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Personal Identification Based on Patterns of Missing, Filled, and Unrestored Teeth

Bradley Jacob Adams
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a dissertation written by Bradley Jacob Adams entitled "Personal Identification Based on Patterns of Missing, Filled, and Unrestored Teeth." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Anthropology.

DR. LYLE KONIGSBERG, Major Professor

We have read this dissertation and recommend its acceptance:

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(Original signatures are on file with official student records.)

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PERSONAL IDENTIFICATION BASED ON PATTERNS OF MISSING, FILLED, AND UNRESTORED TEETH

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Bradley J. Adams
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Additional data was provided by the Tri-Service Center for Oral Health Studies, which is affiliated with the Uniform Services University of the Health Sciences, Bethesda, Maryland. The raw data from this source were originally gathered by the Tri-Service Center for Oral Health Studies as part of an ongoing study observing dental health throughout the active duty and recruit population of the U.S. military. The data was collected in 1994 and 2000 as part of two phases of the Tri-Service Comprehensive Oral Health Survey (TSCOHS).

The remainder of the data was derived from individuals missing in action from WWII, the Korean War, or the Southeast Asia Conflict.

Results of analyses and conclusions reached in this dissertation are solely those of the author.

ABSTRACT

Dental comparison of antemortem and postmortem records provides one of the best avenues for establishing personal identification in the forensic sciences. The types of antemortem dental evidence are extensive (including treatment notes, odontograms, radiographs, casts, photographs, etc.) and in many instances a positive identification can be established strictly on a dental comparison. Perhaps the best form of antemortem dental evidence is the radiograph, which provides a detailed odontoskeletal record of a specific individual at a specific point in the past. Unfortunately, antemortem radiographic evidence is not always available during forensic comparisons. For example, at the U.S. Army Central Identification Laboratory, Hawaii (CILHI), dental radiographs are not commonly available when performing antemortem/postmortem comparisons of military personnel missing from past conflicts, especially those missing from WWII or the Korean War. In these instances, as well as some modern forensic cases, antemortem dental information may only be available in the form of handwritten charts and notes derived from the missing individual's health documents. While these charts are susceptible to human error (not generally a concern with radiographs), dental information of this type that accurately documents an individual's dental condition can be essential for establishing a link to an unidentified set of remains. Obviously, documents that are incomplete or inaccurate, on the other hand, will not assist in the identification process and could actually hinder the effort.

The goal of this dissertation is to validate the use of non-radiographic dental evidence for identification purposes. Statistically, there are trillions of possible

combinations of missing, filled, and unrestored teeth within the adult mouth. This quantity of possible combinations suggests that an individual's dental health pattern should often be of sufficient uniqueness to be used for identification. While the statistical model of possible combinations is mathematically plausible, it does not necessarily represent reality. Each of the 32 teeth in the adult dentition cannot be considered to be at the same risk for loss or disease. Dental morphology will dictate that molars, based on their large surface area, will be more susceptible to decay than other teeth, such as canines or incisors. Furthermore, all dental patterns are not equiprobable, signifying that some patterns will occur more frequently than others and statistical calculations of the total number of possible combinations of dental characteristics are not useful and are potentially misleading. Thus the theoretical number of possible dental health permutations should not be cited to justify the diversity of dental patterns for identification purposes.

In order to adequately address the issue of diversity in dental patterns, large datasets are needed for analysis. As part of this dissertation, four datasets were compiled that represent distinct demographic or temporal groups from the United States. These datasets are referred to as WWII-Korea, Southeast Asia, Modern Military, and Modern Civilian. With the exception of the Modern Civilian data, all other datasets consist of U.S. military personnel. The WWII-Korea and Southeast Asia datasets are composed of individuals missing in action from these conflicts, while the Modern Military and Modern Civilian data were originally collected as part of large dental health studies (the 1994 and 2000 Tri-Service Comprehensive Oral Health Surveys and the 1988-1994 National

Health and Nutrition Examination Survey). Only permanent teeth were considered during this research, excluding third molars.

Initially, it was necessary to explore the accuracy of the dental evidence, specifically the military dental charts from WWII, the Korean War, and the Southeast Asia Conflict. In order to gauge the accuracy of the dental records, the Decayed, Missing, and Filled Teeth (DMFT) index was used to compare the WWII-Korea and Southeast Asia datasets with published results from temporally and demographically similar populations. The DMFT (Klein and Palmer 1937) is a popular index that is reported in many studies of dental health. Distinct variation between the published DMFT scores and those derived from the datasets used in this dissertation is likely indicative of incomplete/inaccurate recordation of treatment within the military dental records. As another test of the accuracy of antemortem dental records, a sample of dental charts was gathered from identified service members who were originally missing from WWII, the Korean War, or the Southeast Asia Conflict. The identification cases had been processed through either the CILHI or the CILTHAI (Central Identification Laboratory, Thailand) and were not part of the datasets used in this dissertation. The antemortem dental records were compared with the postmortem dental findings and the accuracy was assessed as a ratio of corresponding characteristics. It was found that the WWII and Korea records had an overabundance of individuals with "perfect teeth" (defined as the absence of decay and extraction throughout the mouth). In general, the WWII and Korea records were found to either be thoroughly documented or very poor, with the poor records lacking any documentation of treatment. The Southeast Asia cases were found to show excellent antemortem-postmortem congruence.

Next, the overall diversity of dental patterns formed by missing, filled, and unrestored teeth was explored for each of the datasets. As part of this process, the four datasets were transformed into two formats regarding the coding of fillings. Each dataset was coded in a *detailed* format in which all fillings were designated by the affected tooth surface. In the *generic* format, fillings were treated as either present or absent with a single code (i.e. there was no surface information coded). The diversity of dental patterns in both the detailed and generic formats was compared to the diversity found in mitochondrial DNA (mtDNA) sequences. The results of this dissertation show that the diversity of dental patterns, regardless of the data format, is on a scale that is comparable, if not superior, to mtDNA. Dental patterns were validated as an excellent means of forensic identification.

At this point it was essential to explore the diversity of specific dental patterns and to derive a method for quantifying the frequency that a specific pattern could be expected to occur. It was found that a method of empirical comparison to a relevant reference dataset is the most useful approach to the quantification of dental pattern frequency since this removes subjectivity and standards based on arbitrary points of concordance. This technique is nearly identical to the manner that mtDNA sequence frequencies are reported. Based on empirical comparison, it is possible to compare dental patterns formed by any combination of teeth and their characteristics. Postmortem loss is not a hindrance to the technique. It was found that very common dental treatment would often form a very unique dental pattern when all of the evidence is analyzed as a whole. This may be counterintuitive to many dentists. Furthermore, if numerous teeth are available in the postmortem analysis, the generic format of the data is sufficient to create very individualistic dental patterns. In situations of extensive postmortem loss, the detailed format will be critical to the establishment of individualistic patterns.

Prior to this research, forensic odontologists did not have a technique for assessing the strength of an antemortem-postmortem match between non-radiographic dental evidence. Up to this point, the comparison has usually been based on the subjective judgment of the dentist, which cannot be statistically quantified. Through empirical comparison with a large, representative dataset, dental patterns can now be objectively assessed. Patterns that may be initially hypothesized to be common in the general population could actually be shown to be extremely rare and individualistic based on empirical comparison to a reference dataset. By attaching an empirically derived probability value (the expected frequency that a specific pattern would be found in the population), matches based on dental patterns can be quantified in a manner that is easily defensible in a court of law. Two important points need to be understood as part of this research: 1) The end result of this research is not to create a database that can be used to match a dental pattern to a specific individual. Rather once an association to an individual has been made, the technique allows the significance of the dental pattern match to be quantified. 2) The use of non-radiographic dental evidence alone, as discussed in this dissertation, is not sufficient to establish a positive identification. It is anticipated that the evidence, in conjunction with other circumstantial evidence, can be used to form a very strong association between a missing individual and an unidentified set of remains that is beyond reasonable doubt.

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CHAPTER 1: PERSONAL IDENTIFICATION

The reasons for establishing a positive identification of a missing individual are numerous and include legal issues such as for inheritance, payment of insurance, settlement of estates, prosecution in homicides, remarriage of a spouse, and issuance of a death certificate. There are also moral and emotional issues that deal with the surviving friends and relatives and their ability to have closure and a sense of resolution. Due to moral, ethical, and legal considerations it is essential that all possible attempts are made to accurately identify all deceased individuals.

Often times the exclusion of an individual from identification is just as important as making a positive identification. For example, dental charts and radiographs were used to exclude Patricia Hearst from the unrecognizably burned bodies recovered from the Symbionese Liberation Army (SLA) shootout in Los Angeles in 1974 (Sognnaes 1976a, Vale, et al. 1975). It is the responsibility of forensic experts, regardless of their field, to utilize all the available evidence to make the most accurate comparison possible in an effort to identify or exclude missing individuals. In some cases this comparison is very straightforward and can be conclusive. Other cases present more of a challenge and must rely on less conventional forms of evidence. Overall, it is the variable conditions of the body and the availability of antemortem records that dictate the techniques that will be necessary for establishing personal identification.

Although the focus of this research concerns dental identification, it is appropriate to briefly address the various approaches towards establishing personal identifications.

Some techniques commonly used include: visual recognition, fingerprint comparison, dental comparison, anthropological comparison, DNA comparison, and circumstantial evidence. Radiographic comparison is an important identification technique that is used not only by radiologists, but also by odontologists and anthropologists. Brogdon (1998) presents a thorough discussion of forensic radiology, but for this dissertation the role of radiology is included only within the anthropology and dental parameters. Depending on the available antemortem and postmortem evidence, any one, or a combination of several techniques may be critical in establishing a link to a missing individual.

Visual Recognition

It is common that friends or relatives visually make the identification of a deceased individual when the state of preservation of the body is sufficient (Bell 2001). These instances generally represent recent natural deaths or suicides when the body is fresh and there is not likely to be an investigation surrounding criminal or liability issues. Typically, homicides require scientific identification that exceeds visual recognition, although this may depend on the jurisdiction. In most instances the police are able to rapidly locate next of kin or friends who are able to view the body and sign the necessary legal documents to establish an identification (Sopher 1972). Visual recognition of remains for identification purposes is limited to those cases in which the facial features of the body, most commonly, are not distorted by postmortem changes or physical trauma. Examples of erroneous identifications resulting from the visual identification of disfigured bodies have been recorded, and other means of identification are usually sought when the condition of the body is poor (Sopher 1972).

Circumstantial Evidence

In certain instances, identifications must be established based on circumstantial evidence. Personal effects and/or clothing may provide an initial link to a specific individual. Ideally, this circumstantial evidence can lead to more individualistic comparisons, such as through dental records. While not scientifically reliable, circumstantial identifications based strictly on personal belongings in association with human remains are sometimes unavoidable due to the lack of any type of concrete antemortem evidence for comparison (e.g. during human rights investigations). In other instances, circumstantial evidence, such as the discovery of personal effects, may also be used in order to issue a death certificate. This type of situation may occur from a mass disaster, such as a plane crash, when it was known that an individual was on board and items known to belong to that person were recovered in the area of the crash even though human remains could not be definitively linked to the individual. As items may have been borrowed, stolen, or switched with the intent to deceive, this type of association can be problematic and all efforts should be taken to discover additional lines of evidence.

In order to form strong circumstantial identifications, several lines of evidence may be considered together. Multiple consistencies with a missing individual may exist that alone would not be sufficient to establish an identification, but together create a situation where the probability that all matches are due simply to chance events becomes incredibly small. An example of this type of situation may result from a combination of anthropology, personal effects, mtDNA, and geographic provenience.

Anthropological Comparison

Anthropological analysis can be a formidable tool in the identification process. Determination of the biological profile of an individual from their skeletal remains may be a critical factor in limiting the pool of potential candidates. For example, from a well-preserved set of skeletal remains a forensic anthropologist can estimate the age at death, ancestry, sex, and stature of the individual. Each one of these factors narrows the list of possible identities. For example, Charles Snow (1948) describes how he used dental chart records along with the biological profile derived from skeletal remains to identify unknown soldiers at the first Central Identification Laboratory in Hawaii during WWII. In addition to the biological profile, the anthropologist can document evidence of antemortem, perimortem, and postmortem skeletal trauma. Antemortem trauma may be noted in medical records, from which an identification could potentially be established. Perimortem trauma (e.g. a gunshot wound to the head or fractures consistent with an aircraft crash) may be used not only as an indicator of manner of death, but may also corroborate witness reports concerning the circumstances of death.

It is common for forensic anthropologists and radiologists to perform radiographic comparisons of antemortem and postmortem skeletal features in order to establish a positive identification (Brogdon 1998). Although not anthropologists, Culbert and Law (1927) presented the first documented case of skeletal identification based on radiographic comparison. They based their identification on numerous features of the skull, such as the frontal sinus pattern and pneumatic cells of the mastoid. Because the lawyers involved in the settlement of the decedent's estate accepted the identification, this case established a legal precedent for radiographic identification of unknown individuals. Culbert and Law (1927) suggest that radiographic comparison is better for identification purposes than fingerprints since fingerprints can be more easily modified and are more susceptible to postmortem damage. They state, "If such roentgenograms had been taken, for example, of men going into war, there would have been far fewer bodies of unknown soldiers, since identification would be possible from mere fragments of the anterior or lateral skull" (Culbert and Law 1927:1636). It is interesting to note in this case report that the utility of radiographs for identification was stressed by the authors, but only in the realm of sinus patterns and not dental features. This is likely due to the fact that dentists were only recently incorporating radiographs into their standard procedures (Ring 1993).

Overall, anthropological evidence (i.e. biological profile or specific skeletal anomalies) may be used to establish a positive identification of a missing individual, but it is more commonly used in conjunction with other supporting lines of comparison.

Fingerprint Comparison

Fingerprint comparison has been widely used for establishing identification and has a long history of usage. The major discoveries that initiated the widespread adoption of fingerprint evidence began around 1880 (Caplan 1990). This type of evidence is dependent on the availability of antemortem comparative records and the postmortem preservation of dermal friction ridges. One of the assets of fingerprints is that they are unchanging throughout an individual's life. One drawback is that antemortem fingerprinting is not a standard procedure in the general public, except in the case of law enforcement, a criminal record, military service, security clearance, etc. In some instances it may be possible to obtain latent fingerprints from articles used by the deceased in order to perform a comparison (Sopher 1972). In cases of even early decomposition or alteration due to traumatic events such as fire or a crash, soft tissue may not preserve and postmortem fingerprints may not be attainable.

Sopher (1973) completed an analysis of the techniques used for the identification of victims involved in international aircraft accidents that occurred between 1950 and 1971. His analysis is primarily concerned with fingerprint and dental identifications. He found that 36.7% (range of 11% to 89%) of identifications were based solely on dental evidence or a combination of dental evidence in conjunction with other methods. Although dental evidence plays a critical role, Sopher (1972, 1973) considered fingerprint identification, at least in the United States, to be a superior method for identification. As a reason, he refers to the extensive fingerprint information stored on databases and the fact that fingerprint comparisons can be completed rapidly. He states, "…dental identification will never surpass the fingerprint method as the primary mode of identification" (Sopher 1973:362). Part of the potential problems cited for dental comparisons at aircraft crashes stem from the difficulties involved with locating antemortem records and transmitting them to the crash scene. Today many of Sopher's criticisms of dental evidence are irrelevant. For example, the use of high-resolution transmittal options (e.g. email and fax) may facilitate one facet of the problem, and computer programs such as Computer Assisted Postmortem Identification (CAPMI) developed by the U.S. Army Institute of Dental Research or WinID2 developed by James McGivney, DMD, greatly facilitate dental comparisons of an unknown individual when the list of possible candidates is extensive (e.g. in a mass disaster). Still, the greatest obstacle in any type of comparison often proves to be tracking down the appropriate antemortem records.

Dental Comparison

Defined as the application of dental knowledge to matters of law, forensic dentistry (also referred to as forensic odontology) is the branch of forensic medicine that concerns dental evidence. While the expertise of the civilian forensic odontologist may also branch into other legal areas besides identification (e.g. bite mark interpretation, human abuse, malpractice, and fraud), forensic dentistry in the military is almost exclusively limited to dental identification procedures (Kessler 1994). It is not the intent of this dissertation to present an exhaustive overview of the entire field of forensic dentistry, rather it is the specific role of the forensic odontologist in the personal identification of an unknown individual that is of particular relevance to the present research.

The use of dental evidence for identification purposes is based on the vast number of possible combinations of characteristics that are present in the human dentition. The need for the expertise of a forensic odontologist for identification purposes is often required when destruction (mutilation/decomposition) of the human body is extensive, rendering visual identification impossible. This may result from intentional mutilation by an assailant, traumatic mutilation from a collision, destruction of the soft tissue by fire, or natural decomposition of the soft tissue. Studies at the University of Tennessee, Knoxville have shown that soft tissue decay can be complete in as short as two weeks after death (Bass 1997).

Teeth are the hardest structures of the human body and, as such, represent an ideal form of identification in situations of advanced decomposition, fire, or massive trauma (Sopher 1976). Regardless of the condition of the body, it is very likely that the dentition will be preserved and often times proves to be the most reliable comparative tool. Botha (1986) points out that not only are teeth able to withstand extremes from fire, but the various restorative materials used for fillings and prostheses are also able to adequately withstand the thermal assault.

In 1895, Wilhelm Conrad Roentgen discovered the x-ray and in 1896 Dr. C. Edmund Kells demonstrated the use of Roentgen rays for dentistry before a meeting of the Southern Dental Association in Asheville, North Carolina (Ring 1993). As early as 1901 the use of x-rays was recommended for root canal work, but it was not until the 1920s that x-ray machines were commonly seen in dental offices (Ring 1993). The first published identification based in part on dental radiographic evidence was presented in 1943 as part of a British murder investigation (Fry 1943). An unidentified body was discovered that was suspected to be a missing woman. Based on detailed treatment records provided by her dentist, it was discovered that two roots had been left behind in the maxilla during therapeutic extraction (antemortem radiographs were not present). A postmortem radiograph of the remains confirmed the presence of the root apices. This evidence, in combination with other corresponding dental treatment, was used to identify the remains. This identification was upheld by the court and led to the conviction of her killer.

Dental radiographic evidence allows the forensic odontologist the greatest certainty for establishing an identification or exclusion. Unique features of the root anatomy and/or bone structure may be sufficient to make a positive identification, but restorations (usually a result of carious lesions) will allow for the easiest radiographic comparison (Bernstein 1998). In their book on dental identification, Luntz and Luntz wrote: “Because of its accuracy, the dental x-ray is the most desirable antemortem record for use in dental identification” (1973:91). It is worth mentioning that a study performed in Sweden (Ekstrom, et al. 1993) found that forensic odontologists committed numerous identification errors during a comparison of a test sample of antemortem and postmortem radiographs. It was suggested that additional dental chart information present in the files (not made available to the participants) would have facilitated the more difficult comparisons.

Especially with military personnel, dental identification has proven to be one of the best means of identification available due to the mandatory requirements for dental examinations that include radiographs in most instances. Generally these records are maintained for extended periods of time and should be available for comparison. Dental records from WWII, the Korean War, and the Southeast Asia Conflict are still used today in order to identify individuals that remain unaccounted for. More recently during Operation Desert Storm, 97.2% of the American casualties that were recovered with dental evidence (244 out of 251) were identified by dental means (Kessler 1994).

