 | 91% | Y | Y |
| 108 | 5 | 23% | N | Y |
| 107 | 24 | 100% | Y | Y |
| 106 | 4 | 18% | N | Y |
| 105 | 22 | 94% | Y | Y |
| 104 | 7 | 32% | N | Y |
| 103 | 6 | 22% | N | Y |
| 102 | 23 | 100% | Y | Y |
| 101 | 22 | 92% | Y | Y |



**Experiment 3**

The test method proved to be completely useless in the mixed dentition cases. (Table XI) A comparison of the predicted matches to the known matches revealed that there was not a single case in which the technique allowed for the successful matching of the "antemortem" to the "postmortem" radiograph. Of equal importance is the observation that the technique at least did not result in the false identification of any individual. In summary the technique was extremely insensitive, not terribly specific but did not result in any critical errors. Surprisingly a comparison of the number of aligned points using Student's t testing revealed significant differences between matched cases and unmatched cases. ($P<0.007$) A similar comparison of the mean concordance using a t test reveals the results to significant at $p < 0.05$. This may indicate that there is still value in undertaking the test in cases where there is a moderate to large closed population of subjects. Such examination may lead to information as to which bodies may need further study using alternate identification methods such as DNA analysis. Examination of the sensitivity reveals the test to be 0% sensitive but 100% specific. The predictive value of the test in the mixed dentition is 0% making the test impractical for single cases in open populations.



Examination of the radiographs reveals an average increase in the number of erupted teeth as 3.8 (range 1 to 7 teeth per case) which may partially explain the dramatic decrease in the efficacy of the technique in the mixed dentition subject. If a new tooth arrives on the scene it automatically translates into 5 new points which will not align with "antemortem" points of identification. (Table XII)

**Table XI Comparison of the points of concordance within the mixed dentition for a group of 25 sets of bitewing radiographs.**

| I.D. # | points aligned | concordance (%) | match (Y/N) | correct (Y/N) |
|---|---|---|---|---|
| 1 | 5 | 20% | N | Y |
| 2 | 6 | 27% | N | Y |
| 3 | 6 | 24% | N | Y |
| 4 | 10 | 35% | N | **N** |
| 5 | 6 | 27% | N | **N** |
| 6 | 4 | 14% | N | Y |
| 7 | 8 | 26% | N | **N** |
| 8 | 8 | 34% | N | **N** |
| 9 | 6 | 23% | N | **N** |
| 11 | 6 | 26% | N | **N** |
| 12 | 6 | 23% | N | **N** |
| 13 | 4 | 15% | N | Y |
| 14 | 4 | 25% | N | Y |
| 15 | 12 | 44% | N | **N** |
| 16 | 7 | 24% | N | Y |
| 17 | 10 | 38% | N | **N** |
| 18 | 6 | 25% | N | **N** |
| 19 | 8 | 32% | N | Y |
| 20 | 14 | 52% | N | **N** |
| 21 | 8 | 31% | N | **N** |
| 22 | 8 | 28% | N | **N** |
| 23 | 6 | 25% | N | Y |
| 24 | 2 | 7% | N | Y |
| 25 | 4 | 16% | N | **N** |
| 61 | 8 | 32% | N | **N** |

**Table XII Number of new teeth reaching occlusal plane, concordance and presence of "true match." (* = false negative)**

| I.D. # | concordance (%) | #of newly erupted teeth | true match (Y/N) |
|---|---|---|---|
| 1 | 20% | 2 | N |
| 2 | 27% | 2 | N |
| 3 | 24% | 4 | N |
| 4 | 35% | 4 | Y |
| 5 | 27% | 4 | Y |
| 6 | 14% | 1 | N |
| 7 | 26% | 4 | Y |
| 8 | 34% | 7 | Y |
| 9 | 23% | 6 | Y |
| 11 | 26% | 2 | N |
| 12 | 23% | 2 | Y |
| 13 | 15% | 2 | N |
| 14 | 25% | 3 | N |
| 15 | 44% | 5 | Y |
| 16 | 24% | 3 | N |
| 17 | 38% | 5 | Y |
| 18 | 25% | 4 | Y |
| 19 | 32% | 7 | N |
| 20 | 52% | 1 | Y |
| 21 | 31% | 3 | Y |
| 22 | 28% | 4 | Y |
| 23 | 25% | 2 | N |
| 24 | 7% | 6 | N |
| 25 | 16% | 6 | Y |
| 61 | 32% | 6 | Y |



**Results for experiment 4: Evaluation of long term ability to match subjects in the permanent dentition based on a comparison of the spatial relationships of the teeth.**

A single case JC-R was not identified using this technique. The remainder of the tests revealed that the test was employed successfully in predicting a match when a cut off of 80% concordance was used as the lower limit as a match. The mean number of months separating the "antemortem" and "postmortem" images was 188 months with a lower limit of 60 months and an upper limit of 355 months. The median value number of months separating the "antemortem" and "postmortem" images was 176 months (Table XIII). The greatest number of months at which a match could be made was 352 months which translates into more than 29 years. Comparison of the mean number of aligned points using the Student t test reveals there is a highly significant difference between the true matched and true non-matched groups ($p < 0.0001$). This also holds true when concordance is similarly compared ($p < 0.0001$). The sensitivity of the test is 91 % and the specificity and predictive value are both 100%.

**Table XIII Long term stability of 24 patients in the permanent dentition.**

| I.D. # | time difference (months) | points aligned | concordance ( % ) | match (Y/N) | correct (Y/N) |
|---|---|---|---|---|---|
| TM-R | 108 | 26 of 31 | 83% | Y | Y |
| TM-L | 60 | 24 of 26 | 92% | Y | Y |
| PC-L | 297 | 24 of 30 | 80% | Y | Y |
| JC-R | 132 | 17 of 28 | 61% | **N** | **N** |
| PB-R | 352 | 16 of 30 | 53% | N | Y |
| AL-R | 225 | 20 of 25 | 80% | Y | Y |
| PC-R | 355 | 9 of 30 | 30% | N | Y |
| PB-L | 352 | 11 of 29 | 38% | N | Y |
| PC-L | 355 | 25 of 30 | 83% | Y | Y |
| DD-L | 62 | 11 of 28 | 39% | N | Y |
| RA-L | 174 | 12 of 34 | 35% | N | Y |
| PS-L | 63 | 15 of 26 | 58% | N | Y |
| MB-L | 176 | 9 of 27 | 33% | N | Y |
| JC-L | 134 | 15 of 29 | 52% | N | Y |
| RA-R | 174 | 10 of 30 | 33% | N | Y |
| GM-R | 190 | 27 of 31 | 87% | Y | Y |
| PO-L | 173 | 6 of 28 | 21% | N | Y |
| LM-L | 60 | 6 of 31 | 19% | N | Y |
| RC-L | 132 | 8 of 34 | 24% | N | Y |
| JC-R | 305 | 21 of 26 | 81% | Y | Y |
| DB-R | 234 | 24 of 30 | 80% | Y | Y |
| CO-L | 67 | 23 of 26 | 88% | Y | Y |
| RB-L | 132 | 7 of 30 | 23% | N | Y |
| GM-L | 178 | 29 of 31 | 94% | Y | Y |
| DP-L | 220 | 10 of 30 | 33% | N | Y |



## Results for Experiment 5 - Density evaluation

Density had little effect on the ability to match points of concordance between 15 impulses and 75 impulses at 70 kVp and 10 mA. (Table XIV) Below 15 impulses, films were too light and contained insufficient image information to allow assessment. Specifically one of the pulp chambers was not discernible from the dentin at low density. At higher density, pulp chambers and even approximal root surfaces were not well visualised.

**Table XIV Results - Non-enhanced image density matching**

| Impulses | possible points | points matched | non-matched |
|---|---|---|---|
| 8 | 12 | 11 | 1 * |
| 10 | 12 | 11 | 1 * |
| 12 | 12 | 11 | 1 * |
| 15 | 12 | 12 | 0 |
| 18 | 12 | 12 | 0 |
| 21 | 12 | 12 | 0 |
| 24 | 12 | 12 | 0 |
| 30 | 12 | 12 | 0 |
| 36 | 12 | 12 | 0 |
| 48 | 12 | 12 | 0 |
| 60 | 12 | 12 | 0 |
| 75 | 12 | 10 | 2** |
| 90 | 12 | 10 | 2** |
| 105 | 12 | 6 | 6† |
| 120 | 12 | 5 | 7†† |



* unable to visualise pulp chamber on mesial root of first molar
** unable to visualise pulp chamber on mesial root of first molar
† pulp chambers not visible due to excessive optical density
†† pulp chambers and one root surface not visible due to excessive optical density

Following density enhancement (either making lighter images more dense or darker images less dense) a greater number of points of concordance could be seen (table XV). Even allowing for maximal density manipulation it was noted that very dark images did not allow for perfect concordance.

**Table XV Results - Enhanced image density matching**

| Impulses | possible points | points matched | non-matched |
|---|---|---|---|
| 8 | 12 | 12* | 0 |
| 10 | 12 | 12* | 0 |
| 12 | 12 | 12* | 0 |
| 15 | 12 | 12 | 0 |
| 18 | 12 | 12 | 0 |
| 21 | 12 | 12 | 0 |
| 24 | 12 | 12 | 0 |
| 30 | 12 | 12 | 0 |
| 36 | 12 | 12 | 0 |
| 48 | 12 | 12 | 0 |
| 60 | 12 | 12 | 0 |
| 75 | 12 | 12 | 0 |
| 90 | 12 | 12 | 0 |
| 105 | 12 | 10 | 2† |
| 120 | 12 | 10 | 2† |

* enhancement at low density consisted of selecting darker output using levels controls
** enhancement at high density consisted of selecting lighter output using levels controls
† following enhancement two root surfaces still were not well-defined



## Experiment 6

Using non-enhanced images and an optimum horizontal section for comparison most kVp settings allowed all 17 possible points of comparison to be made. At low kVp, without enhancement, (50 kVp) portions of the radiographs for comparison did not have sufficient density for visualisation of the more detailed radiolucent structures such as pulp chambers (Table XVI). At higher kVp, cervical burnout and ultimately complete burnout of the image edges resulted in inability to make matches between anatomic landmarks.

**Table XVI Results - Non-enhanced image contrast matching**

| kVp | #steps visible | possible points | points matched | non-matched |
|---|---|---|---|---|
| 50 | 10 | 17 | 6 | 9 |
| 55 | 10 | 17 | 17 | 0 |
| 60 | 13 | 17 | 17 | 0 |
| 65 | 13 | 17 | 17 | 0 |
| 70 | 13 | 17 | 17 | 0 |
| 75 | 11 | 17 | 17 | 0 |
| 80 | 9 | 17 | 17 | 0 |
| 85 | 8 | 17 | 12 | 5 |
| 90 | 7 | 17 | 11 | 6 |
| 95 | 5 | 17 | 10 | 7 |
| 100 | 4 | 17 | 4 | 13 |



Following computer assisted contrast enhancement (allowing for improvements to the length of the contrast scale) it was possible to improve the number of points of alignment / concordance at the high density / short scale end ( greater than or equal to 85 kVp) (Table XVII). With short scale, low density contrast such as that found with the use of 50 kVp the information was not present to enhance and no improvement in the number of points of concordance was evident. Since the images of the step wedge were digitised at the same time as the radiographs it was possible to see improvement in the number of visually evident steps on the step wedge accompanying each image. These improvements are noted in Table XVII in bold type.

**Table XVII Results - Enhanced image contrast matching**

| kVp | #steps visible | possible points | points matched | non-matched |
|---|---|---|---|---|
| 50 | 10 | 17 | 6 | 9 |
| 55 | 10 | 17 | 17 | 0 |
| 60 | 13 | 17 | 17 | 0 |
| 65 | 13 | 17 | 17 | 0 |
| 70 | 13 | 17 | 17 | 0 |
| 75 | 11 | 17 | 17 | 0 |
| 80 | **11** | 17 | 17 | 0 |
| 85 | **10** | 17 | **17** | 0 |
| 90 | **9** | 17 | **15** | 2 |
| 95 | **7** | 17 | **11** | 0 |
| 100 | **5** | 17 | **6** | 11 |

**Experiment 7**

Examination of the influence of horizontal angulation on the ability to match the spatial relationships of the teeth reveals that angulation differences in excess of 10 degrees from the norm results in a rapid deterioration of the ability to use this technique. (Table XVIII) The percentage of matched points was 100 when a difference of 5 degrees from "antemortem" to "postmortem" was maintained. At an angulation of 20 degrees in either direction, this dropped precipitously to less than 40 percent of points being matched. Additionally, the number of comparable points available to match decreased as images of objects were projected off of the film plane. In the clinical application of this technique (section 10 below) this should be taken into account.

**Table XVIII Points of concordance for matching technique with alterations in horizontal angulation.**

| angle (deg) | possible points (on cut section) | possible points (on angled section) | points matched | points non-matched |
|---|---|---|---|---|
| 5 (from posterior) | 17 | 17 | 17 | 0 |
| 10 | 17 | 17 | 5 | 12 |
| 15 | 17 | 16 | 4 | 12 |
| 20 | 17 | 15 | 3 | 12 |
| 25 | 17 | 14 | 3 | 11 |
| 30 | 17 | 13 | 3 | 10 |
| 35 | 17 | 12 | 2 | 10 |
| 40 | 17 | 10 | 2 | 8 |
| 45 | 17 | 8 | 1 | 7 |
| 50 | 17 | 8 | 1 | 7 |
| 5 (from anterior) | 17 | 17 | 17 | 0 |
| 10 | 17 | 17 | 12 | 5 |
| 15 | 17 | 16 | 10 | 6 |
| 20 | 17 | 15 | 6 | 9 |
| 25 | 17 | 13 | 5 | 8 |
| 30 | 17 | 11 | 3 | 8 |
| 35 | 17 | 11 | 2 | 9 |
| 40 | 17 | 9 | 1 | 8 |
| 45 | 17 | 8 | 1 | 7 |
| 50 | 17 | 5 | 1 | 4 |



## Results section 7-2.

Examination of the influence of vertical angulation on the ability to match cut sections for identification purposes reveals that there is no influence on the ability to match horizontal cuts when vertical angulation varies as much as 30 degrees. This is not surprising in that the comparison of the spatial relationships of the teeth is done using a horizontal orientation and changes in vertical angulation would not effect the antero-posterior position of the image of the teeth. (Table XIX)

**Table XIX Points of concordance for matching technique with alterations in vertical angulation.**

| angle (deg) | possible points (on cut section) | possible points (on angled section) | points matched | points non-matched |
|---|---|---|---|---|
| 5 (elongation) | 17 | 17 | 17 | 0 |
| 10 | 17 | 17 | 17 | 0 |
| 15 | 17 | 17 | 17 | 0 |
| 20 | 17 | 17 | 17 | 0 |
| 25 | 17 | 17 | 17 | 0 |
| 30 | 17 | 17 | 17 | 0 |
| 5 (foreshortened) | 17 | 17 | 17 | 0 |
| 10 | 17 | 17 | 17 | 0 |
| 15 | 17 | 17 | 17 | 0 |
| 20 | 17 | 17 | 17 | 0 |
| 25 | 17 | 17 | 17 | 0 |
| 30 | 17 | 17 | 17 | 0 |



**Results section 7.3**

Over the range of focal-spot to film distances used there was no effect on the ability of the operator to discern the matching points. One would expect a slight difference in the 6 cm to 36 cm focal spot to film distance images however this was not borne out when these were objectively analysed. This could be because the object to film distance is quite small in this positioning jig. This would however also be apparent clinically where the most common dental intraoral radiographs (bitewings) have a very close object to film distance (less than 1.5 cm). For this reason changes in focal-spot to film distance would be insignificant when considered in concert with object to film distance. This is demonstrated by the results presented for changes in focal-spot to film distance as depicted in table XX.

**Table Table XX Points of concordance for matching technique with alterations in focal-film distance (object to film distance held constant).**

| focal-film increase (cm) | possible points | points matched | points not-matched |
|---|---|---|---|
| 6 | 17 | 17 | 0 |
| 11 | 17 | 17 | 0 |
| 16 | 17 | 17 | 0 |
| 21 | 17 | 17 | 0 |
| 26 | 17 | 17 | 0 |
| 31 | 17 | 17 | 0 |
| 36 | 17 | 17 | 0 |

**Experiment 8**

All three scanner systems acquired images in less than one minute. The time for image acquisition for the Microtek slide scanner was doubled since the step wedge and the dental periapical radiograph had to be imaged separately but acquisition times were still less than one minute after the software program was uploaded. The features of the different scanners acquisition of images are depicted in Table XXI. The Microtek scanner file size was smaller because the resolution was less (296 dpi vs. 300 dpi) and because when the radiograph was placed in the slide mount the edges were cut off making the scanning area less. This may or may not have practical influence on clinical cases. All the scanners were capable of producing images which were perfectly adequate, from a subjective standpoint for clinical forensic purposes although the XRS scanner image required enhancement for optimal viewing. Objectively, examination of the scanned step wedges exposed with the radiograph showed the Microtek and UMAX systems to be superior as judged by the ability to see a larger number of shades of grey. While it is possible that this is scientifically significant it is not clinically significant.

**Table XXI Properties of different image acquisition devices used in the digitisation of dental radiographs for forensic purposes.**

| Scanner | scan time | file size | contrast normal | contrast enhanced | acceptable image (Y/N) | dpi |
|---|---|---|---|---|---|---|
| XRS | < minute | 270K | 11 | 13 | Y | 300 |
| UMAX | < minute | 232K | 14 | 14 | Y | 300 |
| Microtek | < minute | 164 K | 14 | 14 | Y | 296 |



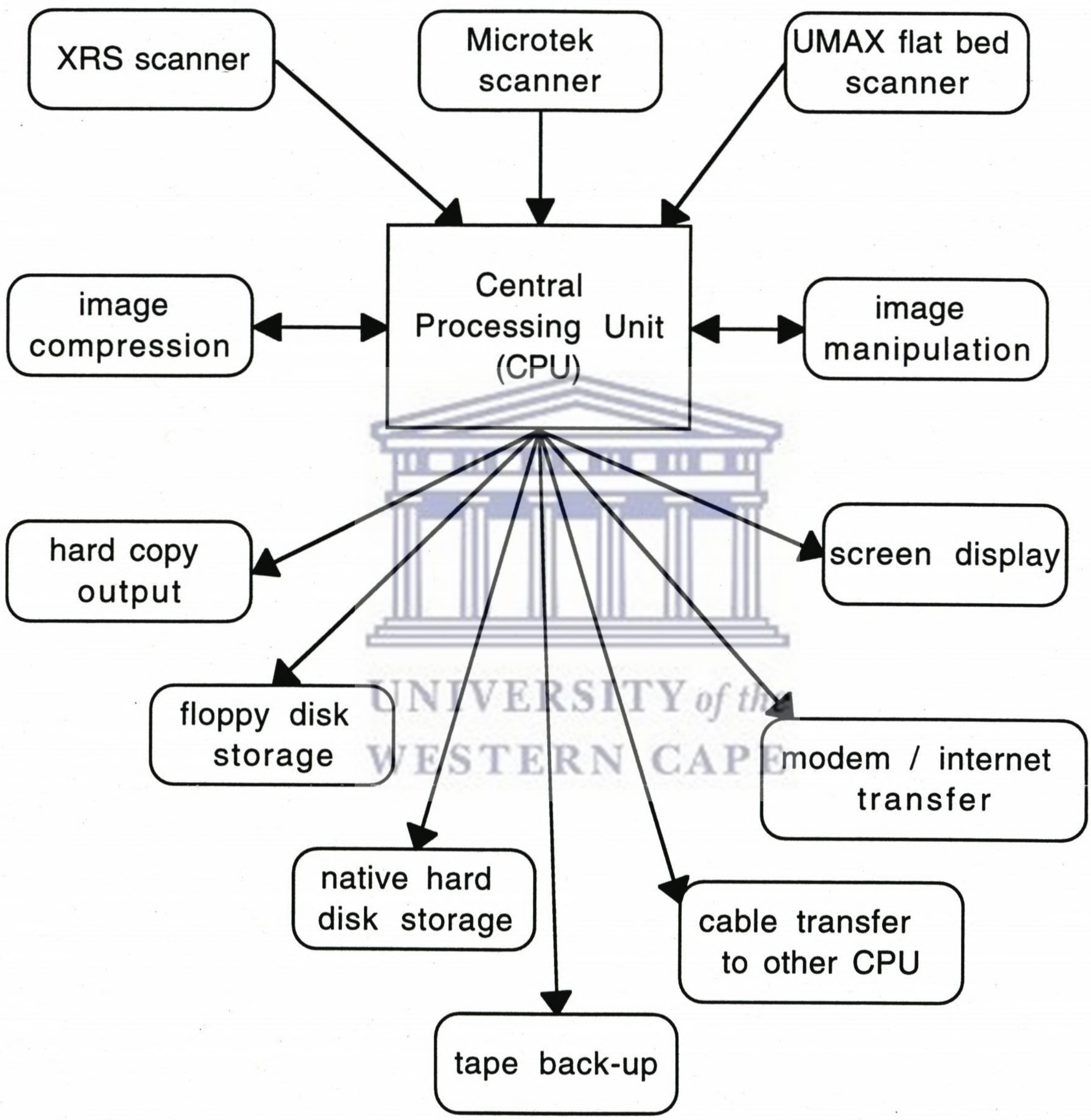
**Experiment 9**

Without any image compression and file sizes in the neighbourhood of 240 K for a typical dental radiograph scanned at 256 shades of grey and 300 dpi resolution, storage is not a problem. Figure 21 depicts the numerous input and storage devices which may be used for data storage.

If images are to be transferred across the World Wide Web (WWW) or Internet, some image compression may be desirable. Figure 20 shows that image compression is associated with image denigration. The author currently saves images as “PICT” files or “GIF” files. If images require compression, “JPEG” is used to compress them. If images are to be sent through the ether, they are UU encoded which converts binary files to non-binary text files. A typical 240 K image can then be downloaded from the Internet or WWW using a web-crawler software package in approximately 5 minutes. After the recipient downloads the file they UU decode it and view it on their own software.

From a practical standpoint this may present a problem since a scanner, software and encoding devices are required at both ends of the transmission. In addition, if using this system in mass disasters the large number of images from antemortem "possibles" would require massive amounts of memory storage. While difficult, it is not impossible. With advancements in technology it is likely that this will be more practical in the future.

Figure 21. Diagram depicting the numerous input and storage devices used for data storage.



**Experiment 10**

Examination of the Coroner's cases reveals the technique of using the horizontal spatial relationships of the root complexes to be highly successful. Unfortunately there was no practical way of introducing non-matches into the Coroner's cases owing to the limited number of cases seen in the Coroner's office per year. This however is addressed in Section 4 above in which non-Coroner's cases were used.

The range of time interval between antemortem and postmortem radiographs was from 1 to 190 months with a mean of 29 and a median of 12 months. (Table XXII) The points available for comparison ranged from 12 on the low end to 54 with a mean number of available points of 35 (s.d. = 12.1). The mean number of aligned points ranged from 10 to 51 with a mean of 32.9 (s.d. = 11.5). Concordance ranged from 83% to 100% with a mean concordance of 93.9 % (s.d. = 4.7). (Table XXIII) The test had 100% specificity, sensitivity and predictive value although this testing must be taken with a grain of salt in that there were no non-matches in this group.

**Table XXII Demographics of study group of Coroner's cases**

| name code | morgue # | circumstances of death | dentition stage | time lapse (months) AM to PM films |
|---|---|---|---|---|
| ANDISON | 4490-025 | suicide | permanent | 60 |
| ARCHIBALD | 4928-368 | unknown | permanent | 72 |
| BAXTER | FPB 301-92 | MVA/fire | permanent | 190 |
| BELLINGHAM | 6026-193 | homicide | permanent | 17 |
| BENFORD | 3142-094 | MVA/fire | permanent | 1 |
| BOTTICELLA | 5112-422 | MVA | permanent | 7 |
| BURT | 3967-412 | Explosion | permanent | 6 |
| CARERE | 5691-049 | Homicide | permanent | 93 |
| COOKE | 3857-127 | Suicide | permanent | 46 |
| DACUNHA | 2073-040 | Misadventure | permanent | 16 |
| DEAN | 3143-095 | MVA/fire | permanent | 29 |
| DERONDE | 3144-097 | MVA/Fire | permanent | 9 |
| FEWKES | ML94-335 | Misadventure | permanent | 24 |
| FRANCIS | 6054-199 | MVA/Fire | permanent | 6 |
| GILMER | 4126-452 | Housefire | permanent | 4 |
| GRANT | 4849-098 | MVA/Fire | permanent | 24 |
| INGRAM | 0703-360 | Fire | permanent | 43 |
| KIRKPATRICK | 2333-091 | MVA/Fire | permanent | 9 |
| KONG | 6052-198 | MVA/Fire | permanent | 6 |
| LAMBE | 3065-242 | Suicide | permanent | 77 |
| LECLERC | 4847-097 | Suicide | permanent | 20 |
| MAKIN | 2729-358 | Fire | permanent | 29 |
| OIKLE | 0636-346 | Fire | permanent | 7 |
| ROBERTS | 5728-280 | Misadventure | permanent | 2 |
| ROCKBURN | 2334-092 | MVA/Fire | permanent | 3 |
| ROSS | 94358 | Suicide | permanent | 12 |
| SANDLER | 4809-090 | Homicide | permanent | 12 |
| SEHGAL | 4165-297 | Suicide | permanent | 7 |
| SELIN | 4219-312 | Homicide | permanent | 36 |
| STALEY | unknown | House fire | early mixed | 6 |

**Table XXIII Application of digital cut technique in matching of actual antemortem and postmortem radiographs in Coroner's cases.**

| Subject | time lapse (months) | points aligned | concordance | match (Y/N) | accepted (Y/N) |
|---|---|---|---|---|---|
| ANDISON | 60 | 40 of 42 | 95% | Y | Y |
| ARCHIBALD | 72 | 34 of 34 | 100% | Y | Y |
| BAXTER | 190 | 20 of 21 | 95% | Y | Y |
| BELLINGHAM | 17 | 47 of 50 | 94% | Y | Y |
| BENFORD | 1 | 43 of 45 | 96% | Y | Y |
| BOTTICELLA | 7 | 28 of 28 | 100% | Y | Y |
| BURT | 6 | 46 of 48 | 96 % | Y | Y |
| CARERE | 93 | 43 of 47 | 91% | Y | Y |
| COOKE | 46 | 16 of 16 | 100% | Y | Y |
| DACUNHA | 16 | 48 of 50 | 96% | Y | Y |
| DEAN | 29 | 16 of 17 | 94% | Y | Y |
| DERONDE | 9 | 51 of 54 | 94% | Y | Y |
| FEWKES | 24 | 44 of 46 | 96 % | Y | Y |
| FRANCIS | 6 | 32 of 36 | 88% | Y | Y |
| GILMER | 4 | 28 of 33 | 85% | Y | Y |
| GRANT | 24 | 10 of 12 | 83% | Y | Y |
| INGRAM | 43 | 24 of 27 | 89% | Y | Y |
| KIRKPATRICK | 9 | 35 of 35 | 100% | Y | Y |
| KONG | 6 | 32 of 35 | 91% | Y | Y |
| LAMBE | 77 | 19 of 21 | 90% | Y | Y |
| LECLERC | 20 | 35 of 39 | 90% | Y | Y |
| MAKIN | 29 | 34 of 34 | 100% | Y | Y |
| OIKLE | 7 | 41 of 43 | 95% | Y | Y |
| ROBERTS | 2 | 18 of 18 | 100% | Y | Y |
| ROCKBURN | 3 | 37 of 42 | 88% | Y | Y |
| ROSS | 12 | 22 of 24 | 92% | Y | Y |
| SANDLER | 12 | 41 of 46 | 89% | Y | Y |
| SEHGAL | 7 | 51 of 53 | 96% | Y | Y |
| SELIN | 36 | 23 of 23 | 100% | Y | Y |
| STALEY | 6 | 29 of 31 | 94% | Y | Y |



Inter-operator and intra operator error testing (Table XXIV) revealed that the test is reproducible although the same number of points and the same number of matched points varies both between and within each examiner. Examiner two did not score as many matches as examiner one. This may be explainable on the basis of examiner 2 using the whole pulp as a "point" of identification whereas examiner 1 used the mesial and the distal of the pulp as separate points. In addition examiner one (the author) has used this technique extensively and examiner two had never used this technique. It is reasonable to assume that with increased use the ability to align the cut section from antemortem to postmortem would improve and scores (and especially concordance) would increase. It is interesting to note that although examiner two had never used the computer system nor the matching program he was able to use the technique effectively within one half hour.