As many individuals have visited a dentist at some point in their life, it is likely that dental records may be available for comparison, as opposed to fingerprints. Even though this may be the case, wide variation exists in the quality of antemortem dental information. Many dental records will contain a range of information that may include a diagrammatic representation of the teeth (odontogram), a verbal description of the treatment, and/or radiographs. In some instances it may be possible to use antemortem photographs or even video footage of missing individuals that show distinctive dental features for comparison to an unidentified set of remains (Marks, et al. 1997). The antemortem diagram, if carefully produced, is extremely useful for comparison with postmortem charts. Unfortunately dental charts are susceptible to errors and are not as dependable as radiographs.

Of course, postmortem findings of numerous restorations and unusual dental conditions are worthless for comparison if antemortem records are lacking. Tracking down the appropriate antemortem records, which is most commonly performed by law enforcement, often proves to be one of the most challenging steps in the dental identification process. As an example, as of 1995 there were over 97,000 active missing persons records on file with the FBI's National Crime Information Center (NCIC) and only less than 3% had dental information entered into the database (Bell 1997).

Dental comparison requires relatively simple equipment, such as that used for producing postmortem radiographs, and antemortem-postmortem comparisons can be completed very rapidly. The comparison is generally straightforward and the visual results are easily recognizable to lay observers, such as a jury during a trial.

DNA Comparison

Recently there has been an increase in the use of deoxyribonucleic acid (DNA) evidence for the identification of the deceased. The use of DNA evidence for identification purposes is even beginning to systematically replace dental means in some instances. For example, the U.S. military currently requires all active duty personnel to submit a DNA reference specimen (Department of Defense Directive No. 5154.24) that is retained in the event that a comparison is needed in the future to a specific individual. this is analogous to the treatment of dental records in the past. This type of comparison is based on nuclear DNA, which is considered to be the "genetic fingerprint" and is the method of choice in the forensic community.

Another type of DNA comparison utilizes mitochondrial DNA (mtDNA), a technique that is more comparable to the scope of this dissertation. Within the mitochondrial genome there are approximately 16,569 base pairs (Holland and Parsons 1999, Smith 2001). These base pairs compose the coding region, as well as one very significant non-coding area referred to as the control region. The greatest variability between individuals is generally observed in the control region, which is divided into two hypervariable regions (HV1 and HV2). There are approximately 610 base pairs that are observed within HV1 and HV2 (Parsons and Coble 2001) and it is this area of the mtDNA genome that is commonly used for forensic purposes. The individual variation in the sequence of the four nucleotides (adenine, guanine, cytosine, and thymine) provides the basis for the genetic code that is useful for identification. These differences are called polymorphisms (Smith 2001).

MtDNA is widely used in the case of degraded skeletal remains. One reason is that mtDNA is present in roughly 1000 copies per cell (as opposed to nuclear DNA which is present in two copies per cell). Additionally, mtDNA is maternally inherited without recombination, with the result that maternally related individuals have matching sequences (barring infrequent mutation). This allows comparison to reference samples (e.g. blood or saliva) from family members separated by even multiple generations from the missing individual. This type of comparison, although not unique to a specific individual, permits an avenue of comparison that is not possible with nuclear DNA. As the mtDNA sequence is not unique to the individual, the comparison must be used in corroboration with additional circumstantial information. It is possible for unrelated individuals to share the same mtDNA sequence due to the presence of relatively common types. As an example of the identification potential of mtDNA, the CILHI relies on mtDNA evidence to establish numerous identifications each year. Perhaps the most publicized identification based in large part on mtDNA evidence was the identification of the Southeast Asia Tomb of the Unknown Soldier (Holland and Parsons 1999). Through the archaeological recovery of human remains believed to be U.S. servicemembers missing from past conflicts, mtDNA evidence often proves to be the crucial piece of evidence for identification. In many situations the quantity of remains is very small and dental evidence may be completely lacking. In other cases the remains may be well preserved, but antemortem records are missing. It is in these types of scenarios that small samples of either bone or tooth are submitted to the Armed Forces DNA Identification Laboratory (AFDIL) in Rockville, Maryland for sequencing. As a result, cases that were once deemed to be unidentifiable can now be associated to a specific individual based on mtDNA results in conjunction with other circumstantial evidence (e.g. artifact analysis or archaeological provenience).

Several potential pitfalls are present with both nuclear and mitochondrial DNA analysis. While the use of DNA for identification purposes is an exciting new field that promises to expand in the future, it is not a final solution to all issues regarding identification of the dead. Besides the availability of a reference sample for comparison, other possible hindrances include: contamination of samples, expense, availability of equipment and personnel, and length of time for sequencing. Contamination may occur in a mass disaster due to commingling of individuals or it may inadvertently occur during sampling or sequencing by the analysts. Also, DNA analysis is currently an expensive and potentially time-consuming process that requires sophisticated equipment and highly trained specialists to complete. A last concern about the use of DNA is that, similar to soft tissue, it is susceptible to destruction by external forces such as fire.

Many of the obstacles to DNA identification are not valid concerning dental evidence and it would be hazardous to put all reliance on DNA at the expense of dental evidence. While extensively burned remains may not produce viable DNA sequences, it is likely that dental comparisons can still be made from thermally altered teeth due to their resilience. Furthermore, dental identifications based on radiographic evidence are of the same caliber as those based on nuclear DNA and are far superior to those based on mtDNA. More importantly, dental comparisons can be completed much more rapidly and economically. As the technology advances, it seems almost certain that DNA identification will become more commonly utilized and will be an essential tool for identification purposes, but for now other identification techniques must be heavily relied upon. While DNA is a great asset for forensic endeavors on many levels, it will never entirely replace the use of the teeth for establishing identities.

CHAPTER 2: HISTORY OF DENTAL IDENTIFICATION

The idea of utilizing the teeth for personal identification has been recognized for centuries, but it is only fairly recently that it has become a universally accepted scientific standard in the medicolegal identification process. It was not until 1966 that the first book dedicated entirely to forensic odontology was published (Gustafson 1966). The first formal instructional program dedicated to forensic odontology in the United States was during the 1960s at the Armed Forces Institute of Pathology (Luntz 1977). It was not until 1969 that the American Society of Forensic Odontology was established, and the Odontology section of the American Academy of Forensic Sciences was not formed until 1970 (Sopher 1972). The American Board of Forensic Odontology was formed in 1976 and has been largely responsible for the board certification of those practicing forensic odontology.

Today, dental records are considered one of the best means of personal identification, certainly in situations of advanced decomposition of the soft tissue or extensive trauma to the body that renders other means of identification impossible. History reveals sporadic examples of the use of teeth for identification purposes. Several examples of the use of dental characteristics for personal identification, ranging from the identification of a single individual to mass fatalities, are briefly presented for historical background.

Lollia Paulina

One of the earliest documented cases of dental identification was in 49 A.D. during the youth of Nero in Rome. Nero's mother Agrippina, wife of Claudius, was protective of her son's future as the Roman emperor and, as such, ordered the execution of those individuals that she deemed to be a danger. One potential adversary was Lollia Paulina, who Agrippina deemed to be a threat to her son and a rival for Claudius' attention. She initially persuaded Claudius to banish Lollia Paulina from Rome, but later ordered her soldiers to find and kill Lollia Paulina. As proof that the deed had been successfully completed, Agrippina ordered that the assassins return with the head of Lollia Paulina. By the time the head arrived, the face was not visually recognizable from the soft tissue and, in order to confirm the identification, Agrippina inspected the teeth since she knew them to have distinctive features (Luntz 1977, Myers and Mirchandani 1986). Although the recognition of unique dental characteristics for confirmation of a murder is not likely an appropriate example of forensic odontology, it certainly shows that the unique attributes of the human dentition have been acknowledged for centuries.

Charles the Bold

Another early example of identification based on teeth comes from France in 1477. Charles the Bold was the Duke of Burgundy. During the winter of 1477 he attacked the city of Nancy, capital of Lorraine. The Duke was known to have been killed during the battle, but his body was not initially recovered. Several days after the battle, a search party arrived and found a body that had been badly mutilated by wolves. Based on the recognition of work that had recently been performed in the extraction of two teeth, the court physician was able to identify the Duke's body (Furness 1972).

Paul Revere/Joseph Warren

Paul Revere practiced dentistry from 1768-1778 and is referred to as a "forerunner of forensic odontology" by Luntz and Luntz (1973:1). Paul Revere initially opened an office in 1768 to practice dentistry and in 1775 he constructed a silver wire fixed bridge for his friend Dr. Joseph Warren. Warren was a physician who was very active in many subversive activities directed against the British during the American Revolution. He was, for example, a leader of the Sons of Liberty and was one of the instigators of the Boston Tea Party. It was also Warren who sent Paul Revere on his famous ride to warn the countryside that the British were coming (Luntz and Luntz 1973). Warren was killed in the Battle of Bunker (Breed's) Hill by a British bullet to the head and was subsequently buried in a shallow grave by the British. It was ten months before a search party composed of Paul Revere, Warren's relatives, and some friends were able to locate the unmarked grave. Revere was able to identify the remains as those of Joseph Warren based on the bridgework that he had recently constructed of silver and ivory (Luntz 1977, Myers and Mirchandani 1986). Warren was subsequently given a hero's burial on April 8, 1776 (Luntz and Luntz 1973). Dr. Joseph Warren was likely the first American on record who was identified based on characteristics of his teeth. Furthermore, Warren was a major general of the Massachusetts Militia and, as such, can also be considered the first American military person identified by dental characteristics.

John Wilkes Booth

The identification of John Wilkes Booth, assassin of Abraham Lincoln, is another example of the application of forensic dentistry. At the time of his death in 1865, some believed that Booth was actually still alive and had left a disguised body in his place. This matter was resolved when the body was transferred to a family plot and, in the process, the family dentist was able to make a positive identification based on the teeth (Stetchey 1991).

Webster-Parkman Case

This trial revolves around the 1849 murder of a prominent Massachusetts doctor. It is significant to the field of forensic dentistry in that it is the earliest case in which dental evidence was used to identify a murder victim in order to prosecute a suspect and, as such, it was also the first time that dental evidence was accepted in the American court system (Luntz and Luntz 1973). Dr. John White Webster was a professor of Chemistry and Mineralogy at Harvard Medical School in Massachusetts. Webster was frequently in monetary trouble and over several years he had borrowed money from one of his colleagues, a wealthy Boston physician named Dr. George Parkman. As collateral, Webster had promised a valuable mineral collection to Parkman. It was later discovered by Parkman that Webster had also promised the same mineral collection to Parkman's brother-in-law for another loan (Luntz and Luntz 1973). As Parkman feared that Webster was likely to default on the loans, he demanded repayment. The two met in Webster's university office to resolve the matter on November 23, 1849 and this was the last time

Parkman was ever seen alive. Once Parkman disappeared, a janitor from the Medical College became suspicious of Dr. Webster based on some unusual activity, such as the uncharacteristic use of a furnace. The janitor inspected the cellar and found portions of a human body (Cleland 1944). A week later, dismembered body parts were found in Webster's office, and skull and denture fragments were recovered from the furnace (Myers and Mirchandani 1986). Police questioned Dr. Webster regarding the human remains and the professor's response was that the bones were anatomical specimens that he had discarded in the furnace. Parkman's dentist, Dr. Nathan Cooley Keep, testified that he could positively identify the denture fragment as one that he had constructed in 1846 for Parkman. As proof, he showed that the denture could be matched to the teeth discovered in the furnace and it also conformed perfectly to the original mould that had been used to cast the denture for Dr. Parkman (Furness 1972, Luntz and Luntz 1973). The defense in the case called an expert witness to testify that it would be unlikely for a dentist to be able to remember the specific appearance of a denture constructed two years previously and that the evidence for a match to Parkman was not conclusive. Despite the defense's expert witness, the jury was convinced of the dental evidence and Dr. Webster was found guilty of the murder and was hanged on August 30, 1850 (Luntz and Luntz 1973).

Bazar de la Charite

Although Paul Revere may be credited as the fortuitous father of American forensic dentistry, it is Dr. Oscar Amoedo who is generally considered the founder of the field of forensic odontology based on his published accounts of dental identifications from a fire in Paris. Amoedo's work was based on the identifications of individuals who died in the tragedy at the Bazar de la Charite in 1897, and this pioneering effort is considered the first modern example of formal dental identification from a mass disaster. Of the 126 individuals killed in the fire, dental evidence was used in the identification of 30 individuals who could not be visually identified. Although Amoedo did not personally perform all of the dental identifications, he used the disaster as an example of the individualistic nature of the human dentition for identification purposes and, as a result, published a book in French on the process (Amoedo 1898). Earlier anecdotal examples of personal identification based on teeth can be cited, but the work by Amoedo was the first published account that formally documented the individualistic characteristics of the human dentition and their utility for identification purposes.

The fire broke out at a fund raising bazaar for the poor, the Bazar de la Charite, in Paris on May 4, 1897 and claimed the lives of 126 individuals. The fundraiser was being held within a varnished wood shed approximately 72 meters long and 30 meters wide, constructed with a roof of tarred cardboard. As a special attraction, a cinematograph was installed in the structure and during the fundraiser the gas lamp exploded and set fire to the surrounding drapes, which quickly spread throughout the entire building (Botha 1986). The structure subsequently collapsed and killed 126 individuals. Many of the victims were badly burned and disfigured, making visual identification often impossible. As an additional means of identification, recognition of clothing and personal effects by friends and relatives was used but 30 bodies could not be identified by any of these means. In order to identify the remaining 30 individuals, dentists were summoned in order to attempt to identify restorative work that they had personally performed. The reports of the investigating dentists involved in the tragedy formed a major part of Amoedo's doctoral thesis in which he recorded the procedures and observations of the dentists. Besides emphasizing the individualistic nature of the human dentition, he also suggested that a uniform charting system and nomenclature was needed so that dental work could be easily documented and understood between practitioners. These concepts were incorporated into his book *L' Art Dentaire en Medecine Legale* (Amoedo 1898) which is regarded as the first comprehensive documentation regarding forensic odontology and dental identification. It was not until 1966 that a formal book was published in English on forensic odontology (Gustafson 1966).

Ruxton Case

An example from the 1930s in Lancaster, England demonstrates that even the criminals were well aware of the utility of teeth for identification purposes (Cleland 1944). The remains of two women had been found in several packages under a bridge, dismembered by someone with an apparent familiarity with human anatomy. Furthermore, several teeth had been intentionally removed in an attempt to hinder any type of dental comparison that could lead to an identification. Due to considerable evidence, Dr. Buck Ruxton was subsequently accused of killing his wife and their nursemaid. He was convicted and hanged in May of 1936. Interestingly, a photographic superimposition with one of the skulls led to the identification of his wife, and fingerprint evidence was used to identify the nursemaid.

Noronic Disaster

The S.S. Noronic, flagship of the Canada Steamship Lines, had tied up overnight at Queen's Quay in Toronto, Canada while en route on a cruise from Detroit to the Thousand Islands, Ontario. On the morning of September 17, 1949, fire broke out on the ship and in a very short time the entire vessel was engulfed in flames and 119 of the 527 passengers were killed. One hundred eleven charred bodies were recovered from the ship, five individuals drowned in the harbor, and three died in transport to or at the hospital (Brown, et al. 1952, Grant, et al. 1952, Singleton 1951). The extensive burning of many bodies made visual identification often impossible. Furthermore, as the fire broke out in the early morning, most individuals were in bed and had removed what might have been diagnostic jewelry or clothing. Through a combination of medical, radiographic, and dental means, 116 of the 119 individuals were identified (Brown, et al. 1952).

Due to the extreme burning of most bodies, visual identification was not possible and dental identification played an important role. The dental identifications were based on antemortem charts, radiographs, and verbal descriptions of dentures by dentists. Forty dentists assisted with the examinations and a chart was completed that documented all dental conditions for each body. Of the 102 bodies that needed dental examinations, 30 had their natural teeth, 29 were completely edentulous, 24 had either upper or lower dentures, and 19 had no facial structures remaining. Those bodies with natural teeth were compared with the dental charts and x-rays that had been furnished by the dentists. In total, 59 bodies were identified due, at least in part, to dental examination.

During the identification process the dentists made several observations regarding the potential obstacles to dental identification, specifically the lack of standardization regarding dental codes and the lack of accuracy in recordation. They wrote,

> "It soon became apparent that there is an appalling failure on the part of dentists to keep any accurate record of the mouth conditions and history of their patients. In most cases their charts only recorded operations they had themselves performed without any notation of mouth conditions or previous dental operations. Then too, they were often in a code that only the dentist himself could understand. Some charts were marked left-right, and others right-left, and some had no indication which was right and which was left" (Grant, et al. 1952:17).

Radiographic comparison played an important role in the identification process with the Noronic disaster. Although radiographic comparison was most commonly based on skeletal features, it was also utilized in several instances regarding the dental evidence. In a general reference to radiographs (skeletal and dental), one of the investigators states, "When good pre- and post-mortem films were available for comparison, this method of investigation was more accurate than fingerprints" (Grant, et al. 1952:8). Radiographic identifications (non-dental) were made from the following elements: skull (4 individuals), cervical spine (2 individuals), thoracic spine and chest (13 individuals), lumbar spine and pelvis (9 individuals), foot and ankle (1 individual). In regard to radiographic dental identifications, the investigators compared postmortem x-rays with those of missing persons that had been forwarded by their dentists and found, "These x-rays gave a positive lead in several cases and at least one case was identified solely by this means" (Grant, et al. 1952:12). Furthermore, it was recommended by the dentists that, "Dental radiograms should be retained on file, to be available if needed at any time for identification" (Grant, et al. 1952:18). A problem that was encountered during the Noronic investigation was that it was often a very difficult and lengthy process to locate antemortem radiographs. The final radiographic identification was not completed until 10 weeks after the disaster occurred (Singleton 1951).

The investigators claim that this case was the first published use of radiographs for identification purposes in a mass disaster (Singleton 1951). Earlier published accounts, e.g. Culbert and Law (1927), performed the radiographic identification of a single individual, but not a mass fatality situation. Regarding the dental evidence, this case appears to be the first published since Amoedo's description of the Paris fire in which dental examinations played a significant role in the identification process of a mass disaster. More importantly perhaps, this case appears to be the first published account of a mass disaster in which dental radiographs were used for identification and the utility of this evidence was stressed.

CHAPTER 3: DENTAL CHARTING METHODS FOR PERMANENT TEETH

A valid concern with the use of dental records for identification purposes is that charting errors may be present or that charts and x-rays may be out of date and not reflect the current dental status. It is common to find discrepancies attributable to numerous causes (Brown 1982). Common charting errors occur when teeth are extracted and shift mesially or distally. For example, a first molar may be extracted and the second and third molars may drift mesially and fill the gap. During the charting process, the second molar may inadvertently be taken for a first. The same may be true with premolars as these are commonly extracted for orthodontic reasons. It is also possible that fictitious treatment may be documented in records with the intent to file fraudulent insurance claims. Finally, if a dentist only documents work that he or she personally performed, then an incomplete record of the person's dental history will be available that could potentially exclude numerous restorations or extractions (Stimson 1975). Any of these factors could impede the identification process and must be considered during all antemortem-postmortem comparisons. The completeness and accuracy of dental charts is entirely dependent on the time, effort, and willingness of the examiner to document all aspects of treatment. Although not as great a concern if radiographic evidence is available, an antemortem-postmortem dental comparison is entirely dependent on charting accuracy and errors in either stage of the documentation may lead to unwarranted exclusions or delays in the identification process.