**Table XXIV Inter-operator error and intra operator error evaluation.**

| | operator one | operator one (repeat) | operator two |
|---|---|---|---|
| Andison | 40 of 42 (95%) | 38 of 42 (90%) | 28 of 35 (80%) |
| DaCunha | 48 of 50 (96%) | 46 of 50 (92%) | 42 of 50 (84%) |
| Deronde | 51 of 54 (94%) | 47 of 50 (94%) | 26 of 34 (76%) |
| Sandler | 41 of 46 (89%) | 41 of 46 (89%) | 41 of 49 (84%) |
| Staley | 29 of 31 (94%) | 27 of 30 (90%) | 23 of 28 (82%) |

## Discussion:

The system as tested seemed to be fairly resistant to most changes in image production and was able to be used in the paediatric, and adult dentitions. Despite this one must pose the question as to how the technique, as outlined above can be applied to the general problem of person identification.

In logical analysis of the basic methodology as outlined in experiment 1 there is an inherent selection bias. In the performance of this *in vitro* experiment the hemi-mandibles were selected for the presence of teeth. If this technique is to be generalised to the population at large the assumption of the presence of some teeth would certainly be false. In approximately 5 per cent of the authors 180 identification cases at the Office of the Chief Coroner of Ontario there are no natural teeth to analyse. This figure is probably artificially low since the author is called infrequently in cases where no teeth are present. Although this makes the technique useless (assuming there are no bony landmarks to utilise) it also makes conventional dental identification very difficult. (24, 170) The absence of teeth is a problem in dental identification in mass disasters thereby making this type of identification method a problem. In certain mass disasters large numbers of subjects may be edentulous underscoring this limitation of the technique. (12) This relative contra-indication of the technique may be of less importance as the patients who have had benefit of fluoridated drinking water and good dental care results in a population with a greater number of natural teeth. (179, 180)

In the authors clinical experience rats and other rodents can remove teeth from skeletonised remains thereby rendering the deceased "edentulous postmortem." This has been documented in the literature previously. (52, 75) Teeth can also be lost during incineration (8) or as a result of decomposition of the periodontal ligament followed by positional changes which would favour gravity mediated tooth loss.

The postmortem loss of teeth creates a serious problem for all dental identifications and would obviously render conventional dental identification (such as analysis of dental intervention) difficult. Smith (1992) demonstrated a method whereby partial tooth reconstruction was undertaken in order to compare root morphology. (178) Using the proposed technique it would be unnecessary to physically reconstruct the teeth since the socket bone would be well visualised on the postmortem radiographs. It could then serve as comparison landmarks with antemortem images of the socket bone. This then is clearly an advantage of this digital comparative technique over the, at least partially reconstructive technique described by Smith (1992) (178)

Another potential point of criticism of the basic methodology portion of the experiment is the selection of a single set of exposure parameters for the entire in-vitro set of experiment one procedures. This is undeniably not true of any group of practising dentists whose exposure parameters would reasonably be expected to be highly individualistic. Frequently individual dentists will use combinations of exposure parameters and developing techniques which will alter the resultant image produced dramatically. This problem will be addressed below. There were no tests of processor errors and their possible influence on the ability to use this technique. It is difficult to quantify most processor errors reliably and ultimately the processing error will result in a change to the contrast or density which are addressed below. If however a film-processing error results in a non-diagnostic or clinically unacceptable image its future use for comparison is dubious.

Despite this, in the authors experience, digital manipulation of poorly processed images may enhance them to the point at which conventional dental identification techniques may be used. In addition, there is a myriad of potential processing problems which may denigrate the image in other ways but are beyond the scope of this thesis. (183)

Throughout the design and implementation of all the experiments with the exception of the Coroner's cases, there was uniform film shape. This means that the image receptor (film) was always flat. Anyone who has practised dentistry and exposed radiographs knows intuitively that the image receptor, in a live subject may be bent deliberately in an attempt to make it more tolerable for the patient. In addition patients may alter the plane of the film by tongue pressure or floor of mouth action. This was not specifically examined for in this paper and could be the subject of further investigation. It is not a problem in postmortem radiography since tissue may be manipulated to fit the film, even in viewable remains. If a film is bent relative to the object and central ray of the x-ray beam then the resultant image is skewed. This is partially overcome in this technique by using the mid-root area for the digital cut which would be less likely to be "bent" than apical regions. It may also be overcome by machining blocks to which the image receptor could be attached. Such blocks could be used to recreate film curvatures. Use of this technique should be done with caution since it puts the postmortem examiner in a situation in which he is attempting to potentially falsely match the antemortem and postmortem landmarks.

Adobe Photoshop ® was used in this study because it is widely available commercially. It may be run on numerous computer operating systems and is relatively cheap. Other image manipulation programs are available on the market and even as "freeware". They were not used here since the author was familiar with the program and its many uses. Adobe Photoshop can be used to degrade images by manipulation of matrix sizes, and shades of grey. Such manipulations could potentially be used to assess the quality of dental radiographic images for forensic purposes and could be a potential avenue of further research. It is likely that using 256 shades of grey and 300 dots-per-inch resolution is in excess of that needed for the balance between adequate image detail and file size.

The author did not fully explore all the features of the Photoshop program. There were no purposeful alterations in scale nor were there attempts to skew images. Both are possible using Photoshop. Scaling of objects could be of use in cases where images were magnified however table XXI shows that gross changes in focal film distance, which might be expected to result in magnification did not limit the utility of this technique.

Another consideration in the implementation of the technique would be to determine the minimum and maximum useful height (and length) of digitally cut sections which can be matched from antemortem to postmortem. Throughout the experiment the height of the cut was restricted to between 1/3 and 1/5 of the total root length. This proved to be adequate and could probably be used as a good general guide.

Despite the development of the concept of concordance and acceptance of a match the judgment of whether a point matches or not is still - a judgment. The technique, in the authors opinion could never be used without the careful supervision of a forensic dentist. This is not a weakness since even sophisticated dental matching programs require the forensic dentist to make the final "call." (132,133,177) The presence of a match or non-match therefore must also rest with the responsible individual(s) as per other identification techniques.

In the implementation of the *in vitro* portions of the experimental methodology the specimen was specifically reversed with respect to its buccal-lingual orientation as a deceit. Although this was done as a purposeful measure by the author the reversal of right and left sides of a mandible is easy to do in fragmented remains and in small specimens. It has occurred in the authors practice on numerous occasions.

Examination of the results of experiment one reveal that in a single case there is a high degree of specificity with a high degree of match. (100 % concordance). In part two of experiment one it was not possible to falsely match the control radiograph to any of the other specimens. This speaks volumes about the specificity of the technique. Specificity is of paramount importance in the subject of dental identification. If a match cannot be made the unknown body remains unknown and could potentially be identified later using other means. If however specificity is low and an unknown deceased is falsely identified as someone else serious consequences can ensue. (45) In a forensic identification method specificity is therefore far more important than sensitivity although both qualities would be useful. In part three of experiment 1 the mock mass disaster resulted in a perfect match of all thirty-nine specimens. This result may not be generalise to an *in vivo* population however since there were no dental interventions, nor potential temporal changes possible in this limited study. In addition it is highly unlikely that fragmented remains would yield specimens of as high a quality as those used in this experiment. (41,135,139)

With regards to the practicality of the technique in the paediatric dentition the results are convincing. (Table X) Despite this, one case could not be identified using this technique. It is important to note that once again the problem was not one of misidentification but inability to identify in case # 117 (Table X). The inability to match in this case is probably more a function of gross geometric differences between the "antemortem" and "postmortem" images. In a mortuary situation this could be accounted for by purposefully altering the image geometry so that the antemortem error could be reproduced in the postmortem image.

The optimistic forecast of the utility of this technique must be tempered with the realisation that the paediatric dentition is not a stable one. It is highly variable since posterior primary teeth can only be expected to remain for a short period of time. The eruption of new primary teeth as the paediatric dentition develops would confound the problem of spatial relationships as an evaluative tool. Equally important is the loss of both posterior primary teeth, eruption of the permanent first molar and loss of the anterior primary teeth all of which may exert an effect on the ability to make a positive match based on spatial relationships of tooth-root complexes. Once again the author directs you to the important point that despite these limitations the test, as used was highly specific with specificity and predictive value of 100%. Sensitivity was also quite high at 91% despite the potential limitations described above. Once again a non-identification is not as grievous an error as a false identification and the solid nature of the test as used in the primary dentition holds true.

The solid utility of the test in the mixed dentition as reflected in the results of experiment 3 is exceedingly not solid. The use of spatial relationships of the teeth is not possible in the mixed dentition. I believe may be generalised to the population at large. This limitation is not extraordinary since by definition the mixed dentition is one of the most dynamic stages of human dental development. This is due in part to the exfoliation of primary teeth and the eruption of permanent teeth. (Table XII) It may also be due at least in part to the highly individualistic manner in which the buccal segments of teeth re-arrange themselves during closure of the buccal segments. It is therefore reasonable to expect that this technique will not work during the mixed dentition. Of interest is the 100 % specificity the test exhibited. This figure may be spurious since the predictive value and sensitivity was 0 % although it does indicate once again the ability of the test to not include false positives. It should also be noted that the test may be useful in individual cases where there has not been a great deal of change in the buccal segments and tooth eruption. The use of spatial relationships of the teeth in the mixed dentition should be undertaken with caution.

There is little doubt of the remarkable ability of the dental spatial relationship analysis to accurately discriminate cases within the permanent dentition. The author is surprised at the length of time over which the technique remains valid. Inter-proximal attrition resulting from normal occlusal function should have shortened the crown width and therefore altered the spatial orientation of the teeth. Despite this the technique was used in one patient with a time span between "antemortem" and "postmortem" of 29 years. One case (JC-R) was not able to be matched due to gross changes in the dentition between "antemortem" and "postmortem."

One may pose the question as to why the technique remained valid over such a length of time. Certainly part of this is due to the skill and uniformity of technique used by the dentist from whom these files were culled. It is reasonable to assume that his technique would remain similar throughout his practising years. It follows then that radiographs such as those received from Coroner's offices (and therefore from different dentists) would not share this uniformity of technique. Fortunately the postmortem radiographs can be exposed without concern to the radiation dose received so that the postmortem radiographs of deceased persons can be matched to the antemortem ones. The sensitivity is less than perfect at 91% but the specificity of 100% more than makes up for this small reduction in sensitivity. It seems that dental spatial relationship analysis is a valid tool when applied to a clinical situation in cases with good image quality and standardised technique. Further, the technique can be used in cases with extensive time intervals between antemortem and postmortem radiographic examinations.

Image density can be problematic in attempts to adequately see tooth-root complexes. The human eye can generally see images ranging from 0.2 optical density to 2.0 optical density. (183) Density of images outside that range are generally not appreciated. In the viewing of tooth-root complexes a more narrow range of useful optical density may need to be defined. This could be the purpose of further research. It is interesting to note that there is not a single study delineating the range of useful densities at which common dental anatomic structures (or pathoses) can be appreciated.

Alteration of density by adjusting mAS is a reasonable means of changing density since upward adjustment of mAS results in a greater number of photons and therefore a darker image. Downward alteration of mAS results in a lighter film for the same reason. However if the number of photons is too low, quantum mottle will result and the image will be useless. (183) Fairly gross alterations in density had little effect on the ability to analyse the spatial relationships of the teeth. (Table XIV) At very high density the edges of structures were burned out and they could not be discerned with any degree of accuracy. The two exposure factors used in these cases (105 /60ths of a second and 2 seconds) are far in excess of any settings which would be used in private dental practice. In addition, alteration in density of images would only be a confounding factor in antemortem radiographs since postmortem dental radiographs could be re-taken with new exposure factors to yield optimal image density.