Besides potential problems in forensic identification that may arise from errors in charting, additional difficulties may occur simply from the various charting/numbering systems that exist for recording antemortem dental information. The need for standardization has long been recognized for both forensic and dental health purposes, and many early researchers have raised this point (e.g. Amoedo 1898, Bodecker 1931, Bodecker 1939, Grant, et al. 1952, Morelli 1924, Ryan 1937). Bodecker states, "As the method of keeping dental records has not been generally standardized, at present it is difficult to compare the records of a number of examiners on the basis of a common denominator" (1939:1453). Although Bodecker was referring more specifically to the impact this lack of standardization has on dental health studies, the problem is equally important in the realm of forensic identification.

The numerous dental charting systems that have been developed throughout the world can cause interpretation problems during forensic comparisons if treatment, or lack there of, is erroneously attributed to an incorrect tooth. Keiser-Nielson states that, "Recent investigations have revealed that more than 30 such systems are in use all over the world, which appears to be an unreasonably large number" (1965:345). In a later article (Keiser-Neilsen 1974), he discusses the recommendation of the Federation Dentaire International (FDI) to standardize dental charting and claims that a worldwide survey revealed 40 different charting systems. In their book, Luntz and Luntz (1973) claim that there are over 34 different systems of tooth designation used throughout the world. Regardless of the actual number of charting systems, it was universally agreed that too many exist and that forensic odontologists would greatly benefit from a standardized technique.

Today, there are basically two techniques that are utilized by most dentists, but it is not uncommon for forensic cases to rely on the interpretation of antiquated dental records and it is essential for forensic odontologists to be familiar with even out-dated and somewhat obscure methods. Several of the most frequently observed charting systems from the past century are described below. In order to limit the scope of the review, the variations on each method regarding the deciduous teeth will not be discussed.

Palmer / Zsigmondy System

One of the first shorthand systems for charting teeth was invented by Adolph Zsigmondy as early as 1861 (Alt and Turp 1998, Frykholm and Lysell 1962). Dentists throughout the world have utilized this system. Conditions of the permanent dentition are charted by dividing the mouth into quadrants and designating the teeth with numerical codes ranging from 1 to 8, starting with the central incisors and progressing distally. An "L" shaped notation was then placed with the appropriate rotation, ⏋, ⌟, ⎿, or ⎾, around the tooth number (1-8) to designate the location within the arcade. For correct interpretation of this system, the observer is facing the subject and a vertical line symbolizes the midline between the central incisors and the horizontal line symbolizes the occlusal plane, thus dividing the mouth into quadrants. As such, designations of teeth from the right side appear with a vertical line to the right of the number and the horizontal line will

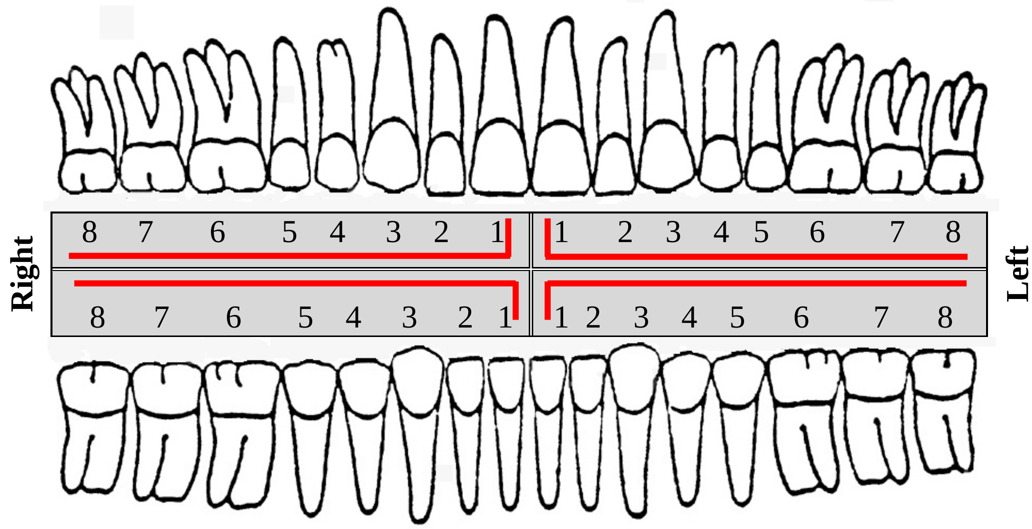


Figure 1. Zsigmondy / Palmer Charting System
(Bold lines denote proper placement of the “⌉, ⌋, ⌊, or ⌈”).

indicate whether the tooth is maxillary or mandibular. For example, an upper left central incisor would be noted as ⌊1, while a lower right central incisor would be noted as 1⌉ (Figure 1).

This method is identical to the charting technique presented by an American dentist named Corydon Palmer in 1870 at the American Dental Association meeting, and for that reason it is generally known as “Palmer’s Notation” in English speaking countries (Frykholm and Lysell 1962). The main drawback of the Zsigmondy/Palmer system is that it is difficult to annotate on a typewriter and is only of real utility when handwritten.

In 1947, the American Dental Association endorsed the Palmer Notation System for the symbolic designation of teeth (Lyons 1947). The association recognized that no uniformity existed between organizations and that the various methods were unintelligible without explanatory comments. This method was the most common form of tooth designation in the U.S. until 1955. Later, the Universal Numbering System was endorsed by the American Dental Association (Luntz and Luntz 1973).

Bosworth System

The Bosworth system of charting is identical to the Palmer/Zsigmondy system except that the mandibular teeth are given alphabetic designations (Figure 2). The addition of alphabetic codes was in an effort to lessen the potential confusion between maxillary or mandibular designations. The same symbolic designations (⌉, ⌋, ⌊, or ⌈) are still used to designate the correct side, although the horizontal bar becomes meaningless since the maxillary or mandibular arch is defined by either a numeric or alphabetic designation (Frykholm and Lysell 1962).

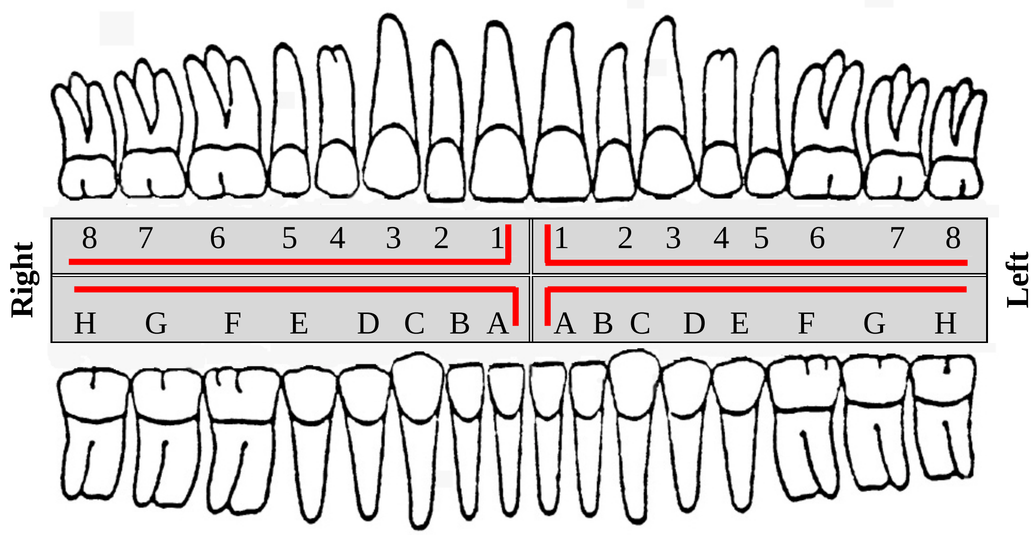


Figure 2. Bosworth Charting System
(Bold lines denote proper placement of the "⌉, ⌋, ⌊, or ⌈").

Haderup System

Another early charting system, originally devised by Viktor Haderup in 1887, gained popularity in the Scandinavian countries and central Europe (Alt and Turp 1998, Frykholm and Lysell 1962). Basically this system is identical to the Palmer/Zsigmondy system but it replaced the rotating “⌊” with either a “+” or a “-” to designate the maxilla and mandible respectively. In order to designate the side, the Haderup system simply placed the sign before or after the number; a sign on the right side indicates a right tooth while a sign on the left indicates a left tooth (Frykholm and Lysell 1962). Both the maxillary and mandibular teeth are numbered 1 through 8 starting with the central incisors and progressing distally (Figure 3).

Gustafson (1966) recommended the use of Haderup’s system of charting, citing that it can be rapidly learned in school and is easy to apply and use correctly. One of the benefits of systems such as Palmer/Zsigmondy and Haderup is that it is very easy to refer

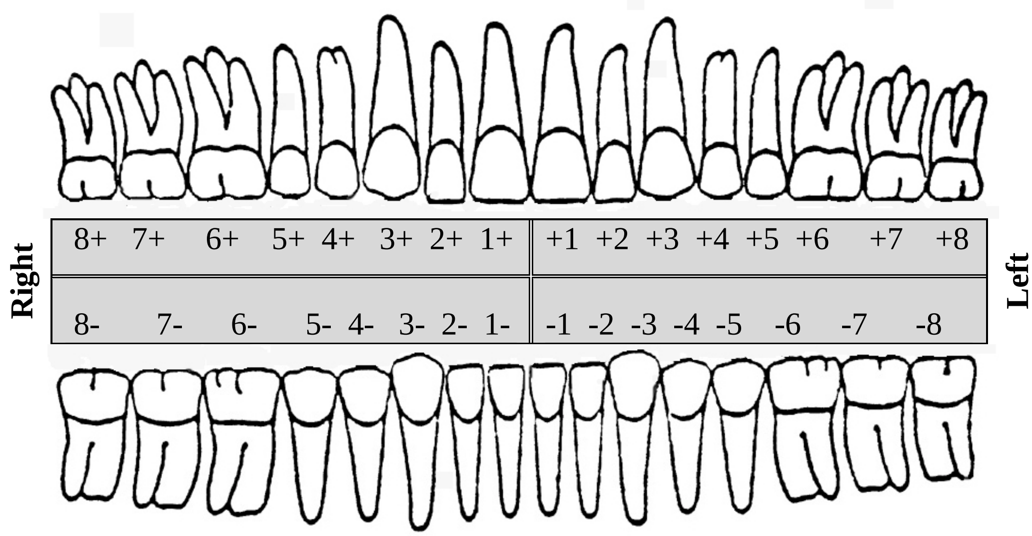


Figure 3. Haderup Charting System.

to all canines as “the 3s” and have the designation be very clear to another person. Other charting techniques, such as the Universal Numbering System, have different numerical designations for each tooth regardless of type.

Army System

The United States Army utilized a nomenclature for numbering the teeth, especially during WWII and the Korean War, referred to as the “Army System” (Frykholm and Lysell 1962). The maxillary teeth are numbered 1-8 and the mandibular teeth are numbered 9-16. Like other techniques, the numbers initiate at the midline and progress distally. The side is designated by placing an “R” or “L” in front of the number (Figure 4). Later, the army switched to the Universal Numbering System, which is still used in all branches of the U.S. military today.

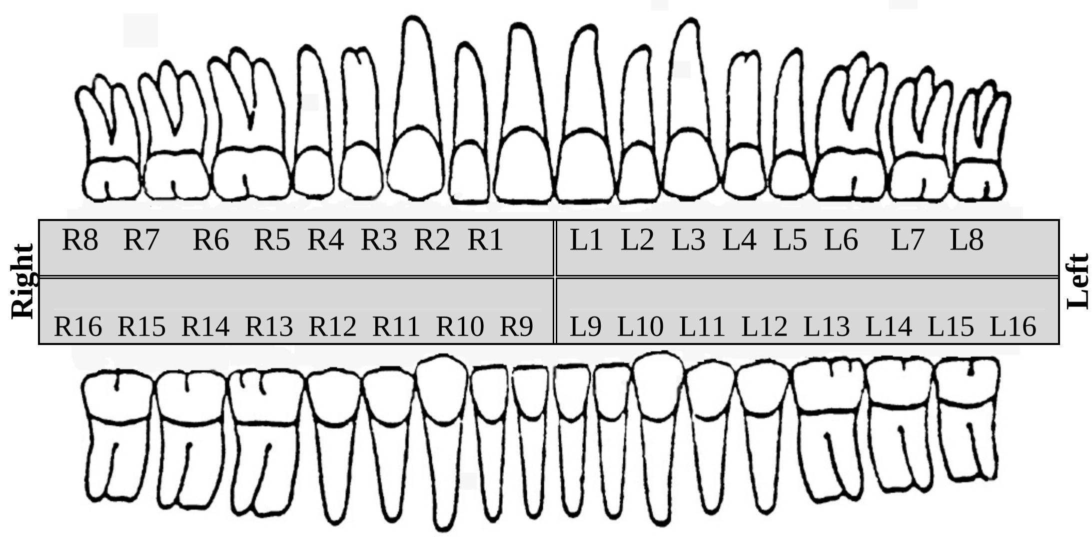


Figure 4. Army Charting System.

Universal System

Perhaps the most simplistic system of dental charting is the Universal Numbering System, which labels the teeth consecutively from 1-32 for the permanent dentition. This system was proposed in 1882 by Julius Parreidt and abandoned the quadrant system that was utilized previously (Alt and Turp 1998). The Universal system assigns each tooth its own numerical designation from 1 to 32, starting with the maxillary right third molar and ending with the mandibular right third molar (Figure 5). This system is the most popular in the United States and is the accepted standard of the American Dental Association (Luntz and Luntz 1973) and the American Board of Forensic Odontology (anonymous 1994). Critiques of this system generally cite the potential of selecting the wrong number to designate a specific tooth and the difficulty of memorizing 32 different designations. Critics claim that the risk of assigning the wrong number is too great due to the quantity of designations and most prefer the FDI system (see following) as the best alternative.

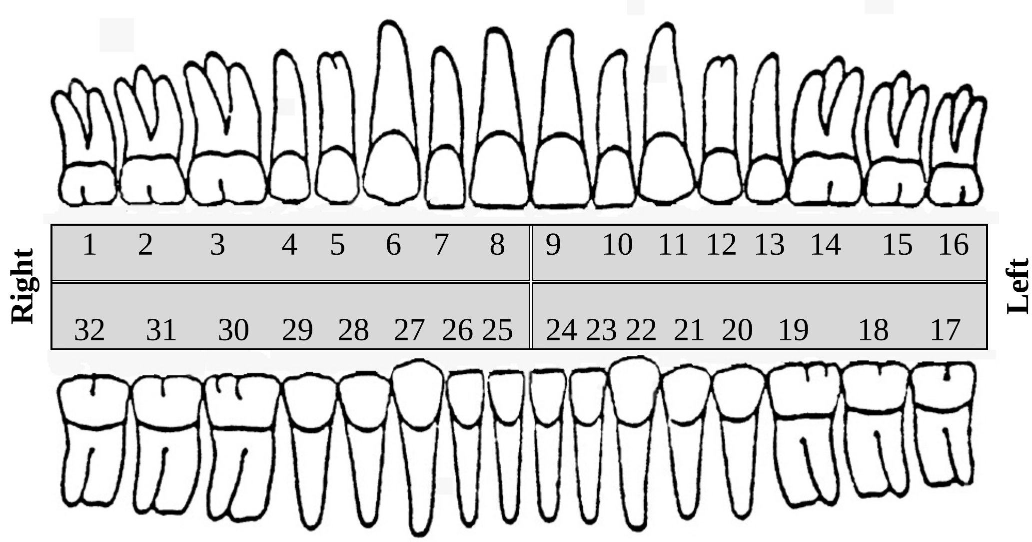


Figure 5. Universal Charting System.

Navy System

A potentially confusing system that is very similar to the Universal System is called the "Navy System" due to its use in the past by the U.S. Navy (Figure 6). The Navy system switches the mandibular numbers so that 17 is the lower right third molar and 32 is the lower left third molar (Committee on Nomenclature 1950, Frykholm and Lysell 1962). During WWII, the U.S. Navy used this type of system for charting dental conditions of its sailors and care must be used in the interpretation of Form H-4, NAVMED H-4, and NMS Form Y when interpreting dental conditions from this time period. The overall similarity between the Universal Numbering System and the Navy System could cause great confusion. This technique was later abandoned and currently all branches of the U.S. military use the Universal Numbering System.

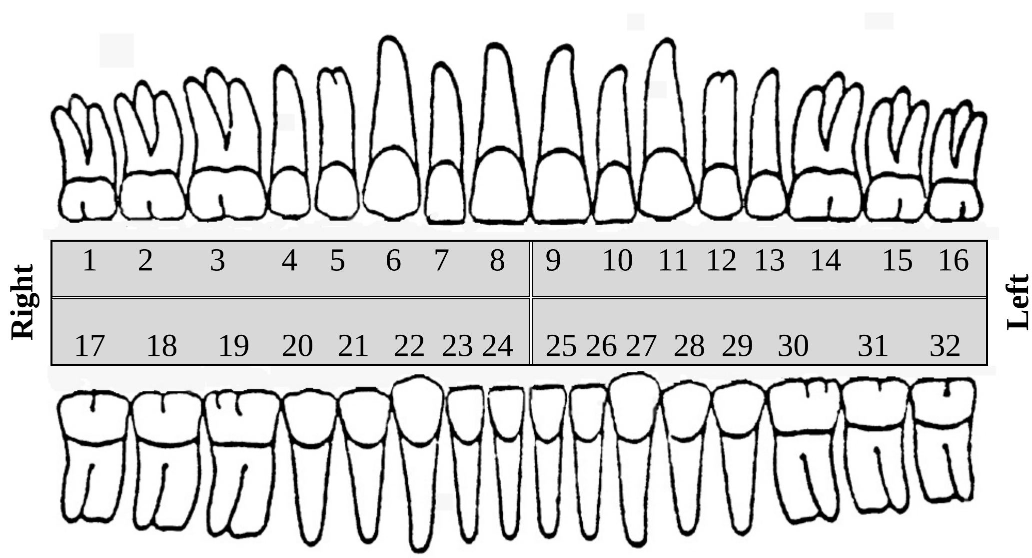


Figure 6. Navy Charting System.

FDI System

In response to the potentially confusing Palmer Notation System utilizing the ⌉, ⌋, ⌊, or ⌈ labels, a modified approach was developed. During the General Assembly of the Federation Dentaire International (FDI) at its 58th annual session in 1970, a two-digit system was recommended for use worldwide (Turp and Alt 1995). The FDI system has been endorsed by the World Health Organization and is used by international agencies such as Interpol (Turp and Alt 1995). The FDI system divides the mouth into quadrants and gives each of the four areas a numeric designation of 1 to 4. Each tooth within the quadrant is given a numeric designation of 1 to 8, starting at the midline and proceeding distally (Figure 7). For example, tooth one-three (13) is in the upper right quadrant, designated by “1” and is the third tooth from the midline, the canine. In order to avoid confusion with the Universal system, these designations should be read as, for example, “one-three” and not “thirteen.”