Another means of increasing optical density on dental radiographs is by the action of "fog." Fogged films result from numerous causes including excess developer temperature, inadvertent exposure, poor storage conditions and advanced age of the film. (183) The author has encountered fogged film in his clinical forensic practice but it has not proven to be a problem in dental identification.

Computer-assisted enhancement of density to allow correction of under or over-exposure was helpful in increasing the number of matching points. (Table XV) If however the radiographs were excessively dense the problem was harder to correct. The correction itself was accomplished with simple keyboard commands in a matter of seconds.

It remains unclear as to the density of incoming antemortem radiographic records. Actually the general image quality of radiographs from clinical forensic cases has not been studied. Sufficient materials exist for examination of antemortem radiographs and perhaps this will be the subject of further investigation.

The effect of alteration of kVp on image quality does result in a diminished number of steps visible on the step wedge accompanying each image. (Table XVI) There were fewer number of the "thicker" parts of the aluminium step wedge visible at the low kVp settings and fewer parts of the "thinner" portions of the aluminium step wedge visible at the higher kVp settings. While this did have an effect on the ability to match "antemortem" and "postmortem" images adequately it may have been partially a function of the resultant increased density of higher kVp images. With higher kVp, more photons pass through the object and reach the film making the resultant image more density. This relationship between image density and kVp is not linear. (183) Image density increases in a linear manner with changes in mAS however image density increases dramatically with alterations in kVp. This can be appreciated by comparing the last four lines of tables XV and XVII where it may be observed that image degradation (and ability to make a match) falls off more dramatically with incremental increases in kVp as compared to image degradation with incremental increases in mAS.

Once again computer enhancement allowed some of these particularly short scale contrast images to be "rescued." If the radiographs were particularly light however (Table XV!! 50 kVp) there was insufficient image to allow enhancement. If the image was very dark with short scale contrast the image was not able to be lightened up to a sufficient degree to allow comparison. Examination of the number of steps visible (Table XVII column 2) reveals that the enhancement did indeed result in improved contrast and was not entirely a density effect. It must again be emphasised that mistakes in kVp selection would be an antemortem problem since postmortem radiographs could be attempted numerous times. It is a strength of the system that computer enhancement of the contrast could be applied to antemortem images to make them more suitable for comparison purposes.

Horizontal angulation is a critical factor in the application of this technique. In bitewing and most other intraoral dental radiographic studies the horizontal angulation is intended to pass directly through the contact points of the teeth. Examination of Table XVIII reveals that an angle change of 10 degrees or more in the horizontal angulation makes comparison of the antemortem and postmortem dental radiographs impossible with respect to spatial relationships of the tooth-root complexes. At and after a 10 degree tube shift matching is impossible using this technique with 17 points of potential matching dropping to from a ratio of 17 :17 matched to possible to 5:17 matched to possible. The diminution progresses with each 5 degree angle change. Table XVIII At excessive horizontal angulations (45 to 50 degrees from normal) a single point can be matched. This is because it is always possible to demonstrate at least one periodontal ligament shadow despite the horizontal angulation change between antemortem and postmortem. It is reasonable to assume that dentists could err in the range of 10 degrees in the exposure of radiographs but once again this is critical only for the antemortem radiographic examination. If the positioning jig is judiciously used it is possible to match the postmortem image geometry to the antemortem image geometry. Enhancement of the image is not possible using horizontal angle changes. This is because radiographs are shadows and not pictures. If enough radiographs are available and their image geometry is known it is potentially possible to re-construct the object although this would be completely impractical in a forensic dental radiographic setting.

Vertical angulation had no effect on the utility of the technique. Even deliberately fore-shortened and elongated images (up to 30 degrees from the norm) had no effect on the ability to use the spatial relationships of the teeth for identification. (Table XIX) It is not likely that dentists would err greater than 30 degrees in vertical angulation in routine clinical practice. If however vertical angulation was so grotesquely off in a manner which would cast the shadows of the crowns of the teeth over the mid-root region the technique could not be used. The use of the mid root region rather than the apex of the teeth or the coronal aspect was selected for use arbitrarily at the commencement of Experiment 1. This selection was serendipitous in that the mid root region is probably the most stable and reproducible portion of the image of the tooth-root complex owing to both its anatomic position and the fact that it lies in the centre of the axis of vertical rotation.

One area which was not addressed specifically in this experiment was the possibility of having both horizontal and vertical angulation changes in tandem (and perhaps in different directions) as a means of confounding the system. While this is not only possible but probable in clinical dental practice the design of the positioning jig allows for independent correction of both vertical and horizontal errors in antemortem film production when preparing the postmortem radiograph. As mentioned above it is also possible to bend the film and this cannot be corrected using the positioning jig as outlined in this thesis.

Focal spot to film distance as used in this study had no influence on the ability to use this technique. This is not surprising since the object film distance was so small. The image produced by a dental x-ray can be likened to a shadow. If the object (the tooth) is close to the film then the shadow of the tooth will be an accurate depiction of the object. If the focal spot is exceedingly close to the object and the film is further away from the object, then the shadow (or image) of the tooth on the film will be much larger than the tooth itself. Therefore if there are gross differences in the focal spot to film to object differences one would expect that relating vertically oriented landmarks would be made difficult. This was not the case either *in vitro* (Table XX) or *in vivo* (Table XXII and XXIII).

With regards to the scanning systems used it seems that all three are adequate. Interestingly the scanner specifically designed for radiograph scanning performed the poorest (albeit slightly). This is possibly due to the age of the machine which predates its sister scanners by approximately 5 years. As computer technology marches on it is not surprising then that newer generation machines produce clearer pictures requiring fewer enhancements. Both flat field scanners (the 3CX and the UMAX 840) have a decided advantage in that they can scan numerous dental radiographs at a time. This would be particularly good in mass disaster situations where a number of antemortem and postmortem radiographs could be evaluated on screen with a single scanning pass. The Microtek slide scanner scans only a single dental radiograph at a time. Although its image quality is excellent, from a practical standpoint single images have to undergo multiple manipulations in order to appear on a single screen. These include scanning the first image, changing the canvas size, scanning the second image, copying the second image to a clipboard and then importing the second image into the first file. If a third and fourth images are to be included further alterations to canvas size and file transfers are required. All the systems used do not use video-camera capture systems. I believe this to be an advantage in that it is possible that video camera lenses are not distortion free and therefore can introduce an error which could reduce the sensitivity of the test. Additionally, all three systems allow selection of both matrix size (dots per inch) and shades of grey (16 or 256). The 3CX and the UMAX 840 also allow a bright light and a dim light scan for overexposed and underexposed radiographs respectively. The scan time of less than one minute is excellent as were the contrast measures and the file sizes. (Table XXI) Finally the file sizes (uncompressed) are quite small for small numbers of bodies. If one were to receive 20 antemortem and 20 postmortem images for 300 air passengers however the resulting disk storage space would have to be in excess of 28 million kB. This would represent a logistical problem for the computers in which the image manipulation software is designed for. It could be partially overcome by deleting records (or storing them on other storage devices) once they have been matched.

Without image compression it is easy to see that personal computers would run out of usable space quickly when large numbers of bodies are involved. Image compression then seems to be the answer although it is always accompanied by image degradation. If individual images are acquired through the WWW or Internet a typical web crawler can acquire such radiographic images in less than 2 minutes which is certainly faster than images can be mailed or shipped. A mock mass disaster in which the technique was used to be the sole means (or perhaps adjuvant means) of identification would have to be analysed for man-hour and cost savings as was done with the Woodbridge disaster computer analysis undertaken by Kogon (1974). (12) Finally the availability of scanning systems at distant sites may be limited making the delivery of antemortem dental radiographic records as slow as it was prior to electronic mail. It would be wonderful to have a world-wide web of available scanning systems for this purpose but that development is highly unlikely.

Examination of the analysis of actual Coroner's cases is the indisputable proof that the technique is clinically applicable. These Coroner's cases included many victims who were macerated, burned, and decomposed. All of them had different dentists practising in different geographic locations and while some had recent antemortem records some did not. The specificity of the test was 100 % which is impressive. One may argue that since the forensic dentists presented with a putative identification based on other factors he is liable to confirm what he already thinks. The author disagrees with this notion since the reputation of the forensic dentist hangs on a case to case balance. The forensic dentists career is always one mistake away from being over and there is a tendency (subjectively) for forensic professionals to try and prove that the identification is not possible rather than the obverse.

The Coroner's cases utilised did not have subjects in their mixed dentition and as mentioned previously this could present a serious problem in clinical work.

Intra and inter-operator error level of agreement were reasonable. Operator one (the author) has extensive experience in using the technique so it is not unreasonable for the author to have acquired a greater skill at its use. Additionally the experienced operator may be more likely to reach the same level of concordance at the second attempt. Operator two was completely inexperienced with the technique but managed to reach acceptable levels in a short period of time after only the barest introduction.

The technique of analysis of the spatial relationships of the teeth from antemortem to postmortem images is a valid one for forensic dental identification.

How then can it be integrated in forensic dental practice ? Spatial relationships of the teeth must be considered to be a comparative rather than a reconstructive method of identification since it is based on a comparison of antemortem and postmortem radiographs. Its utility has been demonstrated in this series of experiments both *in vitro* and *in vivo*. Reconstructive aspects of the technique include alterations in the quality of images to make them suitable for comparative techniques and also alterations in postmortem images by means of adjusting image geometry using the positioning jig. Despite the reconstructive aspects of the technique the technique itself is still, ultimately, a comparative one.

It must also be considered to be a primary means of identification since it utilises antemortem and postmortem image comparisons. It depends only upon the accuracy of the dental radiographic records which are generally thought to be superior to chart based comparisons. (157) While it is possible that radiographs can be missing or changed from chart to chart this is also a weakness of conventional dental radiographic identification.



Application of the technique is limited by logistics. If an operator is familiar with the technique it would add approximately one hour to a dental identification. This is not a problem in cases in which there is a single or a few bodies by would be a serious impediment to cases of mass disaster. Integration of the system into a Coroner's office practice has been successfully undertaken by the author although it has not been tested in a mass disaster yet. Its use in mass disasters must be questioned due to the inordinate amount of time it would add to the identification. It could be brought in to a mass disaster situation as an adjunct means of identification and may prove useful in subjects with minimal dental intervention.

## Conclusions and acceptance or rejection of hypothesis:

1.1 "It is possible to match a known "antemortem" to its corresponding known "postmortem" image using the horizontal slice technique".

This hypothesis is accepted. It is possible to match a known "antemortem" to its corresponding known "postmortem" image using the horizontal slice technique.

1.2 "It is impossible to match an "antemortem" image of one specimen to a "postmortem" image of another specimen in this closed population group".



This hypothesis is accepted. It was impossible to match an "antemortem" image of one specimen to a "postmortem" image of another specimen in this closed population group of mandibular anatomic specimens.

1.3 "It is possible to use this technique in a closed mock mass-disaster of known size".

This hypothesis is accepted. It was possible to use this technique in a closed mock mass-disaster of known size.

2.1 "Identification is possible in the paediatric dentition when there is temporal space between "ante mortem" and "post mortem" examinations".

This hypothesis is accepted. Identification was possible in the paediatric dentition when there is temporal space between "ante mortem" and "post mortem" examinations.

3.1 "Identification is possible within the mixed dentition when comparing the spatial relationships between "antemortem" and "postmortem"pairs of radiographs.

This hypothesis is rejected. Identification is not possible within the mixed dentition when comparing the spatial relationships between "antemortem" and "postmortem" pairs of radiographs.



4.1 "Identification is possible in the permanent dentition when the spacing between "antemortem" and "postmortem" examinations is chronologically protracted "

This hypothesis is accepted. Identification is possible in the permanent dentition when the spacing between "antemortem" and "postmortem" examinations is chronologically protracted.

5.1 "Density of the image has no effect on the ability to adequately visualise the structures of interest for forensic identification."

This hypothesis is accepted. Density of the image has no effect on the ability to adequately visualise the structures of interest for forensic identification. It is noted that at extremes of density the technique will not be able to be used due to excessively light or excessively dark radiographs.

5.2 "Density of the image can be enhanced to increase the degree of matching of anatomic structures as viewed radiologically."

This hypothesis is accepted. Density of the image can be enhanced to increase the degree of matching of anatomic structures as viewed radiologically. The increase in image quality however is modest.



6.1 "Radiographic contrast of the image has no effect on the ability to adequately visualise the structures of interest for forensic identification using horizontal image sections."

This hypothesis is rejected. Radiographic contrast of the image has an effect on the ability to adequately visualise the structures of interest for forensic identification using horizontal image sections

6.2 "Contrast of the image can be enhanced to increase the degree of matching of anatomic structures as viewed radiologically."

This hypothesis is accepted. Contrast of the image can be enhanced to increase the degree of matching of anatomic structures as viewed radiologically.

7.1 "Horizontal angulation of the beam has no effect on the ability to adequately visualise the structures of interest for forensic identification."

This hypothesis is rejected. Horizontal angulation of the beam has a marked effect on the ability to adequately visualise the structures of interest for forensic identification.

7.2 "Vertical angulation of the beam has no effect on the ability to adequately visualise the structures of interest for forensic identification."



This hypothesis is accepted. Vertical angulation of the beam has no effect on the ability to adequately visualise the structures of interest for forensic identification.

7.3 "Change in the focal film distance has no effect on the ability to adequately visualise the structures of interest for forensic identification."

This hypothesis is accepted. Change in the focal film distance has no effect on the ability to adequately visualise the structures of interest for forensic identification.