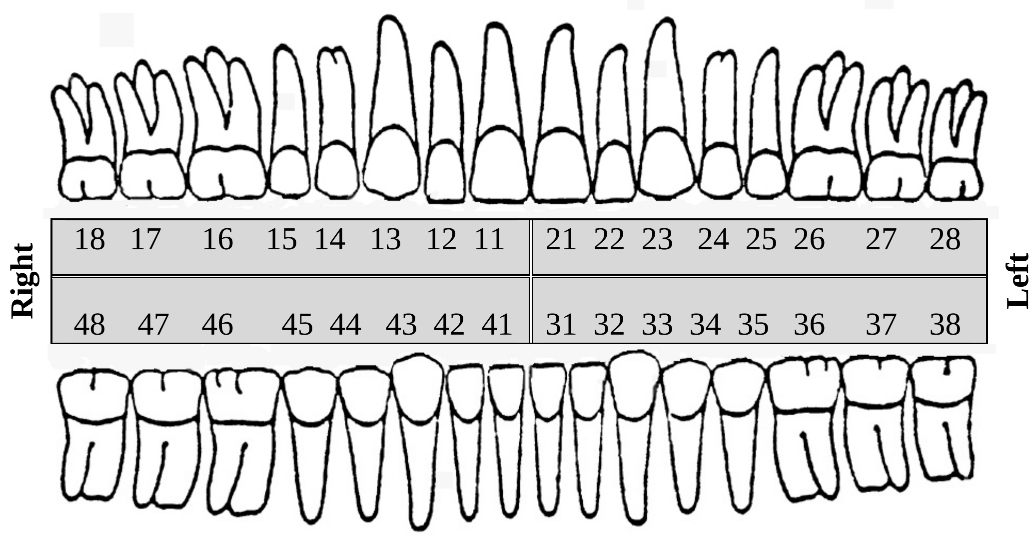


Figure 7. FDI Charting System.

While the notation may be easier than the Palmer system, potential confusion is still possible, especially due to the apparent similarity that many of the codes have to the Universal Numbering System. The Universal Numbering System and the FDI system are the two most widely used charting techniques in the world today. Great care must be taken by forensic odontologists to avoid potential confusion between the numeric designations of these two systems. In 1994, the American Dental Association recognized the usefulness of the FDI system and encouraged that it be taught along with the Universal Numbering System (Alt and Turp 1998).

A problem analogous to the similarity between the Universal and Navy charting systems may exist with the FDI system. Luntz and Luntz (1973) state that the quadrant designations of the FDI system have been modified in some cases so that the even numbered quadrant designations refer to the left side and the odd numbered quadrant designations refer to the right side (this entails switching the quadrant designation for the mandible only). A recent article discussing the FDI system (Turp and Alt 1995) makes no mention of any modified usage of the FDI system and it is unclear how frequently, if ever, the modification has been utilized. In another discussion of charting methods (Alt and Turp 1998), it was noted that Clemens Pirquet described a system similar to the FDI in 1924 that switched the mandibular quadrant designations, although the recommended quadrant designations for the permanent teeth were 5 through 8 instead of 1 through 4.

Charting Summary

In a 1950 article (Committee on Nomenclature 1950), a survey found that the most popular system of tooth designation used by dentists in the United States was the Palmer Method, which they refer to as the "Symbolic System." The next most popular was the Universal System, followed by the Army System, then the Navy System. All other charting schemes were grouped together into an "other" category that fell between Universal and Army in their frequency of use. Most popular within the "Other" category was the Bosworth system. Today, most dentists rely primarily on two charting techniques, Universal or FDI, but as both of these techniques involve numeric designations there is still opportunity for confusion. Due to the wide variety of charting techniques that have been utilized by dentists, it is in the best interest of forensic odontologists to familiarize themselves not only with the Universal and FDI systems, but also with the other variations that have been used in the past.

CHAPTER 4: DENTAL HEALTH INDICES FOR PERMANENT TEETH

Frequently the goal of dental health studies is to track overall changes in dental health, such as the rates of caries and tooth loss in specific demographic or temporal groups, but another concern is to assess the overall dental needs of the population. Regardless of the intent, the published results from dental health studies provide summary statistics derived from large samples of individuals. Although the purpose of this dissertation is not to address issues relating to dental health or dental needs, a brief discussion of the indices commonly used in these fields is warranted.

While modern dental health studies occasionally rely on data derived from dental records, most studies base their research on a detailed analysis of living individuals who are randomly selected from the population as a whole in order to form a representative sample. Other studies focus on the dental health of past groups through archaeologically recovered remains. For example, Hardwick (1960) tracked the caries incidence in England spanning a period from the Neolithic until the present. For his study he considered the number of existing carious teeth and the number of missing teeth. The number of missing teeth was adjusted in order to attempt to reflect the number that would have been lost due to caries. Hardwick assumed that if less than five percent of the existing teeth were carious, then 25 percent of the missing teeth were due to caries; if five to 20 percent of the existing teeth were carious, then he assumed that 33 percent of the missing teeth were the result of caries; if over 20 percent of the existing teeth were carious, then 50 percent of the missing teeth were considered to be due to caries. In another study of archaeological remains from Britain, Moore and Corbett (1971) state that it is unjustified to use antemortem tooth loss in caries studies of ancient remains since the loss may be due in large part to alveolar recession, exfoliation from severe attrition, and trauma.

As part of the research presented in this dissertation, one of the most frequently used dental health indices, the Decayed, Missing, Filled Teeth (DMFT) index, was calculated from the relevant datasets for comparison with published DMFT scores from the dental health literature. The rationale for this comparison is that it can be used as a test of the validity of two of the datasets used as part of this dissertation. Similar results between the published data and those generated as part of the present study are an indication that the data are reliable, while vastly different results may be an indication that bias has been introduced. In essence, the dental health results are treated as the accurate reflection of the true dental status, and significant variation between the published results and those derived from the samples used in this dissertation may be an indication of a deficiency with the data.

Although the DMFT index is the most popular method of quantification used in dental health studies, various researchers have utilized other indices and a brief discussion of some of the most noteworthy techniques is presented.

Morelli Caries Index

The Morelli Caries Index, published in 1924, is one of the first techniques developed for creating a numerical designation of the caries status for an individual

(Morelli 1924). Interestingly, Morelli even considered the possible forensic implications of his caries index and states that it could be used "…in criminal matters as a mark of identity" (1924:1075). The primary reason for the development of this index was that Morelli was critical of dental health studies that only grouped individuals into two categories, those with caries and those without caries (presence-absence for the individual, not the tooth). Obviously the information contained in presence-absence studies may be of interest in young individuals, but the index quickly loses its relevance since only a very small segment of the adult population remains caries-free. He proposed a quantitative measure, **J = An**, to represent the individual's caries status. He refers to **A** as the basic number and **n** as the coefficient. The basic number, **A**, equals the number of existing teeth divided by the number of carious teeth $\left(\frac{\textit{existing teeth}}{\textit{carious teeth}}\right)$ and the coefficient, **n**, equals the number of carious teeth. The larger the basic number, the better the dental health. The lower the coefficient, the better the dental health. Once the expression is formed, the values of **A** and **n** can be multiplied together to derive the number of existing teeth, **J**, and then this value can be subtracted from 32 (number of teeth in the permanent dentition) to derive the number of missing teeth. (This expression assumes that one or more teeth will be carious, otherwise it would require division by zero.) As an example, consider an individual with 24 existing teeth, 6 of which are carious or filled. The base number value (**A**) is 24/6 or 4. Morelli's caries-index is then expressed as **J** = 4(6) and it can be determined that 24 teeth are present, 8 are missing, and 6 are carious.

While this numerical expression may be useful for comparing the dental health of one individual to another, it does not lend itself to dental health studies involving large numbers of individuals since the caries-index is not represented by a single value and cannot be averaged by desired demographic cohorts or compared between studies (Toverud, et al. 1952). The Morelli Caries-Index has also been criticized in that it may not be able to track progressive caries development (Bodecker 1931, Bodecker 1939, Clune 1945). In other words, even though active decay may still occur on the same teeth within the mouth, the value will give the impression that the dental health is stable.

Although this technique does not seem to have received much use, it acted as a catalyst for the development of other dental health indices and represents a change in the manner in which dental caries were studied.

Decayed, Missing, and Filled Teeth (DMFT)

The DMFT index (Klein and Palmer 1937, Klein, et al. 1938) is one of the most widely utilized indices of dental health today. Although other researchers used similar (or identical) methods of quantification prior to Klein and Palmer's (1937) publication, it was this work that received the most recognition in the dental health literature and popularized the term DMFT. This important study (Klein and Palmer 1937) reported on the dental health of the permanent dentition of American Indian children based on data that was collected from 1929 to 1932. The logic behind the index is that the total number of decayed, missing, and filled teeth in the mouth is a reflection of the cumulative dental health from the eruption of the permanent dentition until the time of examination. Active tooth decay represents one facet of the total caries experience, filled teeth represent previously decayed teeth that have been repaired, and missing teeth are assumed to have been lost due to caries (decay is cited as the most frequent cause for missing permanent teeth). The quantitative expression is formed by summing all these factors (active decay, extraction, and restored decay). The various individual scores may then be totaled, divided by the number of persons examined, and multiplied by 100 in order to yield the average number of decayed, missing, and filled permanent teeth per 100 persons. This expression is then used as a measure of the overall caries experience of the population.

The DMFT index provides an accurate way to express dental health, and interpretation of the individual components (D, M, and F) allow for the observation of specific trends. Prior to the development of the DMFT index, studies commonly compared caries-free individuals to individuals with one or more decayed, missing, or filled tooth (Gafafer 1942). While this may be of interest with children, it is of little utility with adults since the adult population with perfect teeth will be quite small.

A criticism of DMFT studies is that they assume that both missing and filled teeth were once carious (Sheiham, et al. 1987). Specifically, concerns are raised since there are situations in which teeth are extracted for non-carious reasons (e.g. orthodontics), lost due to periodontal disease, or filled for preventative reasons. Dental health studies are almost exclusively concerned with conditions that are caused by decay. For this reason, the results of many studies will not consider teeth that are missing or filled for reasons other than caries. A problem caused by the exclusion of teeth that are missing for reasons other than decay is that the analyst, by default, places that missing tooth permanently into the status of “no caries.” The tooth will never have a chance to develop caries and it is essentially removed from consideration and will always be counted as though it is 100% healthy.

Other criticisms to the index stem from the fact that the quality of the teeth is not taken into consideration. All conditions of decayed, filled, and missing are given the same weight, which implies that no benefits are derived from the restoration of carious teeth (Birch 1986). Furthermore, a single, tiny carious lesion on a tooth is counted in the same manner as a tooth with numerous large restorations or a missing tooth. Although two individuals may have the same DMFT score, they may have very different dental health conditions.

A final criticism arises since additional decay occurring on the same tooth cannot be tracked. As the tooth is considered as a whole with the DMFT index, once a tooth has any degree of decay present, additional decay on that tooth will go unnoticed. The concern is that while an individual's dental health may continue to degrade, the DMFT index will not reveal progressive conditions on the same teeth.

Variants Of The DMFT

Although the works of Klein and Palmer (1937) or Klein, Palmer and Knutson (1938) are often cited for introducing the Decayed, Missing, and Filled Teeth (DMFT) index to dental health studies, it appears that several other researchers utilized nearly identical methods in their studies of dental health prior to Klein and Palmer. Nonetheless, it is was Klein and Palmer (Klein and Palmer 1937) who first coined the term DMFT which has become one of the most common indices used to date for dental health studies. Several of the precursors are briefly noted here for historical purposes.

Munblatt's Index: Munblatt (1933) provides the description of a dental health index that was specifically designed for studies of children with mixed dentition. He discusses the pros and cons of recording the number of cavities or fillings per tooth, as well as documenting the size of the decay. Munblatt states that the hazards of quantifying the number of lesions on each tooth can be misleading since two small cavities may represent less area of decay than one large cavity. Also, one large cavity may have started as two smaller lesions. For this reason, Munblatt's caries index considers the tooth as a whole, regardless of the amount of decay. The derivation of the index is described as follows,

> "In determining the percentage of incidence of decay for each age group, we added the number of teeth lost through decay, the number with open cavities (disregarding the size and number of cavities within the individuals tooth), and the number with fillings (or closed cavities), regardless of the size or number within the individual tooth" (Munblatt 1933:594).

The sum of all caries experience is obtained separately for the permanent and deciduous teeth, and then this total is divided by the number of permanent or deciduous teeth present. As this technique was specifically designed for use with children of mixed dentition, it is reported as the percent of affected teeth, but is nearly identical in all other respects to the DMFT index of Klein and Palmer (1937).

Ferguson's Index: Other than the wartime statistics regarding the number of individuals that were rejected from military service in the United States due to poor dental health, one of the first published studies to quantify overall dental health of a military population was completed by Ferguson (1935). He looked at 4,602 White U.S. Navy recruits from various sections of the country and provided information regarding the overall dental health based on geographic background. He presented his results as a summation of the number of decayed, missing, and filled teeth per individual referred to as the "Defective Teeth Average." Ferguson's index is identical in its derivation to the DMFT index but predates Klein and Palmer's (1937) article by two years.

Total Caries Index: The Total Caries Index (Gafafer and Messner 1936) is another example of a technique that is identical to the DMFT index in its calculation and predates the work of Klein and Palmer (1937). The Total Caries Index was used to report on the dental health of inmates in the Ohio State Reformatory, Mansfield. The index is calculated by adding together the number of filled and extracted teeth (the past treatment of the individual) to the number of teeth requiring fillings or extractions (the overall needs of the individual). They state, "…a numerical sum, or an index representing both untreated and treated caries, was formed by adding together for each individual examined the number of his indicated fillings, indicated extractions, filled teeth, and extracted teeth" (Gafafer and Messner 1936:329). The results of this study are not presented in the form of average values organized by age groups, but rather are presented as the frequency of individuals that correspond to specific Total Caries Index values.

Decayed, Missing, and Filled Surfaces (DMFS)

During 1937, dental health data was collected on elementary school children in Hagerstown, Maryland (Klein, et al. 1938). It was from the results of this study that the DMFS index was first presented. This index is very similar to the DMFT index except that the five surfaces of the teeth are tallied instead of treating each tooth as a single unit. The maximum DMFT score possible (i.e. an edentulous individual) would be 32, but with the DMFS index the maximum score would be 160. With the DMFS index, missing teeth are counted as five carious surfaces. Similarly, crowns are considered equal to five filled surfaces affected by past caries. Permanent dentition is more amenable to DMF studies since the reason for loss of deciduous teeth is more difficult to determine. Except for orthodontic or traumatic reasons, missing permanent teeth are generally found to have been lost due to extensive decay and are tabulated as such.

The DMFS has been criticized in that it is well suited for permanent dentition, but has serious limitations in dealing with changing (i.e. mixed) dentition in school children (Porter and Dudman 1960, Porter, et al. 1960). As the study group becomes more homogeneous (e.g. adults) the DMFS is more dependable as an expression of dental caries activity. Other potential problems to the use of the DMFS index are more serious. Foremost, there is variation between researchers concerning how decay is quantified and the appropriate values that should be assigned to missing and crowned teeth. For example, some researchers assign missing teeth a value of three (Bodecker 1939), others assign a value of four (Cross 1952), and others assign a value of five (Klein, et al. 1938).

Furthermore, some researchers considered different numbers of surfaces depending on the location of the tooth in the arcade (i.e. anterior teeth are assigned less surfaces than posterior teeth). This sort of variation between studies makes comparison of results impossible.

Another problem with any dental health study that utilizes tooth surfaces is that restorations are frequently larger than the area of decay and may include portions of the tooth that were not carious. For example, an interproximal filling will generally include the occlusal surface even if there was no decay on the occlusal surface. In this situation, at least two surfaces will be quantified as decayed and will artificially inflate the number of carious surfaces. A final consideration for potential bias is that documentation of affected surfaces is more subjective than simply noting that the tooth has decay. For this reason, interobserver variation is likely to be more prevalent in DMFS studies than DMFT studies.

Other researchers developed similar indices to the DMFS, one of which is briefly presented below, but it was the report of Klein, Palmer, and Knutson (1938) that first popularized the technique for quantifying dental health based on the tooth surfaces.

Bodecker Index

As a response to what he viewed as a flaw with the Morelli Caries-Index, Bodecker (1931, 1939) developed a modified caries index that considered the tooth surfaces that could be affected by caries instead of the tooth as a whole. Bodecker's technique is similar to the DMFS technique outlined by Klein, Palmer, and Knutson (1938), but predates it usage.

Bodecker is critical of Morelli's technique due to the fact that the true progressive pattern of caries may be missed. For example, consider a person who has four carious lesions, one located on each of the 1st molars. Six months later additional lesions develop on other surfaces of the same teeth. The Morelli index does not change and there appears to be no progressive activity in regard to dental caries (this criticism is also leveled at the DMFT index). For this reason, Bodecker considers tooth surfaces and distinct areas of the tooth as the units of calculation. Bodecker uses the number of carious or filled surfaces, allowing certain teeth to have more surfaces than others due to their distinct anatomic features. Missing teeth are also factored into the overall index value as it is considered likely that the tooth is missing due to caries.

Bodecker's index is calculated by counting the total number of carious and filled surfaces, as well as the number of missing teeth. He uses a total of 180 possible tooth surfaces and caries susceptible areas on the 32 permanent teeth (Bodecker 1939). It should be noted that an earlier article by Bodecker (1931) only considered 160 possible surfaces (five for each of the 32 teeth), but this was later expanded due to the tendency of the molars and premolars to develop distinct defects on the same surface. He considered seven surfaces on the upper 1st and 2nd molars (one extra occlusal surface and one extra lingual surface), six surfaces on the upper 3rd molars (one extra occlusal surface), six surfaces on the lower premolars (one extra occlusal surface), and six surfaces on the lower molars (one extra lingual surface). All other teeth are considered to have five possible surfaces. Teeth that have a crown present are assigned a value of three, regardless of the tooth affected, since Bodecker determined that, in most cases, a tooth was crowned when three surfaces were affected. Similarly, the same score of three was assigned to missing teeth as he determined that there were usually three affected surfaces present at the time of extraction. Crowns that were placed as an abutment for a bridge were not counted since they were not a result of caries. Teeth lost or extracted for reasons other than caries were not considered in the calculation of the caries index.

The main difference between the Bodecker index and the DMFS index is that a different number of surfaces are considered and a different value is assigned to missing teeth. Either technique will give satisfactory results, but the DMFS has gained wider acceptance than the Bodecker method, partially because the DMFS index is more straightforward without any significant loss of information.

CHAPTER 5: MATERIALS AND METHODS

The four distinct datasets utilized as the core of this research correspond to different temporal periods or demographics. The datasets are referred to as: WWII-Korea, Southeast Asia, Modern Military, and Modern Civilian. All datasets are composed of dental records of United States residents, the vast majority of who are between 17 and 50 years of age.