8.1 "All three scanning systems are adequate for use in evaluating dental radiographic images for forensic purposes."

This hypothesis is accepted. All three scanning systems are adequate for use in evaluating dental radiographic images for forensic purposes.

9.1 "Digital images can be compressed, stored, sent via electronic mail, and re-assembled at a distant site for evaluation".

This hypothesis is accepted. Digital images can be compressed, stored, sent via electronic mail, and re-assembled at a distant site for evaluation.

10-1 "The analysis of the spatial relationship of the teeth as examined on digitised dental images allows for identification to be made".



This hypothesis is accepted. Identifications could be made on actual Coroner's cases.

10.2 "Intra operator error and intra operator error will be within acceptable ranges".

This hypothesis is accepted. It is noted that familiarity with the technique is likely to improve an examiner's ability to utilise this technique.

## 10.3 "The system can be learned and used within a reasonable length of time".

This hypothesis is accepted. It is noted that performance may improve with increased use of the technique and further case work.

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## Appendices:

Appendix A - Flow charts of the basic experimental design.

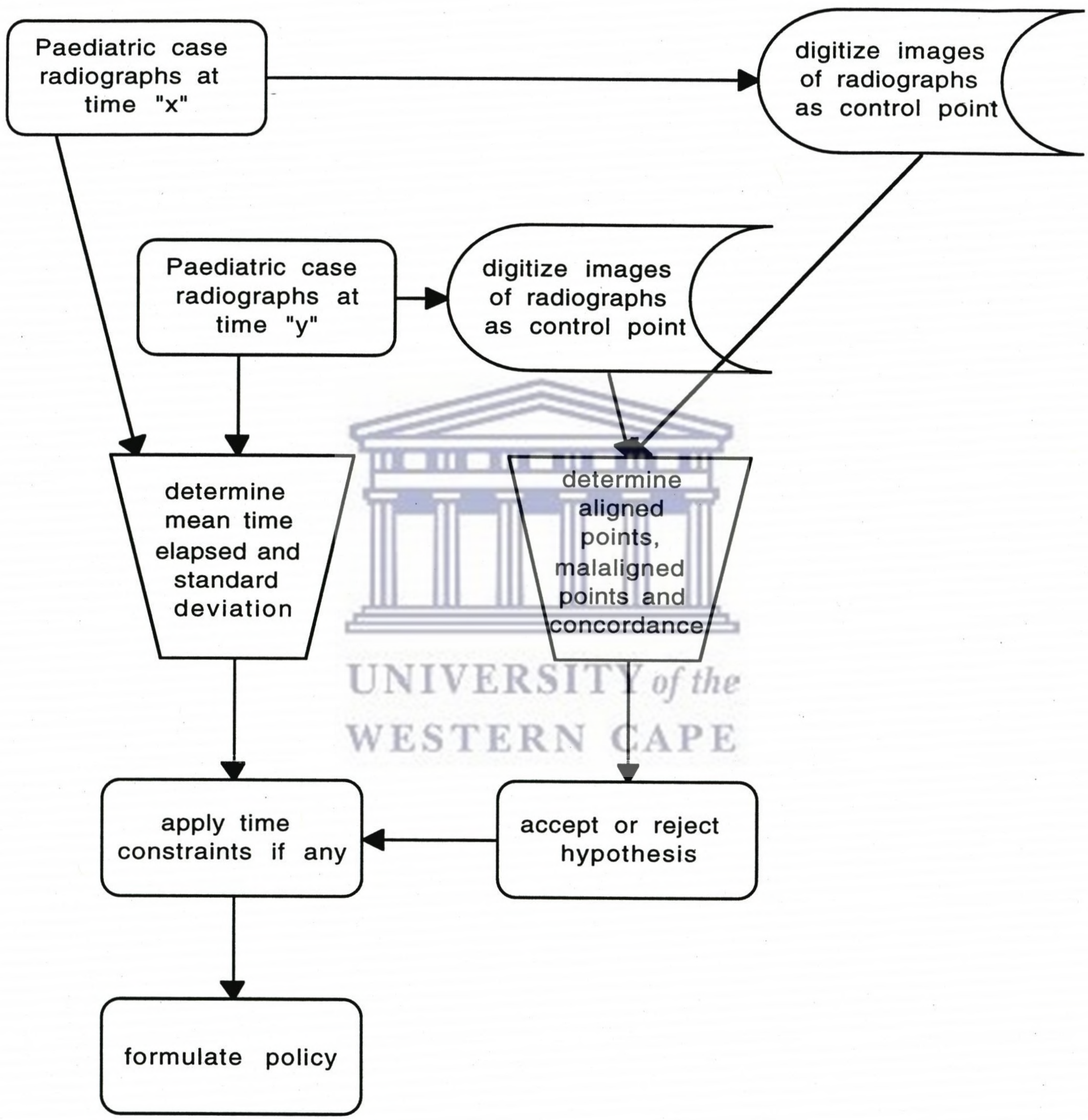
Appendix B - Plans for the radiographic positioning device.

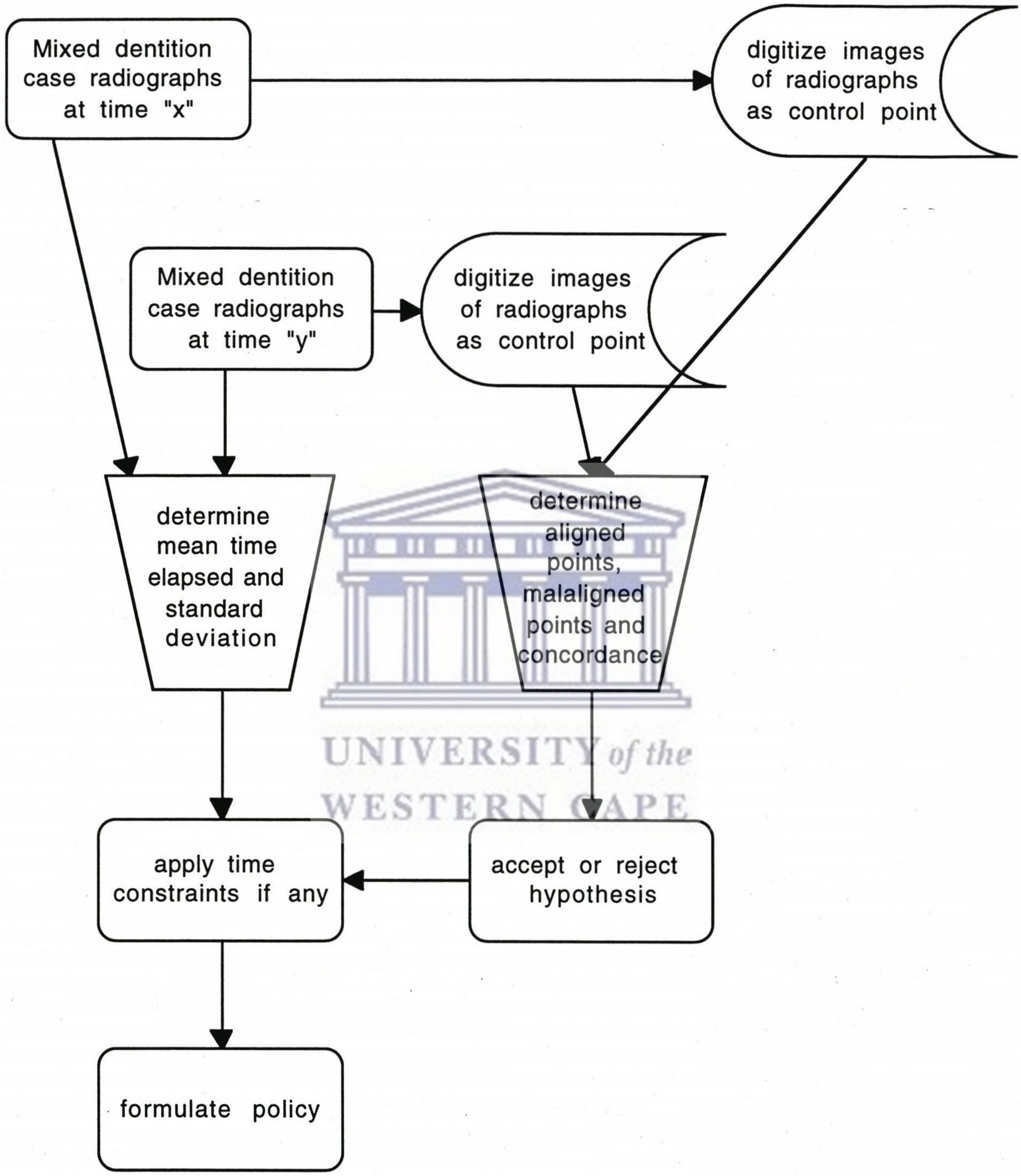
Appendix C - Jaw (dry) specimen measurements.

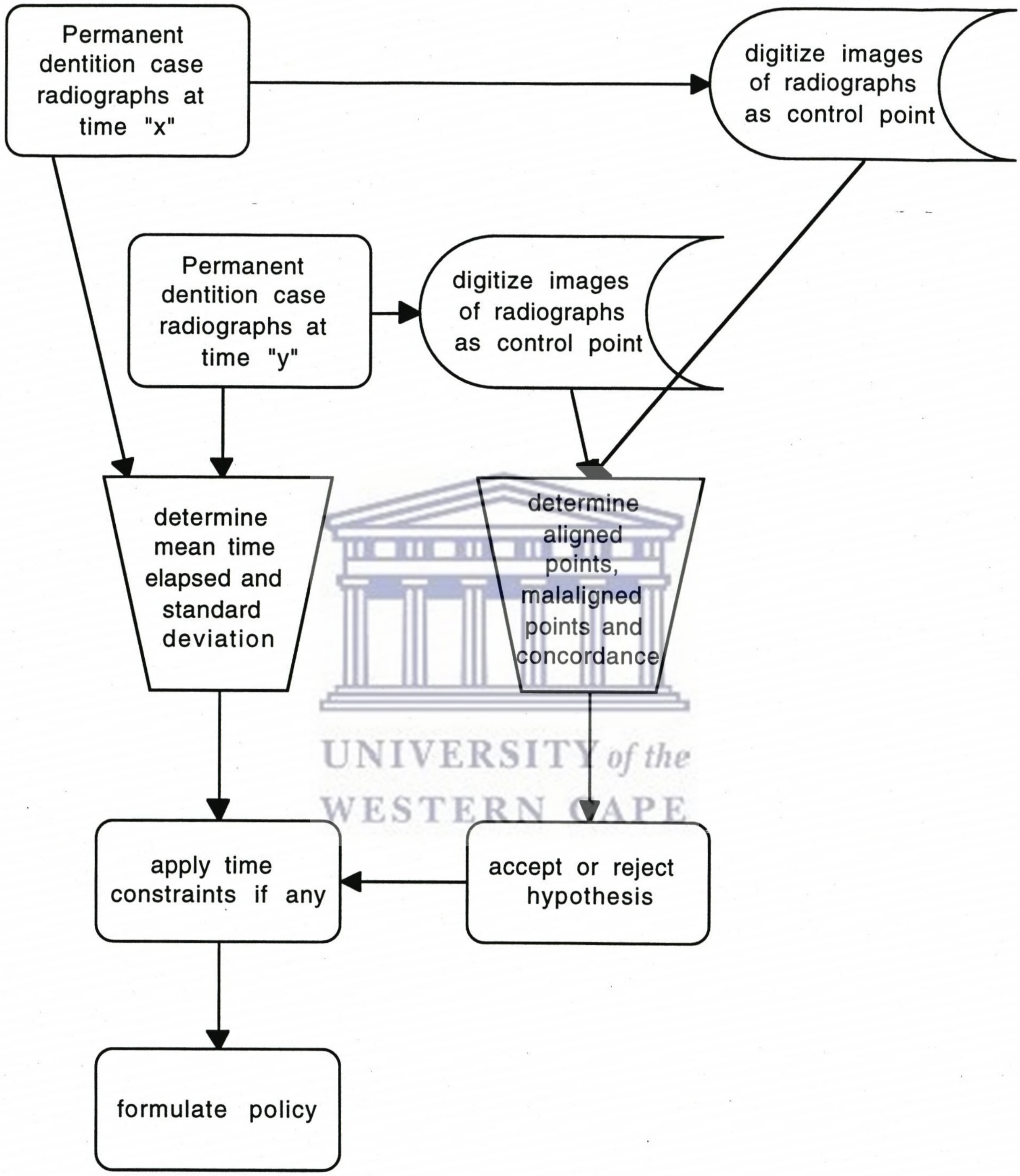
Appendix D - List of equipment used in the experiment.

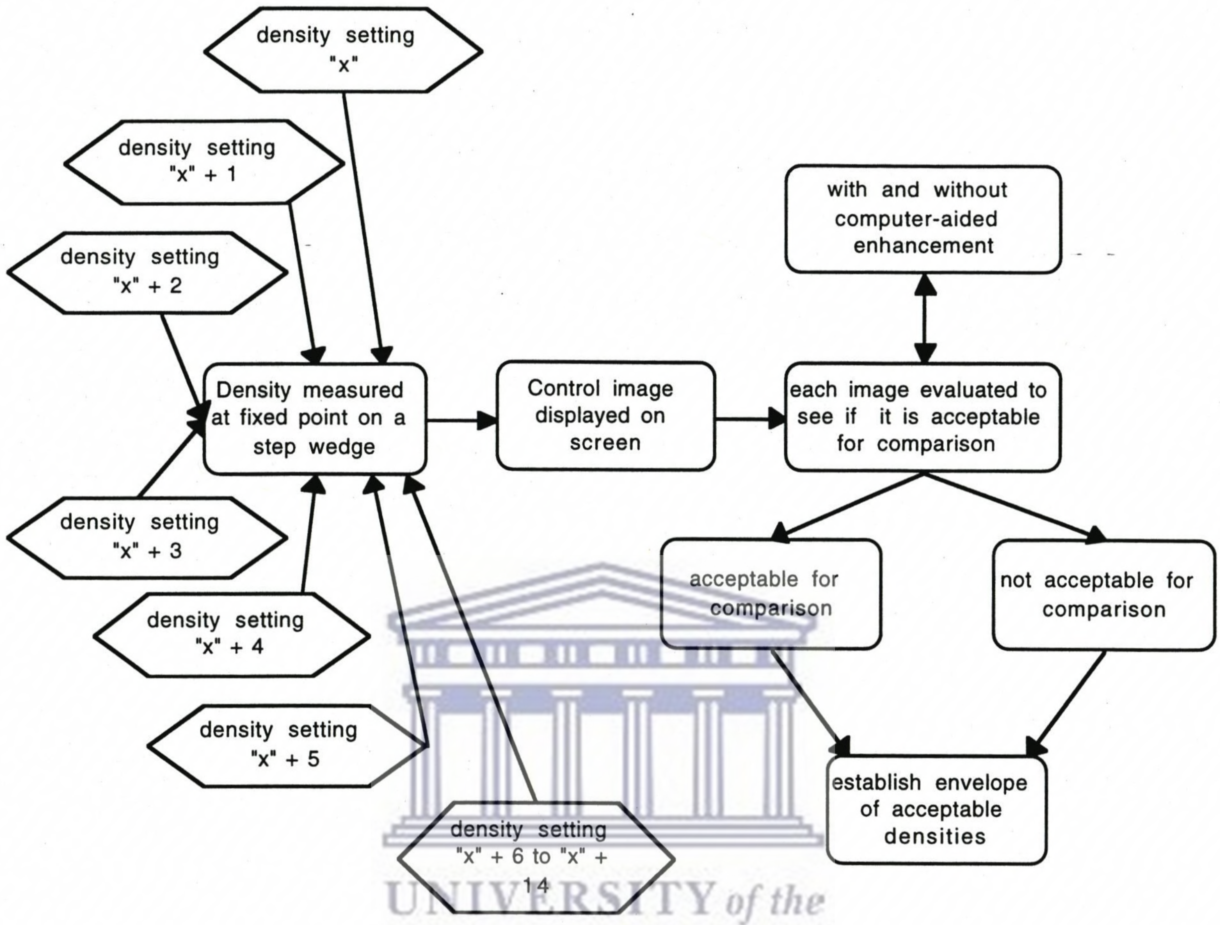
Appendix E - Glossary of terms

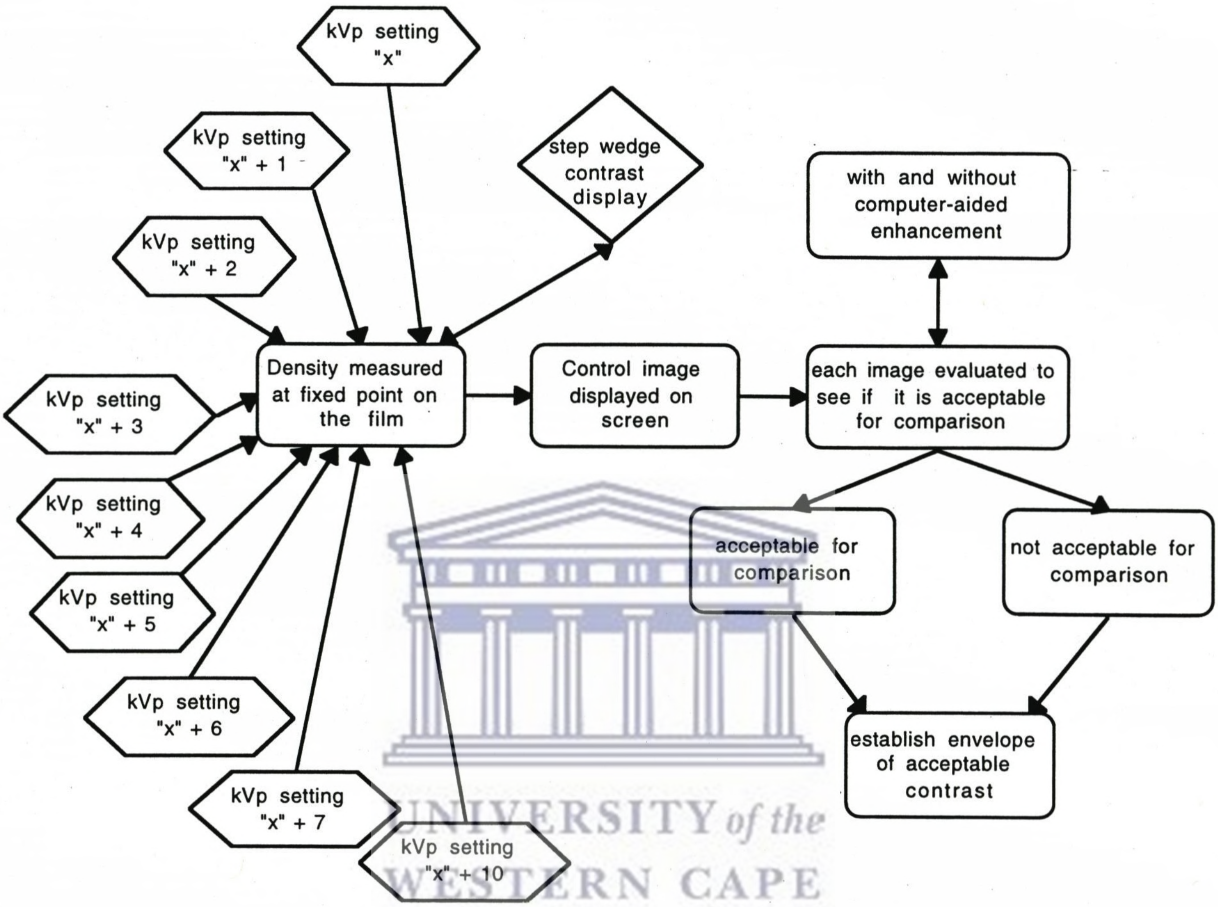
## Appendix A: Experimental designs - Experiment 1 to 10

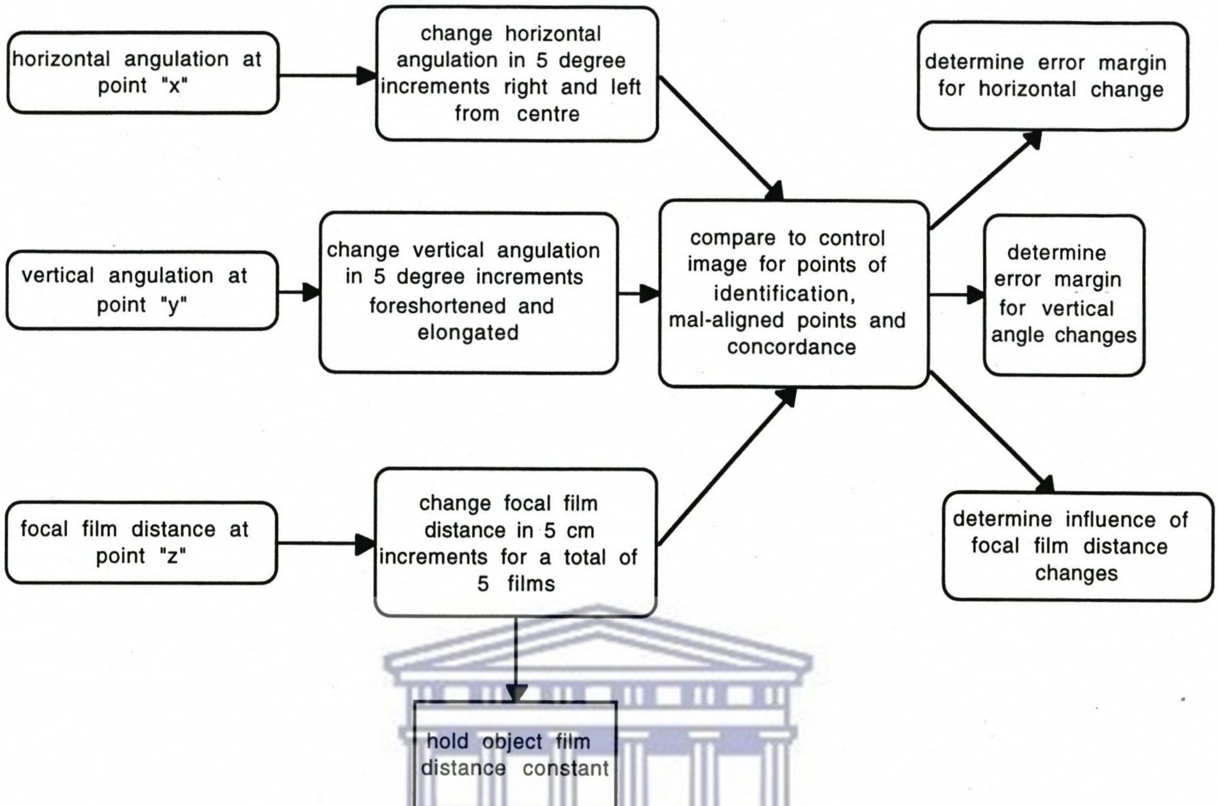



Mixed dentition case radiographs at time "x"
digitize images of radiographs as control point
Mixed dentition case radiographs at time "y"
digitize images of radiographs as control point
determine mean time elapsed and standard deviation
determine aligned points, malaligned points and concordance
apply time constraints if any
accept or reject hypothesis
formulate policy

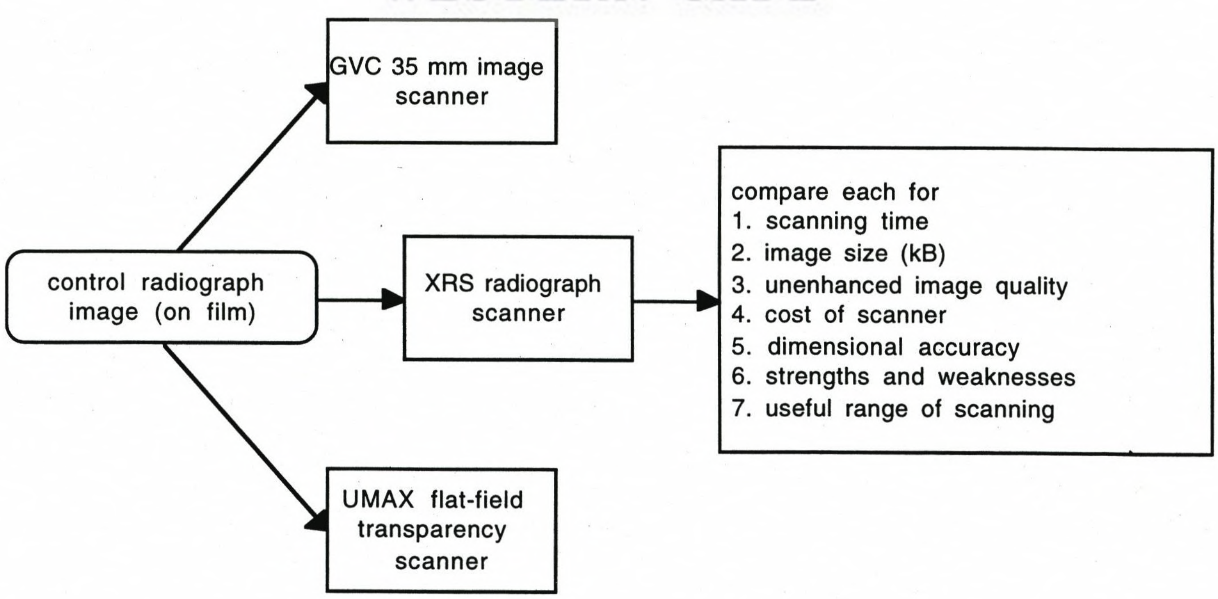

Permanent dentition case radiographs at time "x"
digitize images of radiographs as control point
Permanent dentition case radiographs at time "y"
digitize images of radiographs as control point
determine mean time elapsed and standard deviation
determine aligned points, malaligned points and concordance
apply time constraints if any
accept or reject hypothesis
formulate policy