The datasets were each coded into two separate formats depending on the goals of the analysis (DMFT Data and Forensic Data). The first format, referred to as the DMFT Data, codes the data in order to perform comparisons with published DMFT results of compatible studies. Next, the data were formatted for observing the uniqueness of dental patterns for forensic comparisons. These datasets are referred to as the Forensic Data and were subdivided into "generic" and "detailed" formats regarding the treatment of fillings. The main difference between the DMFT and Forensic data is that dental health studies (DMFT) are primarily interested in caries, while forensic dental comparisons are not as concerned with active (i.e. unrestored) decay.

All of the codes were designed to pertain to permanent teeth and all datasets were formatted to use the same coding system. If retained deciduous teeth were encountered, they were coded as though they were permanent. No consideration was given to supernumerary teeth.

DMFT Data

Two of the datasets used in this dissertation were originally compiled as part of dental health studies, and the other two datasets were derived from the health files of military personnel. Only the DMFT scores from the datasets derived from personnel files (WWII-Korea and Southeast Asia) were compared with published DMFT scores. For generating DMFT indices, it is necessary to calculate the total number of Decayed, Missing, and Filled teeth in an individual's mouth. Teeth with only active decay fall into the Decayed component, teeth with restorations fall into the Filled component, and all antemortem loss comprise the Missing component. Teeth with both a restoration and active decay on different surfaces were coded pertaining only to the restoration. Most dental health studies would take the opposite approach and would code only the decay instead of the restoration since active decay is considered to be of more interest. This slight variation from the standard protocol of most dental health studies will have a slight effect on the individual Decayed and Filled components of the DMFT index, but will not change the overall score. For this study, missing teeth were counted regardless of the reason for their loss. Some dental health studies include all missing teeth, while others attempt to include only those that are missing due to decay. It was essential for comparing DMFT values derived from the WWII-Korea and Southeast Asia datasets to calculate the index in a manner that mimics dental health studies as much as possible, but based on the source of the data used in this study (military dental records), this was not always possible.

Forensic Data

In order to observe the dental pattern diversity that was present for forensic purposes, teeth that exhibited only active decay were considered to be unrestored (i.e. virgin) teeth and the decay was ignored. This treatment of active decay is different than was used with the DMFT comparisons since active decay is a very important factor in the calculation of the DMFT index. The reason for not using unrestored decay as a forensic identification tool is because it is most likely that the observed decay occurred since the last time the person visited the dentist and, as such, would not be indicated in any antemortem dental records, in turn making it forensically insignificant for comparison. Other researchers (e.g. Friedman, et al. 1989) have also recommended the exclusion of unrestored decay from forensic dental comparisons. Other than the variation regarding active decay, the codes used for DMFT analyses and the Forensic analyses were identical.

Dental Coding Formats

The DMFT codes utilized for the datasets are identical to those described below for the forensic codes, with the exception that active decay on a tooth was ignored for the forensic data, but was only coded as "**Z**" in the DMFT data (Table 1). Active decay in combination with a restoration was coded only in regard to the restoration in all formats of the data.

For the Forensic Data it was necessary to code each of the four datasets in two different formats, one that was labeled as the "detailed" version and one referred to as the

Table 1. Dental Codes for All Datasets.

Condition	Code in Detailed Dataset	Code in Generic Dataset
Restoration (Anterior Teeth)	Any combination of M, D, F, L	R
Restoration (Posterior Teeth)	Any combination of M, O, D, F, L	R
Crown (Anterior teeth)	MDFL	R
Crown (Posterior teeth)	MODFL	R
Missing antemortem	X	X
Missing but replaced with prosthesis (denture or bridge)	XP	XP
Unrestored / Virgin	V	V
Active Decay for DMFT Data	Z	Z
Active Decay for Forensic Data	V	V

"generic" version. This was completed in order to assess the variability of dental patterns that were created with the detailed codes versus the variability created by the generic codes. The information contained within the two formats of the datasets is identical with the exception of how restorations are documented (there is slight variation in sample sizes of the WWII-Korea and Southeast Asia datasets since some of the antemortem records only contained sufficient information to allow them to be included as part of the "generic" datasets). The detailed format provides specific surface information concerning the location of a restoration on any combination of the mesial, occlusal, distal, facial, or lingual surfaces (**M**, **O**, **D**, **F**, **L**). The generic format disregards the surface information and simply designates the tooth as restored (Table 1).

Detailed Format

A dataset of detailed information was constructed to record the specific locations of restorations on the tooth (Table 1). The codes **M**, **O**, **D**, **F**, and **L** were utilized which correspond to surface designations for mesial, occlusal, distal, facial, and lingual. Multiple restorations on a single surface (e.g. two distinct occlusal restorations on the maxillary right 1st molar) were only assigned a single code (in this case **O**). Furthermore, there is no differentiation between a single restoration that affects multiple surfaces and distinct restorations on different surfaces of the tooth. For example, it would be impossible to differentiate between a tooth that had two restorations, one on the occlusal surface and one on the facial surface, and a tooth that had a single restoration that was present on the occlusal surface and wrapped onto the facial surface. Both would be coded as **OF**. For the posterior teeth (Universal #s 2-5, 12-15, 18-21, and 28-31) five tooth surfaces (**M**, **O**, **D**, **F**, and **L**) were considered for each tooth and restorations could be any combination. On the anterior teeth (Universal #s 6-11 and 22-27) only four surface codes were assigned due to the lack of a significant occlusal, or incisal, surface. For the anterior teeth any combination of **M**, **D**, **F**, or **L** surfaces could be recorded. If a restoration was present only on the incisal surface of the anterior teeth (very infrequent), it was coded as **L**. Unique codes were not utilized for teeth with crowns or abutments. Posterior teeth with crowns or abutments were as assigned the code **MODFL**, while anterior teeth were assigned the code **MDFL**. It is not possible to distinguish between teeth that have restorations present on all surfaces and teeth with crowns or abutments. Missing teeth were designated by an **X**, while missing teeth that were replaced by prosthesis (denture or bridge) were designated as **XP**. Teeth with only active caries were coded as **V** for "virgin" (note that for the DMFT comparisons teeth with active caries were scored as **Z** without any information regarding the specific surface). If a tooth was both carious and filled, it was scored only in regard to the filling as this was deemed to have greater utility for forensic identification and would not alter the overall DMFT index (note that most public health studies would be more interested in the active decay instead of the restoration). Teeth with no decay or fillings (virgin teeth) were scored **V**. On occasion, individuals were found to possess a deciduous tooth that had been retained in the place of a permanent tooth. In these situations the deciduous tooth was treated in the same manner as a permanent tooth and was coded as such.

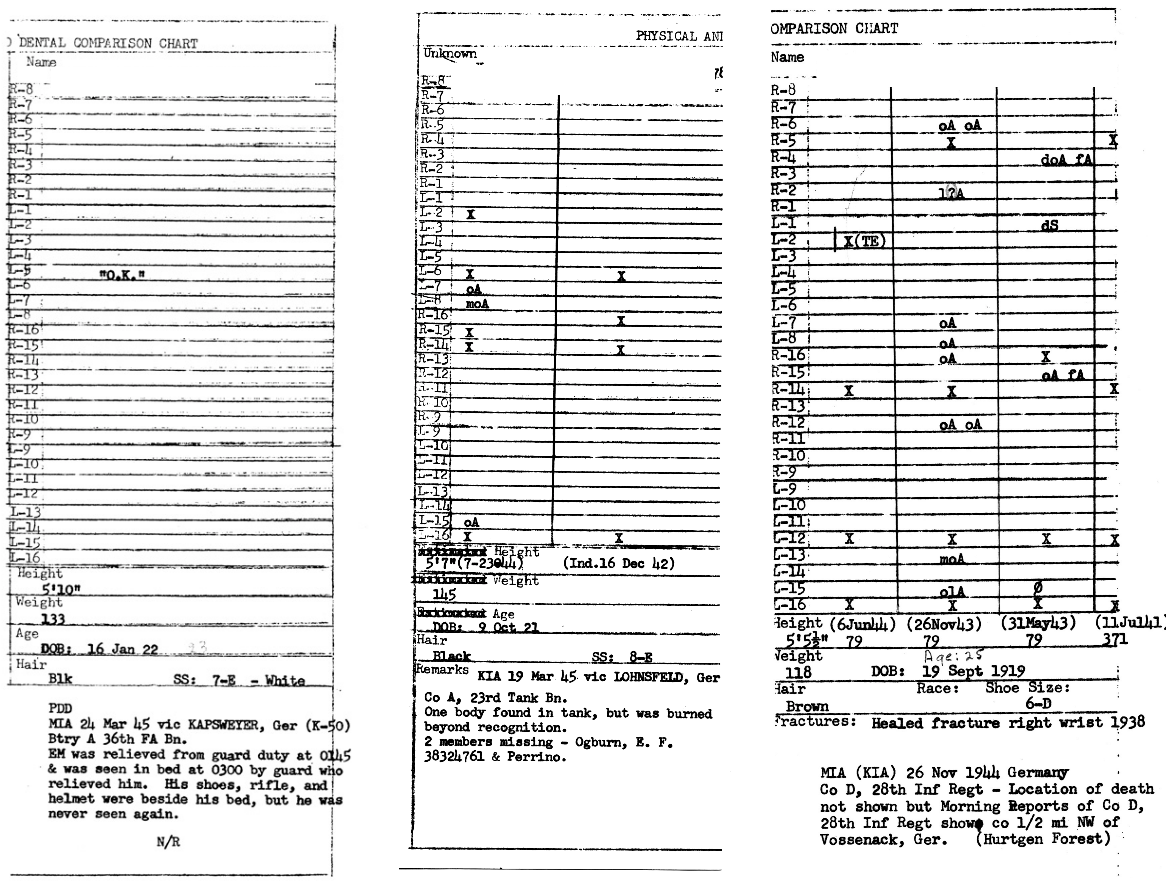
Generic Format

In the simplified datasets all filled surfaces were condensed into a single code, **R**, and the surface information was ignored. Similarly, teeth with crowns or abutments were coded simply as **R**. For example, if the detailed data showed a tooth to have a **MOD** restoration, this would be converted to a code of **R** in the generic format. The remaining codes were the same for missing, decayed, and unrestored teeth depending on the type of analysis being completed (Table 1).

WWII-Korea Data

The dental data representing the WWII-Korea timeframe was collected from the records of missing soldiers presumed to have been killed in various countries during either WWII or the Korean War. The data representing WWII were compiled from over 1,000 randomly selected dental charts of missing individuals. The data from the Korean War were compiled from the records of over 8,000 individuals missing from the war whose dental information had already been entered into a database for comparison using the CAPMI computer program. All branches of the service are represented in the dataset. The data from each of these conflicts was combined into one WWII-Korea dataset due to the temporal similarity (most records were originally charted during the early 1940s-early 1950s).

The WWII data were originally derived from a “Physical and Dental Comparison Chart” (Figure 8). Although there is not a specific military form reference number on these files, they are nearly identical to the DD Form 897 that was used during the Southeast Asia Conflict. The data on these records represent a compilation of dental treatment as derived from an individual’s personnel files once they were determined to be missing in action. The purpose of the “Physical and Dental Comparison Chart” was to allow the rapid comparison of a missing individual’s antemortem profile to an unidentified set of remains. Typically, these records were based on any combination of induction records, dental treatment records (Form 79-Medical Department), or Data on Remains Not Yet Recovered or Identified (OQMG Form 371). Based on the availability of information and the number visits to the dentist, these charts may consist of numerous columns of dental information (organized by date of examination). As can be observed in Figure 8 there is variation in the degree of detail contained from one record to another.


DENTAL COMPARISON CHART

Name

L-5 "O.K."

Height 5'10"

Weight 133

Age DOB: 16 Jan 22

Hair Blk SS: 7-E - White

PDD
MIA 24 Mar 45 vic KAPSWEYER, Ger (K-50)
Btry A 36th FA Bn.
EM was relieved from guard duty at 0145 & was seen in bed at 0300 by guard who relieved him. His shoes, rifle, and helmet were beside his bed, but he was never seen again.

N/R

A.

PHYSICAL AN[D]

Unknown

Height 5'7"(7-23-44) (Ind.16 Dec 42)

Weight 145

Age DOB: 9 Oct 21

Hair Black SS: 8-E

Remarks KIA 19 Mar 45 vic LOHNSFELD, Ger
Co A, 23rd Tank Bn.
One body found in tank, but was burned beyond recognition.
2 members missing - Ogburn, E. F. 38324761 & Perrino.

B.

[C]OMPARISON CHART

Name

Height (6Jun44) (26Nov43) (31May43) (11Jul41)
5'5½" 79 79 371

Weight 118 DOB: 19 Sept 1919 Age: 25

Hair Brown Race: Shoe Size: 6-D

Fractures: Healed fracture right wrist 1938

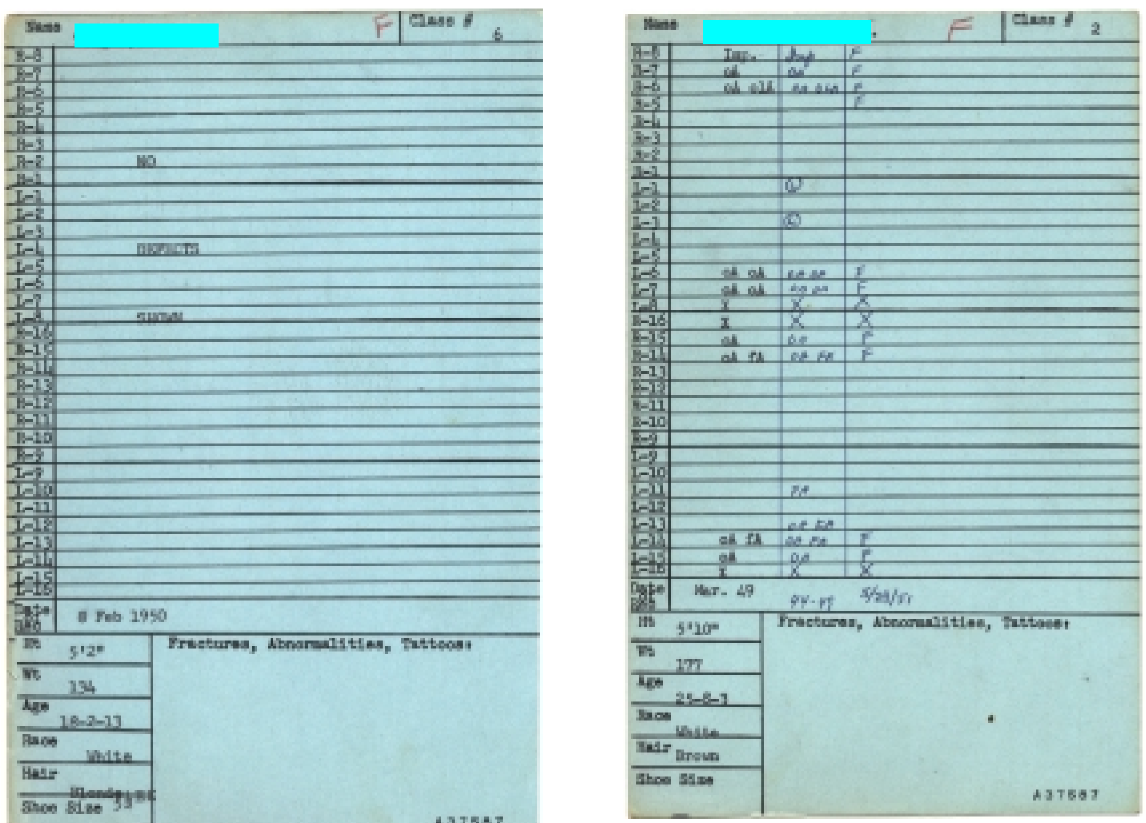
MIA (KIA) 26 Nov 1944 Germany
Co D, 28th Inf Regt - Location of death not shown but Morning Reports of Co D, 28th Inf Regt shows co 1/2 mi NW of Vossenack, Ger. (Hurtgen Forest)

C.

Figure 8. Three examples of WWII era dental records. A. Example of ambiguous notation listed as "O.K." B. Example of record with limited information from induction and additional information from treatment. C. Example of a detailed record listing several episodes of dental treatment.

Some records contain detailed surface information in regard to fillings, others contain only generic codes, and others are ambiguous as to treatment.

The Korea data was derived from a similar format as the WWII data. Individual cards consisting of relevant antemortem information were compiled for persons missing in action during the Korean War (Figure 9). These blue colored cards (OQMG Form T-320) represent a compilation of all available dental treatment. While these cards were



A. B.

Figure 9. Two examples of Korean War dental records. A. Example of ambiguous notation listed as "No Defects Shown." B. Example of a detailed record listing several episodes of dental treatment.

originally completed around the time of the Korean War to assist in antemortem-postmortem comparison, they were subsequently input into a database for use with CAPMI during 2000-2001. It was possible to use the CAPMI database as a source of Korean War era dental information for this dissertation.

As the causes of restorations and tooth loss (e.g. trauma or caries) could not be determined from either the WWII or Korean War records, all dental treatment was regarded in the same manner. If contradictory information was present (e.g. a tooth listed as missing in one column was subsequently listed as filled in the next), one column was arbitrarily considered to be correct and the others were disregarded. As the date of each exam was generally listed along with the relevant treatment information, precedence was given to the most recent data when possible. An individual's age corresponds to his age at the time of his last dental examination or presumed date of loss, depending on the available information. The demographic composition of the sample is presented in Tables 2 and 3 according to the detailed and generic data formats.

Southeast Asia Data

The dental data representing the Southeast Asia era were compiled from the records of missing soldiers from the Southeast Asia Conflict. Individuals from all branches of military service are represented. These data had been previously entered into a dental database (CAPMI) for comparison with postmortem dental evidence during the 1980s (Mr. Richard Huston, personal communication 2001). During this time, the dental

Table 2. Sample Size and Demographic Composition of the Detailed WWII-Korea Data.

Detailed **WWII-Korea** (All males, N=7,920)				
Age	White	Black	Other	No Race Information
17-19	1,599	160	26	5
20-24	3,069	350	157	13
25-29	1,101	81	25	9
30-34	540	56	7	7
35-39	191	17	4	1
40-56	46	5	2	-
No age information	397	30	12	10
Total	6,943	699	233	45

Table 3. Sample Size and Demographic Composition of the Generic WWII-Korea Data.