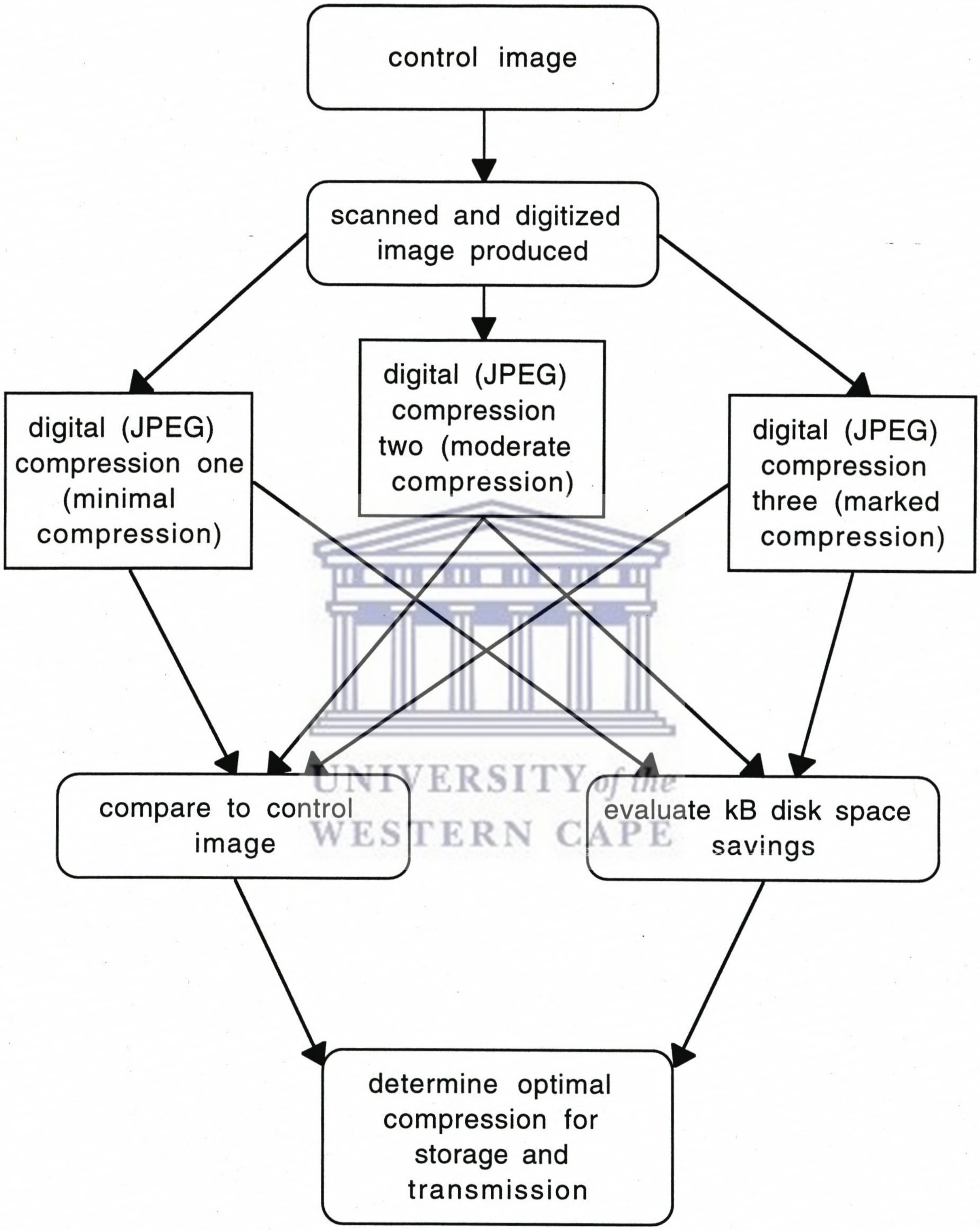

density setting
"x"
density setting
"x" + 1
density setting
"x" + 2
Density measured
at fixed point on a
step wedge
density setting
"x" + 3
density setting
"x" + 4
density setting
"x" + 5
density setting
"x" + 6 to "x" +
14
Control image
displayed on
screen
with and without
computer-aided
enhancement
each image evaluated to
see if it is acceptable
for comparison
acceptable for
comparison
not acceptable for
comparison
establish envelope
of acceptable
densities

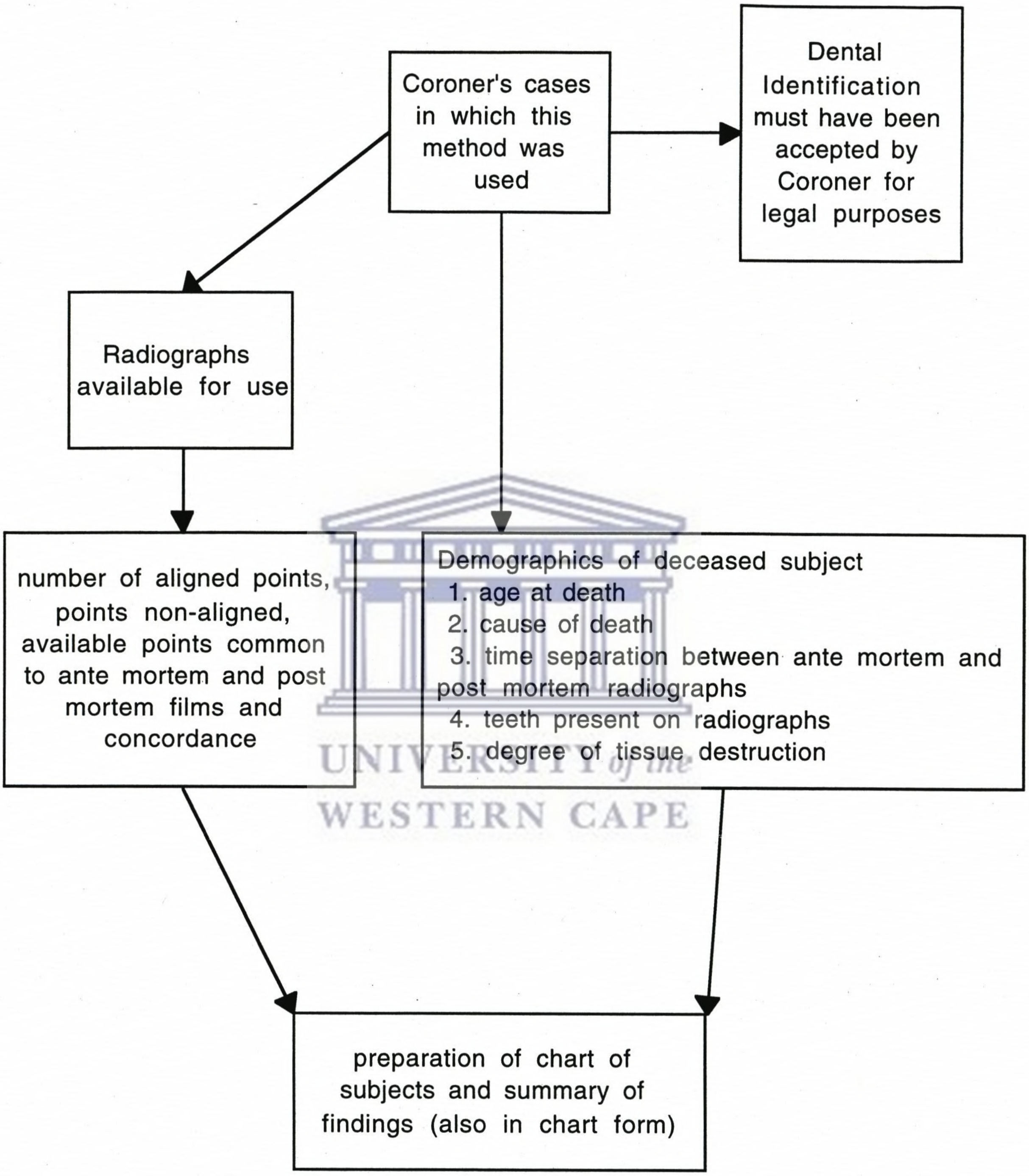

kVp setting "x"
kVp setting "x" + 1
kVp setting "x" + 2
kVp setting "x" + 3
kVp setting "x" + 4
kVp setting "x" + 5
kVp setting "x" + 6
kVp setting "x" + 7
kVp setting "x" + 10
step wedge contrast display
Density measured at fixed point on the film
Control image displayed on screen
with and without computer-aided enhancement
each image evaluated to see if it is acceptable for comparison
acceptable for comparison
not acceptable for comparison
establish envelope of acceptable contrast


horizontal angulation at point "x"
change horizontal angulation in 5 degree increments right and left from centre
determine error margin for horizontal change
vertical angulation at point "y"
change vertical angulation in 5 degree increments foreshortened and elongated
compare to control image for points of identification, mal-aligned points and concordance
determine error margin for vertical angle changes
focal film distance at point "z"
change focal film distance in 5 cm increments for a total of 5 films
determine influence of focal film distance changes
hold object film distance constant



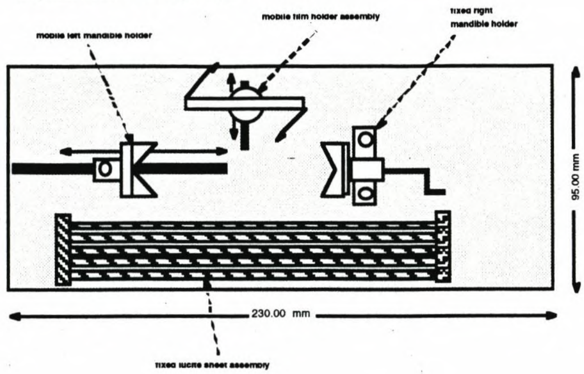

GVC 35 mm image scanner
control radiograph image (on film)
XRS radiograph scanner
UMAX flat-field transparency scanner
compare each for
1. scanning time
2. image size (kB)
3. unenhanced image quality
4. cost of scanner
5. dimensional accuracy
6. strengths and weaknesses
7. useful range of scanning


control image
scanned and digitized image produced
digital (JPEG) compression one (minimal compression)
digital (JPEG) compression two (moderate compression)
digital (JPEG) compression three (marked compression)
compare to control image
evaluate kB disk space savings
determine optimal compression for storage and transmission

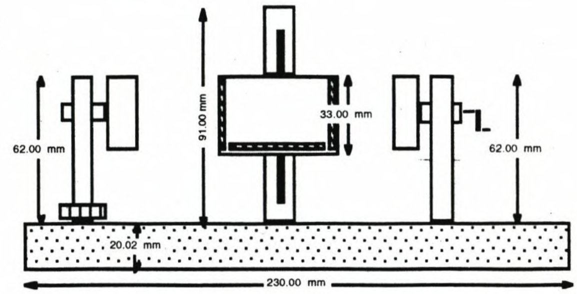

Coroner's cases in which this method was used
Dental Identification must have been accepted by Coroner for legal purposes
Radiographs available for use
number of aligned points, points non-aligned, available points common to ante mortem and post mortem films and concordance
Demographics of deceased subject
1. age at death
2. cause of death
3. time separation between ante mortem and post mortem radiographs
4. teeth present on radiographs
5. degree of tissue destruction
preparation of chart of subjects and summary of findings (also in chart form)

# Appendix B Plans for the radiographic positioning device.

**Top view of jig to hold mandibular specimen for radiographic alignment when doing test procedures.**

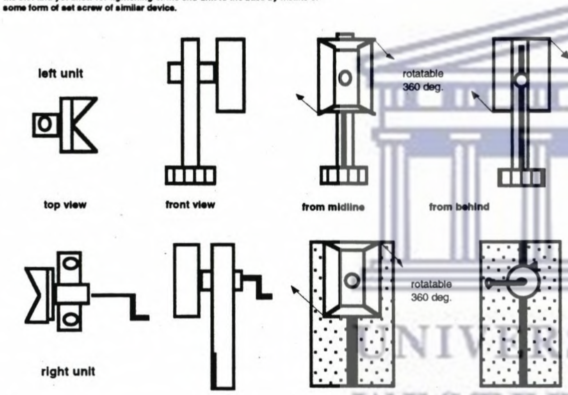



**Front view with lucite sheet assembly cut away**

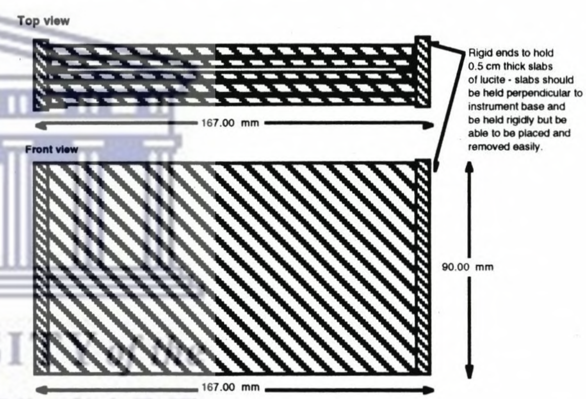



**Detail of mandible holders.**

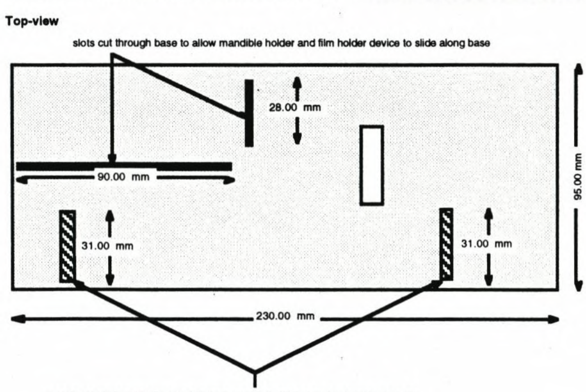
The right end holder is fixed and the left end holder must be able to slide along the slot and yet allow for tightening of the end unit to the base by means of some form of set screw of similar device.