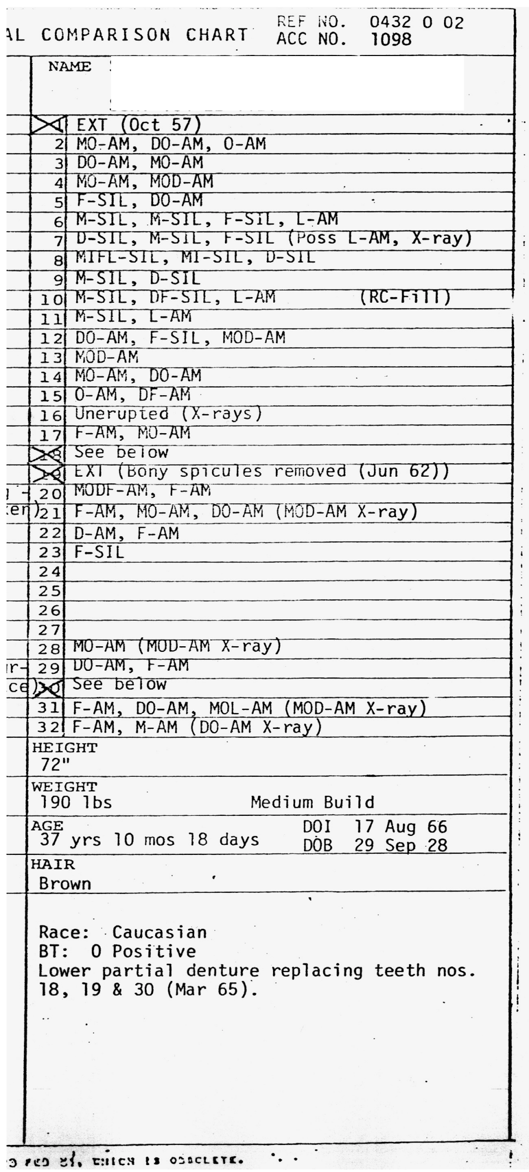
Generic **WWII-Korea** (All males, N=9,102)				
Age	White	Black	Other	No Race Information
17-19	1,777	170	32	7
20-24	3,486	399	177	15
25-29	1,320	88	31	11
30-34	686	75	6	7
35-39	230	25	8	2
40-56	69	6	5	1
No age information	411	35	14	9
Total	7,979	798	273	52

data for the individuals missing from the Southeast Asia Conflict were compiled into a single format (DD Form 897-Physical and Dental Comparison Chart) by several dentists for ease of data entry into the CAPMI program (Mr. Richard Huston, personal communication 2001). A team approach was used to review and verify data, and random checks were performed to verify data entry (Dr. Richard Fixott, personal communication 2002). Antemortem dental data were derived from all types of treatment records, including radiographic evidence, photographs, odontograms, and written treatment notes. It is estimated that approximately 60-70% of the files had radiographs present (Dr. Richard Fixott, personal communication 2002).

Figure 10 shows a typical antemortem record that contains detailed treatment information. In most instances, these records were found to be thoroughly documented. As the causes of restorations and tooth loss (e.g. trauma or caries) could not be determined from the records, all dental treatment was regarded in the same manner. The demographic composition of the data is listed in Tables 4 and 5 for the detailed and generic formats.

Modern Military Data (TSCOHS)

The dental health data representing the modern military population was graciously provided by the Tri-Service Center for Oral Health Studies, which is affiliated with the Uniform Services University of the Health Sciences, Bethesda, Maryland. The raw data from this source were originally gathered by the Tri-Service Center for Oral Health Studies as part of an ongoing study observing dental health throughout the active duty



AL COMPARISON CHART REF NO. 0432 0 02
ACC NO. 1098

NAME

1 (X)	EXT (Oct 57)
2	MO-AM, DO-AM, O-AM
3	DO-AM, MO-AM
4	MO-AM, MOD-AM
5	F-SIL, DO-AM
6	M-SIL, M-SIL, F-SIL, L-AM
7	D-SIL, M-SIL, F-SIL (Poss L-AM, X-ray)
8	MIFL-SIL, MI-SIL, D-SIL
9	M-SIL, D-SIL
10	M-SIL, DF-SIL, L-AM (RC-Fill)
11	M-SIL, L-AM
12	DO-AM, F-SIL, MOD-AM
13	MOD-AM
14	MO-AM, DO-AM
15	O-AM, DF-AM
16	Unerupted (X-rays)
17	F-AM, MO-AM
18 (X)	See below
19 (X)	EXT (Bony spicules removed (Jun 62))
20	MODF-AM, F-AM
21	F-AM, MO-AM, DO-AM (MOD-AM X-ray)
22	D-AM, F-AM
23	F-SIL
24	
25	
26	
27	
28	MO-AM (MOD-AM X-ray)
29	DO-AM, F-AM
30 (X)	See below
31	F-AM, DO-AM, MOL-AM (MOD-AM X-ray)
32	F-AM, M-AM (DO-AM X-ray)

HEIGHT
72"

WEIGHT
190 lbs Medium Build

AGE
37 yrs 10 mos 18 days DOI 17 Aug 66
DOB 29 Sep 28

HAIR
Brown

Race: Caucasian
BT: 0 Positive
Lower partial denture replacing teeth nos. 18, 19 & 30 (Mar 65).

... WHICH IS OBSOLETE.

Figure 10. Example of Southeast Asia era dental chart.

Table 4. Sample Size and Demographic Composition of the Detailed Southeast Asia Data.

Detailed **Southeast Asia** (All males, N=1,852)				
Age	White	Black	Other	No Race Information
17-19	61	7	-	-
20-24	447	11	5	1
25-29	572	9	2	-
30-34	312	10	6	-
35-39	219	8	1	-
40-63	113	3	1	-
No age information	55	8	-	1
Total	1,779	56	15	2

Table 5. Sample Size and Demographic Composition of the Generic Southeast Asia Data.

Generic **Southeast Asia** (All males, N=1,854)				
Age	White	Black	Other	No Race Information
17-19	65	8	-	-
20-24	459	12	5	1
25-29	583	9	2	-
30-34	316	10	6	-
35-39	222	8	1	1
40-63	112	3	1	-
No age information	24	6	-	-
Total	1,781	56	15	2

and recruit population of the U.S. military. The data was collected in 1994 and 2000 as part of two phases of the Tri-Service Comprehensive Oral Health Survey (TSCOHS). The 1994 data is composed of detailed dental conditions of active duty and recruits from all branches of the service and from different military installations across the continental U.S. The year 2000 phase of TSCOHS considered all branches of the military, but only in regard to recruits. Because the 2000 data only included recruits, the combined TSCOHS dataset is biased towards the recruit population as opposed to active duty.

These data represent the first military oral health study to be conducted on a tri-service level. The study design was created to be comparable to large-scale civilian dental health studies. The TSCOHS utilized electronic data collection, which greatly reduced the chance of data entry errors and expedited analysis. The data was collected from airmen, sailors, and soldiers by clinical examination and with radiographs. Additional information regarding TSCOHS can be found at their website (http://www.usuhs.mil/tscohs).

The demographic composition of the Modern Military data used in this dissertation is listed in Table 6.

As this data was originally collected for dental health assessments, thorough documentation and coding of information was available to an extent that surpassed the detail needed for this dissertation research. For example, the raw data had separate codes for teeth missing due to decay and teeth missing for reasons other than decay. Similarly, teeth with sound restorations were differentiated from teeth with faulty restorations. For

Table 6. Sample Size and Demographic Composition of the Detailed and Generic Modern Military Data.

Detailed and Generic **Modern Military** Dataset (N=19,422)						
Age	White		Black		Other	
	Male	Female	Male	Female	Male	Female
17-19	2,116	474	521	192	468	119
20-24	3,652	673	980	281	642	123
25-29	2,137	331	562	133	294	43
30-34	1,736	171	416	85	218	18
35-39	1,230	143	297	42	135	11
40-61	799	77	154	26	112	11
Total	11,670	1,869	2,930	759	1,869	325

the present study, it was then possible to collapse these distinct codes into single codes designating, for example, that a tooth was simply missing regardless of the cause. The methodology behind the code conversion is presented below and in Table 7.

Due to slight modifications in data collection protocol between the 1994 and 2000 TSCOHS studies, some of the characteristics were recorded differently during the original data collection. The 2000 study collected more specific information that was not present during the 1994 study. For this reason the two datasets are not completely compatible and certain adjustments were made to minimize the differences when possible for use in this dissertation. All of the relevant TSCOHS codes and their subsequent conversion for use in this dissertation are listed in Table 7.

Table 7. Code Conversion from Original TSCOHS Data.

Original Codes Used by TSCOHS		Converted Codes Used in Dissertation
Primary Tooth Code	*Surface Codes*	
T=Has Filling or Needs Filling	D=Decayed	V
	W=Incipient (*)	V
	T=Defective Surface (*)	V
	F=Restored (because of decay)	M, O, D, F, or L
	B=Restored (not do to decay) (*) (***)	V
	R=Defective Filling (with decay)	M, O, D, F, or L
	N=Defective Filling (without decay)	M, O, D, F, or L
	Z=Sealant present	V
	C=Crown (*)	MODFL
	A=Abutment (*)	MODFL
	I=Implant (*)	X
	X=Unable to Score	record deleted
	S=Sound (***)	V
	L=Surface needs a Sealant (**)	V
I=Impacted		X
E=Missing (Not because of Decay)		X
M=Missing (because of decay)		X
S=Sound		V
B=Missing (replaced by a fixed bridge)		XP
P=Missing (replaced by partial denture)		XP

(*) = Only in 2000 recruit data set
(**) = Only in 1994 Data Set
(***) = 1994 “Sound” included what the 2000 data set called “B”

The main differences between the data collection of the 1994 and 2000 TSCOHS are as follows:

- The most problematic difference between the 1994 and 2000 datasets concerned restorations that were placed on teeth for reasons other than decay. These would usually have been placed for aesthetic reasons on the anterior teeth. The 2000 dataset tracked the presence of this type of restoration. While not frequently encountered in the raw data, 5.5% of the year 2000 recruits were found to have at least one tooth surface with an aesthetically placed restoration (240 out of 4,346 individuals). However, this type of restoration would have been classified as "sound" (i.e. virgin) in the 1994 study and the restoration would have been ignored since the study was mainly concerned with decay (LTC Bruce Brehm, personal communication 2000). Since the 1994 dataset did not provide information on this type of restoration, all aesthetically placed restorations (any reason other than decay) encountered in the 2000 dataset were considered in the same fashion and were treated as a "virgin" surface. While somewhat unfortunate for a forensic comparison that would be concerned with treatment for any reason, this issue was unavoidable and needs to be acknowledged as a slight drawback to the dataset as a whole.
- The 2000 dataset also used codes for small, insignificant decay (incipient decay and defective surface) that would have been considered to be a sound surface during the 1994 study. This decay was reportedly so small that it would not be likely to appear on radiographs and would not have required a

restoration. If the decay were of a large enough size to require treatment it would have received a different code for active decay (LTC Bruce Brehm, personal communication 2000). During the data conversion, incipient decay and defective surfaces were considered to be virgin.

- In the 1994, study all crowns and abutments were coded with the maximum number of surfaces (e.g. **MODFL**), while in the 2000 study a separate code was established for either a crown or an abutment (LTC Bruce Brehm, personal communication 2000). Since crowns and abutments were impossible to differentiate from multiple surface restorations in the 1994 data, it was necessary to refer to all crowns and abutments in both the 1994 and 2000 data by their surface designation during the data conversion.
- Finally, during the 2000 study, a code was provided for the presence of "implants," although this was only rarely encountered (LTC Bruce Brehm, personal communication 2000). The 1994 study did not have a specific code for "implants," so any that were encountered in the 2000 dataset were converted to a code that designated simply that the tooth was missing.

Modern Civilian Data (NHANES III)

A final dataset was utilized that was derived from the Third National Health and Nutrition Examination Survey (NHANES III). The NHANES III is a cross-sectional survey that was conducted by the National Center for Health Statistics and the Centers for Disease Control and Prevention, in collaboration with a large consortium of federal agencies, including the National Institute of Dental Research. The NHANES III study is a multifaceted health examination survey that was conducted between 1988 and 1994 in the United States to collect data on the civilian, noninstitutionalized population (U.S. Department of Health and Human Services / National Center for Health Statistics 1996). Dental health information represents only a single facet of the overall study. Oral health examinations were conducted in Mobile Examination Centers that traveled to 88 locations across the United States and each oral examination lasted approximately 7.5 minutes. Only data for 28 permanent teeth were collected. In total, dental information was collected for 31,311 individuals aged 2 months to over 90 years and this data is available to the general public for research purposes via their website (http://www.cdc.gov/nchs/about/major/nhanes/datalink.htm).

As this data provides a large sample of adults from the civilian population, it was determined that it would be extremely useful as a forensic comparison dataset. Furthermore, it complements the Modern Military dataset and the two can be used together or separately to observe the modern population. As the NHANES III dataset contains information on a range of individuals from infants to the elderly, a subset of data was extracted for this dissertation research that consisted of only individuals between the ages of 17 and 50 years. The demographic composition of this sample is presented in Table 8.

As this study was conducted in order to examine the dental health of the U.S. civilian population, much more detail was documented than was necessary for this dissertation research. For example, dental health studies are only concerned with teeth

Table 8. Sample Size and Demographic Composition of the Detailed and Generic Modern Civilian Data.

Detailed and Generic **Modern Civilian** (N=9,730)						
Age	White		Black		Other	
	Male	Female	Male	Female	Male	Female
17-19	305	344	183	204	18	19
20-24	490	553	236	324	43	33
25-29	487	518	231	282	39	26
30-34	435	527	234	313	30	32
35-39	365	472	214	286	23	33
40-50	731	817	355	438	43	47
Total	2,813	3,231	1,453	1,847	196	190

that are missing due to decay, but based on the information included in this study it was possible to include teeth missing due to any cause. The format of the data contained in NHANES III is very similar to the TSCOHS and generally allowed for the codes to be simplified for use with this dissertation research. Obviously, for forensic purposes, the fact that treatment is present is of utmost importance, regardless of the cause. The relevant NHANES III codes are presented in Table 9 along with their conversion for use in this dissertation.

The methodology behind the NHANES III code conversion for use in this dissertation is presented below.

- The NHANES III data provides distinct codes for teeth missing due to decay and teeth missing for reasons other than decay (e.g. trauma or orthodontics), which allows for easy conversion into the necessary format.

Table 9. Code Conversion from Original NHANES III Data.

Original Codes Used by NHANES III (primary and secondary codes)	Converted Codes Used in Dissertation
00=Present but excluded	record deleted
01=Sound deciduous*	V
02=Decayed deciduous*	V
03=Filled deciduous*	M, O, D, F, or L
04=Unerupted	X
05=Sound permanent	V
07=Decayed permanent	V
08=Filled permanent	M, O, D, F, or L
09=Crown	MODFL / MDFL
10=Missing (due to caries)	X
11=Missing (replaced due to caries)	XP
12=Missing (not due to caries)	X
13=Missing (replaced due to non-disease)	XP

*Although only adults were considered in the conversion process, retained deciduous teeth were found to occasionally be present. As this was infrequent, they were treated in the same manner as permanent teeth in the converted dataset.

- More problematic are codes associated with decay. In situations where an individual tooth exhibited active decay on one surface and a restoration on another surface, it was more relevant for the NHANES III purposes to document the decay. The opposite is true for forensic comparison. Fortunately, the NHANES III data was collected with primary tooth codes (overall condition of the tooth) and secondary codes (specific surface conditions). Although a tooth may have a primary code that indicates that the tooth has active decay, the secondary codes allowed for restorations to be documented as well. For code conversion into the format used in this dissertation, precedence was given to the filled surfaces over the decay (opposite of dental health studies). For example, if a tooth had an occlusal restoration and a distinct area of active decay on the facial surface, it would be possible during the code conversion to ignore the decay on the facial surface and simply code the occlusal restoration. It is not clear how restorations due to reasons other than decay (aesthetic reasons) were coded, but it is likely that they were ignored in a similar fashion to the 1994 TSCOHS study.

- The most problematic aspect of the NHANES III data codes concerned situations in which there was a restoration associated with recurrent decay (occurring on the same surface). As decay was more critical to the goals of the NHANES III research, the active decay took precedence over the restoration and the primary code for the tooth would indicate only that it was decayed (code 07, see Table 9). Furthermore, the secondary surface code would also reflect the active decay instead of the restoration (also code 07). In this respect some filled surfaces were not regarded as such during the data conversion if they were associated with active decay. Equally problematic, if a tooth had a multisurface restoration (e.g. **MOD**) and one surface exhibited recurrent decay (e.g. **M**), then the secondary surface codes would only indicate that there was a two surface restoration (e.g. **OD**). While this will not affect the generic format of the converted data, the detailed format may not reflect every restored surface in a few instances. As a separate variable was present in the NHANES III data concerning restorations and tooth condition, it was possible to calculate how frequently teeth were found to have recurrent decay associated with a restoration (note that since this variable would not have resolved all the issues associated with recurrent decay and would have greatly complicated the conversion procedure, it was not used). Analysis of this specific variable for the upper left first molar (#14) was completed for the entire NHANES III sample (n=31,311 including all ages). The code for recurrent decay associated with a restoration was found to occur only 92 times on this tooth. As the upper left first molar was found to have this code present most often, this should represent a "worst case" scenario for the frequency that this code was used (0.29% of the sample). Obviously the recurrent decay code is very infrequently observed in the original dataset. This conversion problem is not believed to have a noticeable effect on the research derived from these data, although it does need to be recognized.

CHAPTER 6: BRIEF HISTORY OF DENTAL HEALTH IN THE U.S. MILITARY

Statistics regarding dental health have been calculated in regard to United States military personnel since the Civil War (Lewis 1865). Poor dental health was a prevalent reason for rejection from military service until the standards were relaxed during WWII. During the Civil War it was found that there was an enormously large number of exemptions occurring for loss of teeth. Draftees of the Northern states for the Federal Army had an average rejection rate of 20-25 men per thousand due to a deficiency of teeth. At this time the New England states had the highest rates with Massachusetts as the worst at 33.38 per 1,000 men rejected in 1863 and 40.36 per 1,000 men rejected in 1864 for poor dental health. In 1863, nearly one-fifteenth of all exemptions were related to dental health, and in 1864 nearly one-tenth were related to dental health (Lewis 1865). It was found that "…diseases of internal organs, as disease of the brain, spinal cord, heart, and lungs, consumption, etc., are in a ratio nearly corresponding to the condition of the teeth" (Lewis 1865:240).

A study by Hurme (1950) analyzed data on military personnel that was collected from 1901-1903 in the Philippines, Cuba, and Puerto Rico by Dr. John S. Marshall. The dental requirement for enlistment during this time was a minimum of two serviceable opposing molars or premolars in each jaw (one above and one below) on each side. The data regards the counts of different morphological classes of permanent teeth treated or extracted by U.S. Army dental surgeons between 1901-1903. Hurme states that the data indicate that unidentified factors present in tropical regions at the turn of the 20th century led to more rapid rates of tooth decay among military personnel transferred into the tropics than among personnel living in a temperate climate.

During WWI the condition described as “Defective and Deficient Teeth” caused an average of 24 rejections per 1,000 men, nearly identical to the Civil War statistics (East 1942, Keene 1974). In addition, during WWI, a similar geographic trend was noted towards dental health. The New England states were found to be the worst and reported rates of 78.15 rejections per 1,000 men from military service due to deficient teeth (Nizel and Bibby 1944).

During the period from November 1940 through September 1941, “Dental Disorders” were still the most frequent cause for rejection of registrants for the Selective Service. Of the 1,600,000 men rejected during this time, 250,000 were due to dental defects (Hellman, et al. 1957, Keene 1974). During this time the ten leading causes of rejection for registrants aged 21 to 36 were, in order, due to teeth, eyes, cardiovascular, musculo-skeletal, venereal disease, mental and nervous defects, hernia, ears, feet, and lungs (Rowntree, et al. 1942). As poor dental health was the number one reason for rejection, dental deficiencies accounted for an estimated 188,000, or 20.9 per cent, of the 900,000 registrants not qualified for general military service at this time (Rowntree, et al. 1942).

Early in WWII, in order to meet the national security needs, new wartime standards were enacted in regard to vision, teeth, and educational qualifications. Deficient teeth went from being the leading cause for rejection in peacetime to almost a non-existent factor during WWII. The number rejected due to dental conditions was only

0.8 per 1000 individuals (Rowntree, et al. 1943). The new standards prescribed by the Army required only that individuals are "…well nourished, of good musculature, are free from gross dental infections, and have a minimum requirement of an edentulous upper jaw and/or edentulous lower jaw, corrected or correctible by a full denture or dentures" (Wells 1943:110). Dental reasons for rejection were described as, "Diseases of the jaws and associated structures which are irremediable or not easily remedied, or which are likely to incapacitate the individual for satisfactory performance of military duty" (Wells 1943:110).

As a result of the relaxed dental standards during WWII (which have remained relaxed to date), numerous dental needs studies were conducted by the military in order to gauge the manpower requirements of the military dentists. Prior to the modification of the dental standards in the military, the minimum dental requirements for the Navy and Marine Corps were 20 serviceable permanent teeth (Hellman, et al. 1957). For this reason dental officers were able to maintain high standards of oral health during this time, but the lowered dental standards created increased workload on the dentists who now had to conduct extensive treatment on the new recruits. In 1935, when the dental standards were still high, legislation was passed that called for a ratio of two dental officers per 1,000 troops. Previously the ratio had been only one per 1,000. During 1956 there were two dentists and 3.7 dental technicians per 1,000 persons in the Navy and Marines (Hellman, et al. 1957). The role of the average civilian dentist is basically the maintenance of a core base of clients from all age groups. In the civilian realm the needs of the clients tend to stabilize after the initial work has been completed. With military dentistry there is a constant influx of new individuals needing potentially extensive work and there are only a limited number of military dentists to treat them. The personnel attended to by the military dentists will be constantly changing, but will mainly consist of young adults in need of a large amount of dental work as they enter the military. During 1956 only one out of ten new recruits required no dental care, and the treatment needs of military personnel far exceeded the treatment capacities of the Dental Corps (Hellman, et al. 1957). This high workload may be the reason that some of the induction records from WWII and the Korean War may be incomplete in regard to dental conditions.

Dental health studies during the era of the Southeast Asia Conflict showed that caries and poor dental health were still a problem in the military. A study by Keene (1974) claimed that the prevalence of dental caries in the U.S. military at that time was practically 100 per cent.

CHAPTER 7: DMFT COMPARISONS

Introduction

Dental health studies of the U.S. military population provide a large sample of individuals drawn from across the United States. Similarly, large public health studies of the civilian population that draw samples from across the United States also provide valuable information regarding dental health. On the other hand, regional studies of the civilian population provide a glimpse into dental health that is geographically specific to only a small segment of the United States. Variation between the results of cross-sectional samples derived from geographically diverse locations is likely indicative of changing dental health, while variation in results from geographically specific studies may be due to regional factors such as the fluoride content in the water. From the large, cross-sectional studies consisting of individuals from throughout the United States (military and civilian), it is generally agreed upon that dental health has been gradually improving over the years, but that the overall state of dental health in the United States is still poor.

Several studies suggest there is a racial difference in dental health. Generally, the average DMFT scores are lower for blacks in comparison to whites (National Center for Health Statistics 1979, National Center for Health Statistics 1981, Toverud, et al. 1952). Furthermore, studies have shown that there is evidence that the caries experience in the permanent dentition is greater in females than males of a comparable age (Brown, et al.

1996, National Center for Health Statistics 1967, National Center for Health Statistics 1979, Toverud, et al. 1952, White, et al. 1995).

While dental health has generally improved over time in the United States, the teeth that have been most commonly attacked by decay remain consistent. In general it is the posterior teeth that are most commonly affected by loss or decay, while the anterior teeth usually remain unaffected. The consistent pattern of Decayed, Missing, Filled, and Unrestored teeth can be observed in the four datasets used in this research. Figures 11-14 show a consistent pattern regarding the frequencies of conditions for each tooth. While there is some variation in the specific values of each component, the overall pattern is nearly identical.

Mandibular anterior teeth are consistently the least affected by decay and extraction. The most frequently affected teeth are the mandibular first molars. This is likely due to not only their morphology, but also due to the fact that they are the first teeth to erupt into the oral cavity. The Southeast Asia dataset has the highest frequency of affected teeth, which is also reflected by higher DMFT scores. It is generally agreed that, of the permanent teeth, the lower first molars are the most frequently attacked teeth, followed by the upper first molars. The lower anterior teeth are the least susceptible to carious attacks. Both upper and lower canines are relatively free from caries. These patterns were confirmed by all four of the datasets, regardless of the temporal period considered. Toverud et al. (1952) summarized numerous dental health studies and found

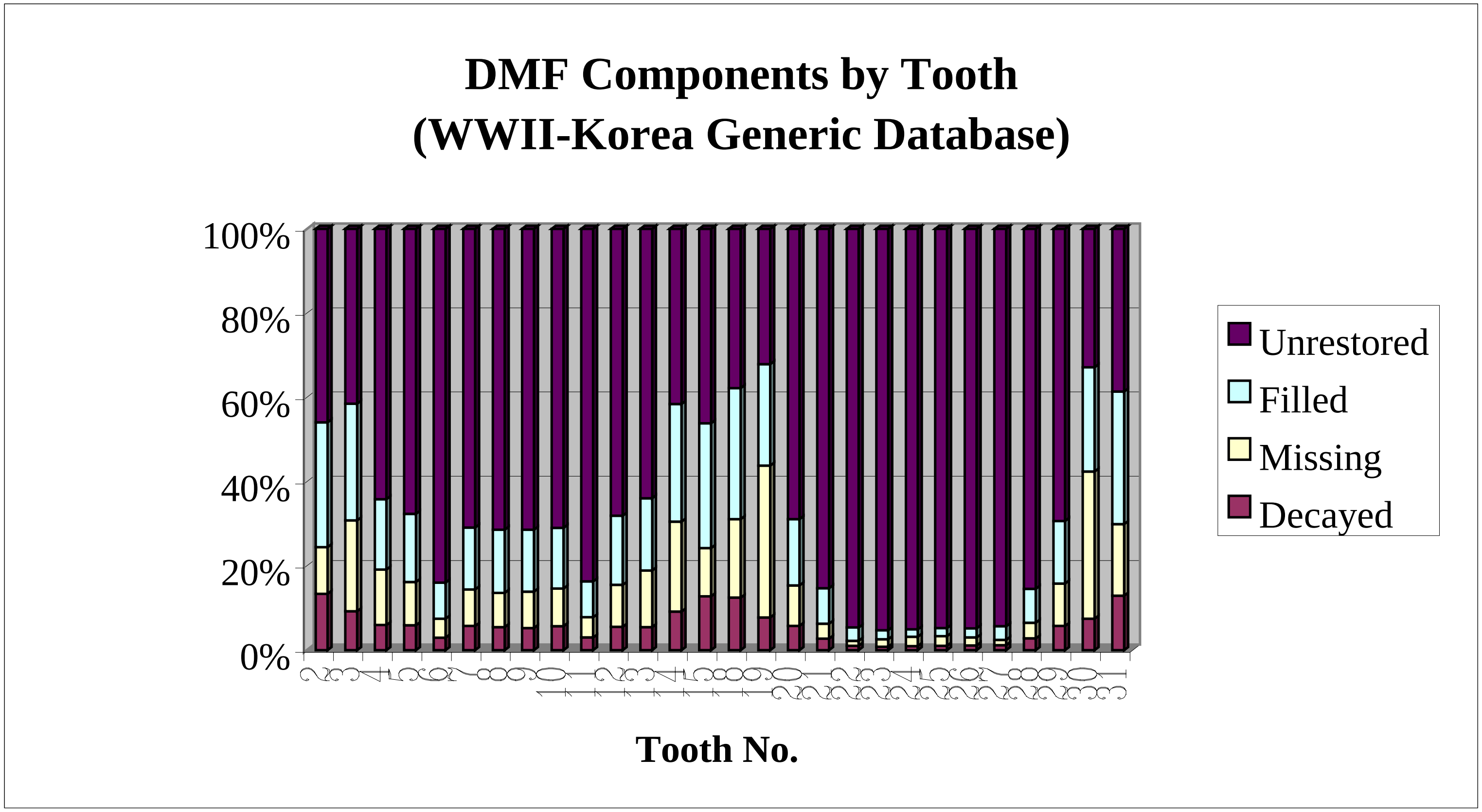


Figure 11. Frequencies of dental characteristics by tooth (excluding 3rd molars) for the Generic WWII-Korea dataset.

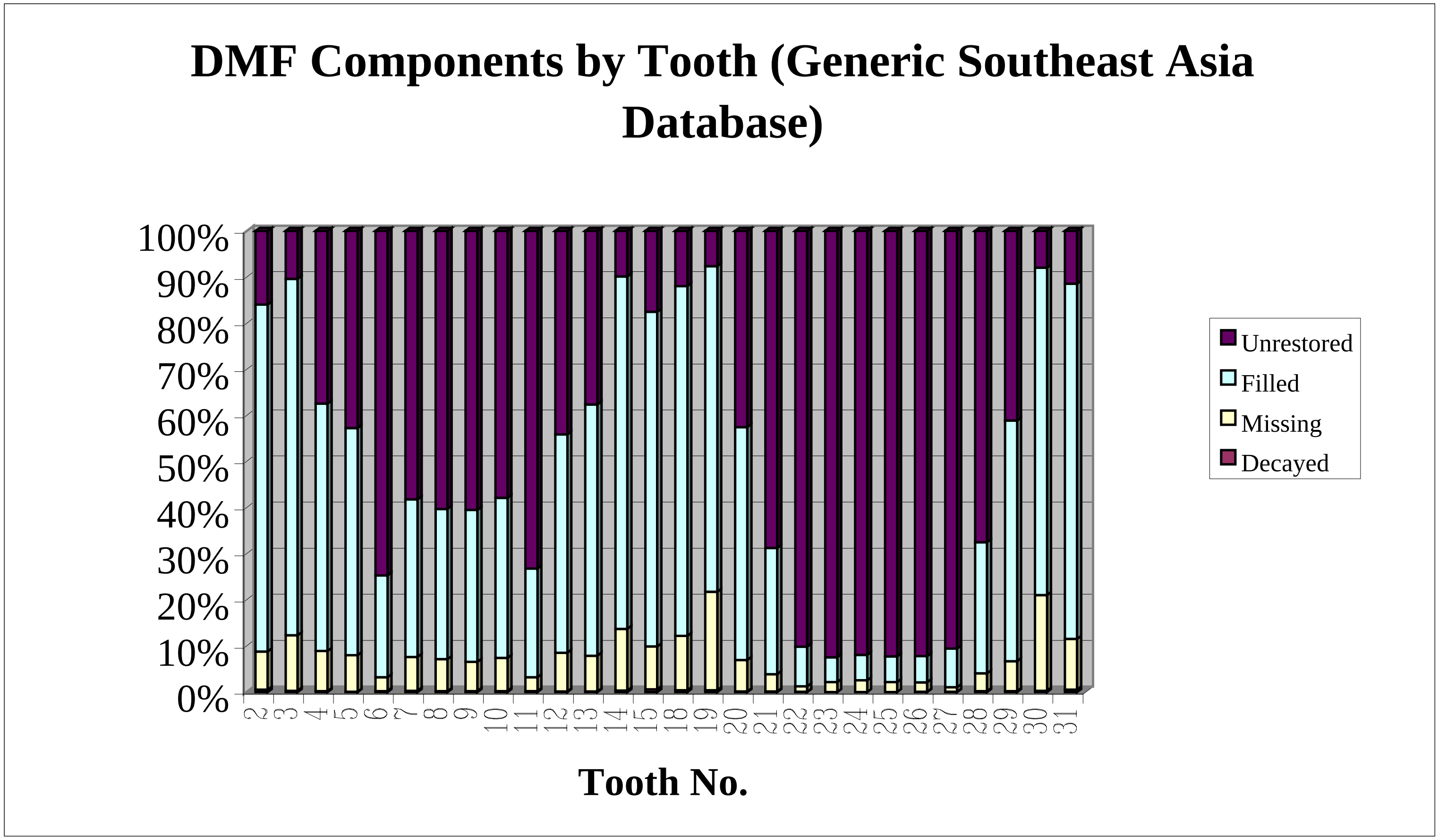


Figure 12. Frequencies of dental characteristics by tooth (excluding 3rd molars) for the Generic Southeast Asia dataset.

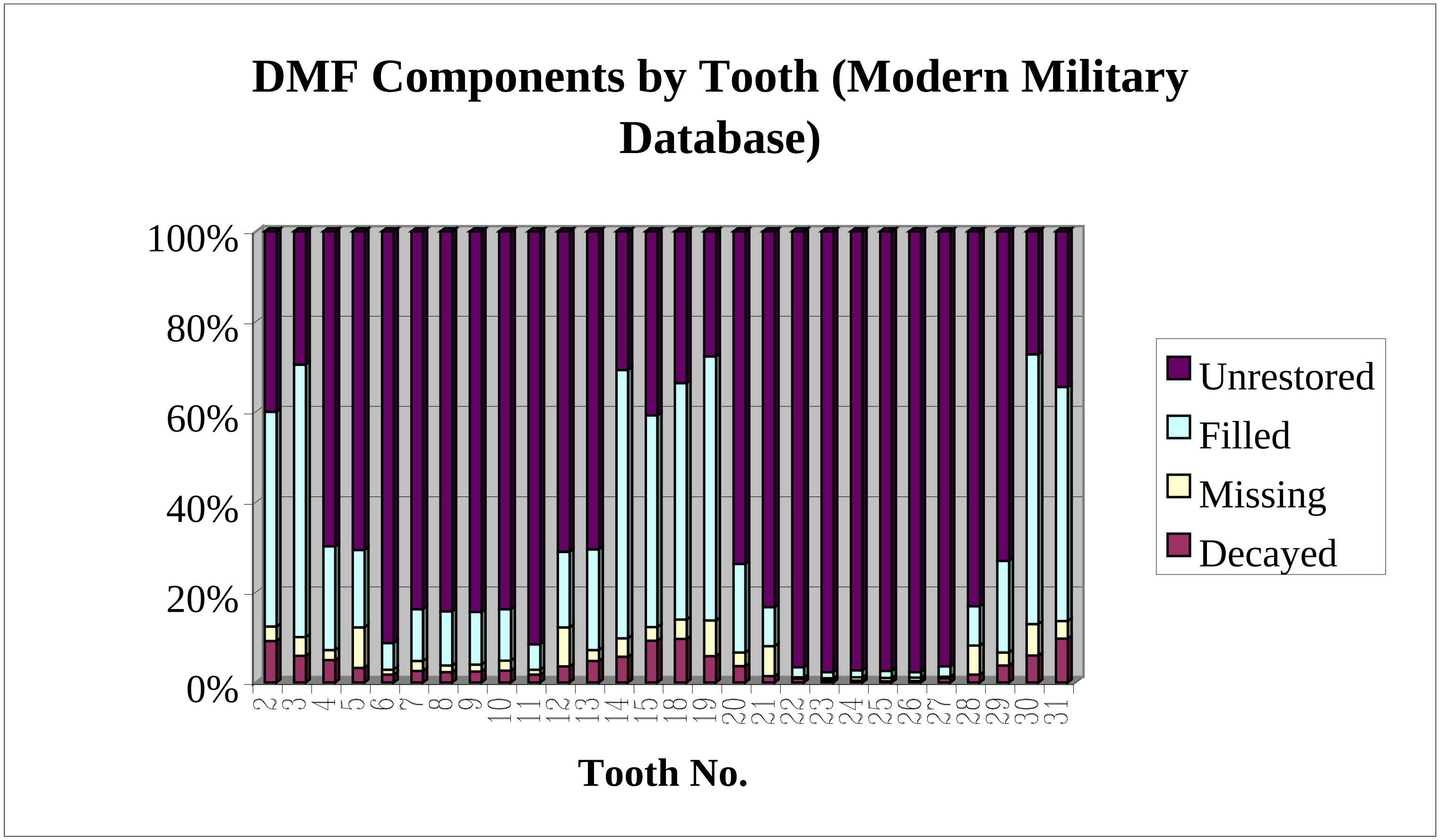


Figure 13. Frequencies of dental characteristics by tooth (excluding 3rd molars) for the Modern Military dataset.

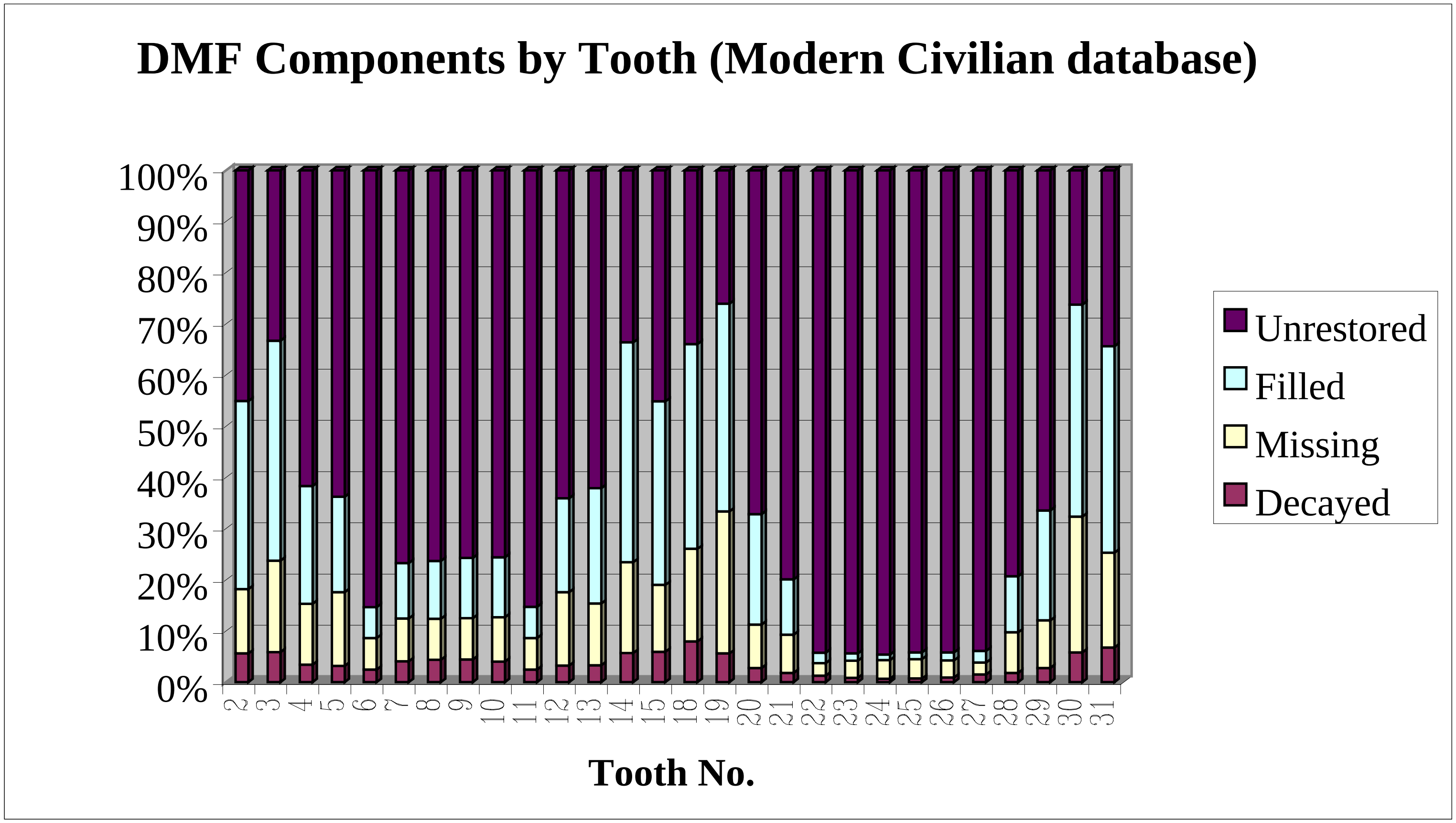


Figure 14. Frequencies of dental characteristics by tooth (excluding 3rd molars) for the Modern Civilian dataset.

that in the permanent teeth occlusal caries are the most prevalent and that 43 to 75 percent of all lesions are occlusal, depending on the study cited. Interproximal caries are most frequently observed in the anterior teeth.