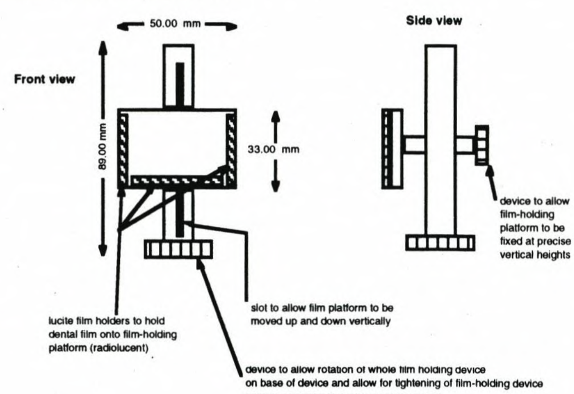

**Detailed view of components of the lucite sheet assembly**




**Detailed view of the base component of the mandible holder**




**Detailed view of the film holder assembly**



## Appendix C Jaw (dry) specimen measurements.

| Specimen number | greatest AP | width at anterior | width at posterior | vertical anterior | vertical posterior |
|---|---|---|---|---|---|
| 272 R | 10.0 | 2.1 | 0.9 | 3.4 | 7.1 |
| 618-R | 9.0 | 2.4 | 0.8 | 3.1 | 7.0 |
| 613-R | 10.5 | 2.6 | 0.7 | 3.4 | 6.0 |
| 703-R | 9.5 | 1.0 | 0.6 | 3.6 | 6.8 |
| 19-R | 10.0 | 2.1 | 0.6 | 3.1 | 6.1 |
| 25-L | 9.5 | 1.6 | 0.6 | 3.0 | 6.5 |
| 154-R | 9.2 | 2.3 | 0.5 | 3.5 | 7.3 |
| 122-L | 8.5 | 0.7 | 0.6 | 3.2 | 3.5 |
| 191-L | 6.5 | 0.6 | 0.5 | 3.3 | 4.0 |
| 830-L | 9.0 | **3.0** | 0.6 | 3.0 | 7.0 |
| 35-R | 9.5 | 2.5 | 0.6 | 3.0 | **7.5** |
| 726-R | 8.2 | 1.0 | 0.6 | 3.0 | 4.0 |
| 208-R | 10.0 | 2.3 | 0.6 | **2.4** | 6.2 |
| 212-R | 9.6 | 2.5 | 0.6 | 2.5 | 6.4 |
| 188-R | **10.1** | 2.5 | 0.7 | 3.2 | 6.5 |
| 91-L | 10.0 | 1.4 | **1.0** | 3.0 | 2.0 |
| A69 -R | 9.3 | 2.2 | 0.6 | 3.3 | 6.8 |
| 169-L | 8.3 | 0.6 | 0.6 | 2.5 | 4.0 |
| 7031-L | 9.5 | 0.5 | 0.8 | **3.8** | 4.3 |
| 464-L | 8.3 | 0.4 | 0.6 | 3.0 | 2.6 |
| 893-R | 9.7 | 1.1 | 0.6 | 3.2 | 6.8 |
| 1-L | 8.8 | 0.6 | 0.6 | 3.3 | 3.4 |
| 185-L | 9.0 | 0.6 | 0.6 | 3.2 | 4.0 |
| 83-R | 9.6 | 1.7 | **0.5** | 2.5 | 5.5 |
| 239-L | 9.0 | 1.3 | 0.6 | 3.2 | 0.5 |
| 270-L | 8.0 | 0.4 | 0.6 | 3.2 | 1.5 |
| 9.0-L | 9.0 | 0.4 | 0.5 | 3.5 | 4.2 |
| 209-L | 7.7 | 0.5 | 0.5 | 3.0 | 4.4 |
| 179-R | 10.0 | 2.4 | 0.6 | 3.0 | 7.0 |
| 600-L | 9.0 | 0.5 | 0.6 | 3.0 | **2.0** |
| 213-L | 7.5 | 0.3 | 0.5 | 3.0 | 3.0 |
| 213-R | 9.2 | 2.0 | 0.5 | 3.0 | 7.0 |
| 370-R | 9.7 | 0.6 | 0.6 | 3.0 | 6.8 |
| 113-L | **6.0** | 1.3 | 0.5 | 3.0 | 3.0 |
| 193-R | 9.3 | 1.8 | 0.6 | 3.0 | 6.8 |
| 239-R | 8.0 | 0.3 | 0.5 | 3.0 | 2.0 |
| 618-L | 6.5 | **0.3** | 0.7 | 3.0 | 4.0 |
| 370-L | 8.5 | 0.4 | 0.6 | 3.0 | 3.5 |
| 124-L | 8.7 | 0.6 | 0.6 | 2.6 | 3.5 |

## Appendix D List of equipment used in the experiment.

1. Macintosh IIci with 16 MB RAM / 150 MB hard drive, internal and external 3.5 inch floppy drive.

2. Macintosh Centris 610 with 12 MB RAM / 230 MB hard drive & internal 3.5 inch floppy drive

3. Accessory 40MB external hard drive for the IIci above.

4. External 1.44 MB 3.5 inch floppy drive for the IIci above.

5. 9600 BAUD GVC modem link

6. XRS flat bed radiograph scanner capable of imaging 300 DPI

7. Flat bed scanner capable of scanning 960 DPI radiographic and print images.

8. Slide scanner capable of scanning 1400 LPI transparent images.

9. Direct connection or Ethernet connection between all scanners and computers. Note: scanners are all geographically located within our departments fiscal and local domain.



10. Adobe Photoshop soft ware for above (upgrades and original)

11. End-Note plus reference manager soft-ware for above (upgrades and original)

12. Tape back up System for images accessed through soft ware.

## Appendix E Glossary of terms

**Accidental characteristic:** The property of having unique identifying characteristics. An unusually shaped amalgam would have accidental characteristics which would make it useful for comparative identification purposes.

**Algorithms:** A process or set of rules used for calculation or problem solving. Most algorithms used in forensics are used in comparison of antemortem and postmortem records.

**Annulations:** The presence of rings (usually concentric) which may be used to determine age. Most persons are aware of the presence of growth rings in trees and their relation to age of the tree. Some have suggested similar rings are present in the cementum of the teeth or animals and humans.

**Antemortem:** Prior to death.

**Anthropological:** Dealing with the study of mankind, its customs and societies. in Forensics this most often is used in terms of physical anthropology which is the study of human tissue (most often, but not exclusively bones) for clues to identity or habits.

**Anthropometric:** The study of measurement of the physical aspects of a human or humans. It translates literally as man-measurement and describes the study of human tissue, especially bones for clues to identity, habits, or disease.

**Appendicular skeleton:** That portion of the human skeleton excluding the skull, spine, sternum and ribs - ie the limbs and pelvic bones.

**Appliances:** A term used to describe any fixed or removable device found in conjunction with human remains (or not) which may be considered to be "part of" the person. A fixed bridge and a hip prostheses may be considered to be appliances.

**Ashing:** The property of conversion of structure to ash via the action of high temperatures.

**Attrition:** The physiological wearing away of normal tissue as a consequence of use. In dentistry it is most often seen in wear facets and absence of tooth material in association with long use.

**Axial skeleton:** The skull, ribs, sternum and spinal column.

**Carabelli's cusp:** A cusp found on the mesi-lingual aspect of a maxillary molar tooth which is suggestive of Caucasian heritage.

**Calcfication:** The process by which organic tissue becomes hardened via the deposition of calcium salts within it.

**Calvarium:** The dome-like superior aspect of the cranial vault.

**Canid-scavenged:** Destruction and disturbance of remains as a consequence of interference by domestic or wild dogs and related species.



**CAPMI:** Computer assisted post mortem identification. This system, developed by the United States Military is used for selecting possible matches from a group of antemortem and postmortem charts of humans and human remains respectively

**Cheiloscopy:** The art and science of the study of the architecture of the human labial surfaces for the purposes of identification.

**Chronological:** Pertaining to time. In forensics it refers specifically to age determination using comparisons of dental, skeletal and other information to assess the probable chronological or "actual" age.

**Closed disaster:** see closed population

**Closed population:** A group of persons (deceased or alive) of known number and supposedly known identities.

**Commingled:** Purposeful or accidental mixing of human remains at or after the time of death.

**Comparative identification:** Identification undertaken based on a comparison of antemortem and postmortem materials.

**Concordant:** Agreement or harmony between things. In Forensic Dentistry this term is used to desribe physical similarities between antemortem records and features observed at post mortem.

**Congenital:** Existing at and usually before the time of birth.

**Congruous:** See concordant

**Cynodont:** A canine or canine-like tooth.

**Decedants:** Under United States law - a deceased person(s)

**Diaphysis:** The shaft of a long bone.

**Diploic:** Literally "double". The diploe is the loose osseous tissue between the inner and outer aspects of the cranial bone.



**Discordant:** Disagreeing with, not in harmony with. In Forensics this term is used to desribe physical differences between antemortem and postmortem.

**DNA:** Deoxyribonucleic acid.

**Elimination:** The antemortem and postmortem records are inconsistent and they are definitely not from the same person.

**Elimination charts:** A chart, physical or computerised which allows for the recording of features found at postmortem which aids in making positive identification or identification by exclusion.

**Epiphysis:** The end of a long bone which is usually wider than the shaft.

**Exclusion:** The antemortem and postmortem data are clearly inconsistent. However it should be understood that identification by exclusion is a viable technique in certain circumstances.

**Exhumation:** To unearth. In Forensics this term is used to desribe the act of dis-interring a set of human remains.

**Fingerprint:** The most reliable scientific method of comparison used for identification of the deceased compares visible similarities and differences in the patterns of whorls and spaces between antemortem and post mortem records

**Fluoresce:** The ability to become fluorescent which is caused by visible or invisible radiation produced by certain substances as a result of incident radiation of a shorter wavelength.

**Heterogeneity:** Diverse in character or varied in content.

**Homogeneity:** Uniform or consisting of parts of all the same kind.

**Identification by exclusion:** In a closed population if all antemortem and postmortem matches are made except for one and there is no unexplainable discrepancies the remaining body may be identified by exclusion.

**Identity:** The quality or condition of being a specific person. In forensics this implies ability to determine, to a high degree of moral certainty the proper person.

**Insufficient evidence:** The available information is insufficient to form the basis for a conclusion.

**Interment:** The burial of the deceased.

**Jurisdiction:** The administration of justice, the office or area to which judicial authority is present.

**Kinship:** The sharing of characeristics of origins.

**Metaphysis:** The area of a long bone between the shaft (diaphysis) and the end epiphysis) of a long bone.

**Mis-identification:** An incorrect identification of a deceased or living person.

**Nomenclature:** A system of naming things. In Forensic Dentistry this refers to systems of labelling the dentition.

**Odontogram:** In actual fact this is a tracing of the teeth but in Forensic Dentistry this refers to a diagrammatic representation of the dentition of an antemortem or postmortem situation on a written record for comparison purposes.

**Ossification:** The formation of bone or of a bony substance or the conversion of fibrous tissue or of cartilaginous tissue into bone or a bony substance.

**Passenger manifest:** The passenger list, usually for an aircraft or ship which gives (supposedly) an accurate list of persons on board.

**Perikymata:** The numerous small transverse ridges on the exposed surface of the enamel of a permanent tooth.



**Polygenic:** Pertaining to or determined by the action of several different genes.

**Polymerase chain reaction (PCR):** The biological manipulation of a small quantity of DNA which results in amplification of the DNA products to allow comparisons to be undertaken.

**Polymorphic:** Having the property of many shapes.

**Positive identification**Defined by the A.B.F.O. as: The antemortem and postmortem data match in sufficient detail to establish that they are from the same individual. In addition there are not irreconcilable differences.

**Possible identification:** The antemortem and postmortem data have consistent features but due to the quality of either the postmortem remains or the antemortem evidence, it is not possible to positively establish dental identification.

**Postmortem:** After death. It also refers to the series of procedures undertaken in the medical evaluation of the dead.

**Primary identifier:** A means of identification, almost always physical which allows identification, in a scientific manner. Examples of primary identifiers are fingerprints and dental identification.

**Probable identification:** The antemortem and postmortem data are consistent but due not allow a definitive positive identification. This term carries with it greater importance than the term possible identification.

**Pugilistic attitude:** The attitude or position of the body of a person after partial incineration. It has been likened to the position a boxer takes because the arms are drawn up in a fighting stance due to partial destruction of the flexor muscles.



**Radiolucent:** The quality of allowing x-rays to pass through it thereby turning the radiograph dark.

**Radiopaque:** The quality of blocking of x-rays from passing through the object thereby not allowing the film to turn black.

**Racemization:** The transformation of one half of the molecules of an optically active compound into molecules which possess exactly the opposite (mirror-image) configuration.

**Reconstructive identification:** Methods of identification where there is no antemortem evidence so that determination of identity must be accomplished by careful and complete analysis of the postmortem materials. Such evaluation may allow assessment of age, gender, race, occupation and country of origin. 2

**Regressive changes**Changes to the dentition or other parts of the body which diminish or deteriorate as a function of age or excess wear.

**Rugae:** A ridge, wrinkle or fold it most often refers to rugae palatina which are transverse ridges on the anterior hard palate.

**Secondary identifier**An physical property or feature common between antemortem and postmortem records of an individual which allows identification to be made. Dental identification is usually not a means of secondary identification.

**Sella turcica:** The "Turkish Saddle" which is part of the sphenoid and forms the receptacle for the pituitary gland.

**Serology:** The study of antibody-antigen reactions in-vitro.

**Skeletal identification:** Identification techniques which may be either comparative or reconstructive which rely on the use of skeletal landmarks, unique features or anthropometric measurements for the purpose of identification.

**Taurodont:** "Bull tooth". This tooth has shortened root ends, an enlarged pulp, and a large mid-root area and crown giving it the appearance of a "bulls head."

**Tertiary identifier:** An identifier which is not primary or secondary it is a piece of evidence which allows for possible identification. It may carry little weight.

**Thermostability:** The quality of withstanding the effects of heat without undergoing change.

**Unique identifiers:** The property of possessing physical or radiographic features which would allow differentiation from similar properties of other persons.