Graves (1985) discusses the well-documented decline in caries during the past decades and how the improvement is altering the oral health status of the population. Graves states that caries experience recorded for military population groups is not representative of the U.S. population since radiographs are not used in national civilian studies, but are commonly used in the military. This is likely to inflate dental health scores since interproximal caries will be more readily identified by radiographs than by visual examination. He further states that military populations are of lower socioeconomic status and include a higher proportion of minorities. The DMFT results generated for the Modern Military and Modern Civilian datasets used in this dissertation reveal very similar values, but due to the large sample sizes the differences between the two samples will be statistically significant (Table 10). In general the Modern Civilian

Table 10. Comparison of Military and Civilian Dental Health Scores.

	Modern Military		Modern Civilian	
age	N	DMFT (std dev)	N	DMFT (std dev)
17-19	3,890	5.42 (4.47)	1,073	4.33 (4.08)
20-24	6,351	6.92 (4.89)	1,679	5.67 (4.77)
25-29	3,500	8.65 (5.11)	1,583	7.89 (5.76)
30-34	2,644	10.73 (5.44)	1,571	9.54 (6.12)
35-39	1,858	12.32 (5.55)	1,393	11.40 (6.87)
40+	1,179	13.75 (5.63)	2,431	13.85 (7.44)

sample has a lower average DMFT value by approximately one tooth for all groups except the 40+ years.

Limitations of DMFT Data

Oral health data from different studies have several potential limitations. Some of the caveats include: conservative classification of caries (e.g. classifying a questionable lesion as sound versus carious), classification of a filled tooth as carious when the restoration was placed for other reasons, inconsistent use of radiographic data to supplement clinical examination, inclusion of third molars, and variable definitions used between studies to classify decay (Caplan and Weintraub 1993, White, et al. 1995). The inconsistent use of radiographic analysis is the most commonly cited danger of dental health studies and the impact of this analytical variation has been explored.

One of the earliest studies to address the effect of radiographs on dental health studies was completed by Day and Sedwick (1935). They stress the need for radiographs to be used in dental health studies since they found that only conducting a visual examination will miss many carious lesions. As evidence they state that in their study 7,335 caries were discovered by visual examination only, and an additional 419 were found when radiographs were used in conjunction with the visual examination. While Day and Sedwick found that 5.4% of the total number of caries was found by radiographs, they cite a study by Delabarre (1933) in which 51.6% of the total number of lesions would have been missed without radiographic analysis.

Sognnaes (1940) examined the variation present in dental health studies that utilize different diagnostic methods. For his study, he observed 32 children aged 4 to 13 years and examined their teeth with four procedures: 1) a mirror and explorer, 2) aided by drying the teeth, 3) aided by cleaning and drying, and 4) aided by radiographic diagnosis. The full examination of each child took 1.5 hours. Sognnaes found that radiographs will reveal interproximal caries that are missed by the explorer, and that cleaning and drying will reveal pre-carious defects in the tooth (initial stages of smooth surface lesions appearing as white discolorations in the enamel). His results showed that simple examination by mirror and explorer will reveal nearly all carious cavities, but if the subtle lesions are to be considered as carious then radiographs are needed.

Several separate studies were completed on military personnel to examine the effect of radiographs in dental health studies. Schlack (1941) examined a group of 707 male naval personnel between the ages of 17-51 in order to test the effect of utilizing a combination of clinical and radiographic analysis for caries detection versus only a clinical examination. He found that variation in the caries rates may be an artifact of the examination strategy and interpretation of results derived from different sampling methods could be misleading. White (1944) observed naval aviation cadets and found similar results that indicate additional caries were discovered with the use of radiographs. Through the use of radiographs an average of an additional 4.4 new carious areas were found per cadet. Arnold et al. (1944) also found that there was an increase in the number of carious teeth found in U.S. Coast Guard cadets when radiographs were used along with a clinical examination, as opposed to only a clinical examination.

Hadjimarkos and Storvick (1948) looked at the effect of radiographic analysis versus clinical examination on a sample of college students. They found that 30.4% of the cavities requiring filling would have been missed without radiographs. On the average there were 5.5 cavities per student that required filling. Of these, 3.8 were found by using the dental explorer and 1.7 were found by radiograph.

Toverud et al. (1952) state that there is much evidence to indicate that radiographs will reveal additional caries, but they feel that visual examinations are sufficient for DMF studies. They state that for the investigation of large groups of individuals intended to show life experience of caries, mirror and explorer examinations that are carefully conducted under good light will be adequate. Although this method will likely miss incipient interproximal lesions, it is not of great concern. The most important need is to derive a universal standard of what is to be considered a carious lesion.

Comparison of WWII-Korea and Southeast Asia Datasets with Selected Military and Civilian Studies

By utilizing several military and civilian dental health studies over the past century, it is possible to compare their results with DMFT scores generated from the WWII-Korea and Southeast Asia datasets used in this dissertation. Since the Modern Military and Modern Civilian datasets used in this dissertation were derived from dental health studies, it was not necessary to test the validity of these datasets.

As the WWII-Korea and Southeast Asia data are to be used for establishing the uniqueness of dental patterns for forensic identification purposes, it is necessary that the samples are an accurate reflection of the population. Similar results between the published DMFT data and those derived from the WWII-Korea and Southeast Asia samples are likely indicative that the data used in the present study is an accurate reflection of the true dental health of that population and the reliability of the data. Large discrepancies between the dental health indices suggest that bias may be present within the data, likely occurring from incomplete recording of treatment. An important fact to consider when comparing the average DMFT scores from different studies is that the standard deviations are generally quite large due to the marked variation in the overall caries rates observed in individuals, but that large sample sizes will make even small differences between samples statistically significant.

Several military and civilian dental health studies were used for comparison with the WWII-Korea and Southeast Asia datasets. The military studies selected for comparison provided DMFT data of a military population that is temporally compatible with the datasets used in this dissertation. For that reason, the comparisons to published military dental health studies are not exhaustive, but only focus on those that are most relevant to this dissertation. In addition, several civilian studies were selected due to their cross-sectional sampling strategy, which was generally not geographically specific. Again, the review of civilian studies is not exhaustive, but only selects a few examples that can be relevantly compared to the datasets used in this dissertation.

Ferguson

A study by Ferguson (1935) is the first to look at military dental health and quantify the results. His results are derived from information on 4,602 White U.S. Navy recruits from various sections of the country. Much of the work was completed at the Naval Training Station, Naval Operating Base, Norfolk, Virginia. The average age of the recruits was 20 years. Ferguson's study was concerned with geographic variation in dental health, so he grouped his sample by geographic areas (primarily he grouped them as New England, Middle Atlantic, Southern, and Mississippi River Basin). Due to small sample size, statistics for individuals from the Rocky Mountain and Pacific Coast states were not provided, but these individuals were included into a category of "all others." He found that, of the states he quantified, Arkansas was the best in regard to defective teeth with an average score of 3.0, while Massachusetts and Connecticut were the worst with 12.2 and 12.54 respectively. Other studies have found a geographic variation in dental health with the New England states having the highest DMFT rates (e.g. East 1942, Keene, et al. 1971, Lewis 1865, Massler and Ludwick 1952, Nizel and Bibby 1944, Rovelstad 1966, Schlack, et al. 1946, Senn 1943).

Ferguson found the mean DMFT to be 6.57 for all individuals, regardless of geographic location. This value is very similar to the DMFT score calculated for the WWII-Korea data (Table 11), but is uncharacteristically low when compared with other studies from this time period. Part of the reason for the low score may be related to the

Table 11. Comparison of Ferguson Study with WWII-Korea dataset (White males only).

Data	Age	DMFT
Ferguson (n=4,602)	Average of 20	6.57
WWII-Korea (n=4,347)	17-22 years	8.04 (std dev= 6.3)

high dental standards for acceptance into the military at the time of this study. Schlack (1946) states that there are arithmetical errors in Ferguson's results and believes that the small sample sizes for some regions prevent reliable interpretation.

Ferguson attributes dental health to the exposure to sunshine and dietary factors. Curiously, he faults the introduction of clothing to some populations as a cause for their subsequent decline in dental health. As an example he refers to Samoa and discusses how certain individuals have access to luxury items due to increased wealth. He states, "The body is usually entirely clothed and the carrying of umbrellas is prevalent, especially among women, who thus deprive themselves of the beneficial effect of the ultraviolet rays of the sun" (Ferguson 1935:393). He also found that recruits from rural areas tended to have fewer defective teeth than those from the cities. He concludes that naval recruits have a wide variation in dental health and he attributes this to climatic and dietary factors.

Klein

Klein (1941) examined 642 registrants for Selective Service between the ages of 21-35 years from Maryland and West Virginia. This study considered all 32 teeth. Data was collected during 1940-1941 for the purpose of determining how many individuals would meet the dental requirements of the Selective Service for admittance to military duty as outlined at that time. The guidelines (United States War Department Mobilization Regulations MR1-9, issued August 31, 1940) state that there must be a minimum of three serviceable natural masticating teeth (molars and premolars) above and three below, and there must be three serviceable natural incisors and/or canines above and three below. All of these teeth must be so opposed as to serve the purpose of incision and mastication. Teeth with crowns or false teeth attached to bridgework will be considered serviceable natural teeth if they serve their purpose.

Klein found the average DMFT for dentally rejectable recruits to be 22.5, while the dentally acceptable recruits scored an average of 11.0. Of the 642 individuals examined, 545 were acceptable for military service and 97, approx 15%, were rejectable for military service. There was a noticeable increase in the percent of individuals deemed to be dentally rejectable at age 28, although there was also a considerable drop in the sample size (generally less than 18 total recruits) and this may be a biasing factor. If only the 21-27 year age group was considered (n=528), 10.2% of all recruits would be rejected based on dental criteria.

For comparison with other studies of recruits or soldiers after the military dental standards were relaxed, it is logical to conclude that the DMFT scores generated from the combined “acceptable” and “rejectable” individuals from Klein’s study would best reflect a comparable population. For comparison with other studies of military personnel before the dental standards for admission were relaxed, the “acceptable” group would be appropriate. Per rejectable man (21-35 years) more than 22 permanent teeth have been attacked by caries (13 extracted, 2 in need of extraction, 2 filled, and 5 that are carious and need treatment). Per acceptable man (21-35 years) 11 permanent teeth have been

Table 12. Comparison of Klein's Study with WWII-Korea Data.

Age	Klein (Includes 3rd molars)		WWII-Korea (Black and White males) Excludes 3rd molars
21-35 years	n=642 (Rej=97, Acct=545)	Both-12.8 Reject-22.5 Accept-11.0	n= 5,045 DMFT=9.88 (std dev= 6.6)
21-27 years	n=528 (Rej=54, Acct=474)	Both-11.6 Reject-21.1 Accept-10.6	n= 3,706 DMFT=9.47 (std dev= 6.5)

attacked by caries (3 extracted, less than 1 in need of extraction, 2 filled, and just over 5 are carious and need treatment).

Comparison of the results of Klein's combined DMFT scores for rejectable and acceptable recruits with the WWII-Korea data (Table 12) shows that the values are consistently lower in the WWII-Korea data. This may be attributable to several factors. Primarily the difference may be due to differing methodologies regarding third molars. Klein's study included third molars, while the WWII-Korea data excludes third molars from consideration. Table 13 provides a comparison of DMFT scores for the same group of individuals (Modern Military dataset) based on the inclusion and exclusion of third molars. It is clear that inclusion of third molars will significantly raise the overall value of the average DMFT score. In the Modern Military data, the average difference was over three teeth. A final consideration is that Klein's study is derived of individuals from the eastern United States, an area with notoriously bad dental health, while the WWII-Korea data are not as geographically specific.

Table 13. Comparison of the Variation in DMFT Scores Based on the Inclusion or Exclusion of Third Molars.

	Modern Military including 3rd molars (Black and White males)	Modern Military excluding 3rd molars (Black and White males)	Diff based on 3rd molars
21-35 years n=8,636	12.02 (std dev= 5.69)	8.65 (std dev= 5.35)	3.37
21-27 years n=5,181	10.74 (std dev= 5.29)	7.47 (std dev= 4.96)	3.27

Dunning

Perhaps one of the most relevant comparisons of a published dental health study of a military population with the WWII-Korea dataset comes from Dunning (1944). This study consists of data from 1943 from the induction records of 1,208 midshipmen. The average age of the recruits was 21.6, with 750 of the members either 21 or 22 years of age (no other demographic information given). Third molars were not included in Dunning's study. As the author did not perform a special examination for this study and all the data was compiled from induction records, this data is very similar to the format of the WWII-Korea data.

Since the data are derived from induction records, the author states that the DMF values are lower than would be the case with more detailed examinations. As an example of the attention to detail provided by the dentists, Dunning states, "About 1,200 midshipmen must be examined in 2 or 3 days; therefore great detail in each dental examination is not possible" (1944:895). He also states, "The examiners concentrate on missing teeth (which include unerupted teeth) and the location of restorations for identification purposes" (1944:895). This indicates that, although the examinations must be rapidly completed, existing conditions were documented at the time of induction since they were recognized to be valuable for identification. Whether this attention to detail was specific to the Navy dentists or practiced throughout the service at this time is unclear.

Dunning found an overall DMFT of 9.78 (D=.58, M=.68, and F=8.52) excluding third molars. The results show that the D and M components are very low, with the majority of the index consisting of the F component. Dunning acknowledges that the values are low and makes the bold statement that the midshipmen "…appear to be a superior group, either economically or educationally, or both, with resultant better dental care than the average, from early childhood onward" (1944:897).

Comparison with the generic WWII-Korea data is shown in Table 14. Although the individual components show some variation, especially the Missing and Filled components, the overall DMFT indices are similar. This congruence between the overall DMFT scores may be the result of a similar sampling technique (data derived from records) used in the compilation of each dataset. One variation is that Dunning's study is

Table 14. Comparison of Dunning's Results with the WWII-Korea Data.

	D	M	F	DMFT
Dunning (n=1,208)	0.58	0.68	8.52	9.78
Generic WWII-Korea (17-24 year old males, n=6,060)	1.93	2.65	3.52	8.10 (std dev= 6.4)

based on Naval personnel, while the WWII-Korea dataset is composed of individuals from all branches of the service. It is unclear why the results of Dunning's study revealed an F component that is so much greater than the WWII-Korea data, but this may be due to the suspected overabundance of records in the WWII-Korea dataset with DMFT=0.

Massler, Ludwick, and Schour

Massler, Ludwick, and Schour (1952) provide DMFT data for 17-20 year old White male naval enlistees (n=4,043) predominately from the Central, Northeastern, and Southeastern states. The individuals in this study were examined during 1949 and 1950 at the Great Lakes Naval Training Center, Great Lakes, Illinois. Radiographs were not used in the study. The study does not specifically state if third molars were considered, but it seems likely that they were not since the individuals are young and the third molars would not have erupted in many cases.

Massler, Ludwick, and Schour report the overall DMFT as 11.3. They found that the percent of individuals with DMFT=0 was 6%, while nearly 25% of all individuals had a DMFT score of 9-12. They found that dental health of military recruits was similar to other studies of U.S. civilians. The DMFT score for the generic WWII-Korea dataset is listed in Table 15 and does not include third molars. Obviously there is a substantial difference between the scores (11.3 versus 7.27), although the large standard deviation is noteworthy. Furthermore, the percent of individuals with DMFT=0 was found to be 14.89% for the WWII-Korea sample, compared with only 6% for the naval inductees.

Table 15. Comparison of Massler, Ludwick, and Schour with the WWII-Korea Data.

	Naval enlistees n=4,043	WWII-Korea data n= 2,754
17-20 year White males	11.3	7.27 (std dev= 6.1)

This frequency of individuals with no extractions or treatment from the WWII-Korea dataset is much higher than the frequencies observed in any other studies and almost certainly indicates a bias in the form of incomplete recordation of dental health in numerous records. Also worth note is that the sample of individuals from the Massler et al. study is predominately from the eastern United States, an area that has been repeatedly documented with higher DMFT scores.

In an apparently related article, Massler and Ludwick (1952) look at the effect of geographic location on caries. While not specifically stated, it appears that this study draws from the same data as above (17-20 year old white male naval inductees at the Great Lakes Naval Training Center, Great Lakes, Illinois). A smaller subset of the data is used in this study of geographic factors (n=2,368) and an overall DMFT for all regions combined was 9.9. This value is less than they found in the study presented above, likely due to the regional composition of the sample sets. They grouped the individuals into three major geographic areas east of the Mississippi River: Northeast (Conn, Del, Maine, Mass, N.H., N.J., N.Y., Pa., R.I., Vt.), Southeast (Ala, D.C., Fla, Ga, Ky, Md, Miss, N.C., S.C., Tenn, Va, W.Va), and Central (Ill, Ind, Mich, Ohio, Wis). In addition, 226 individuals were grouped into a category of Western states, which includes 22 states west

Table 16. Comparison of Massler and Ludwick with the WWII-Korea Data.

	Naval Enlistees				WWII-Korea data N= 2,754
	Northeastern N=692	Central N=751	Southeastern N=699	Total Group (including Western states) N=2,368	
17-20 year white males	11.6	9.8	8.1	9.9	7.27 (std dev= 6.1)

of the Mississippi River, Hawaii, and Puerto Rico. Their findings, which are generally concerned only with the three primary geographic areas (n=2,142), are in agreement with other studies that found geographic variation in dental health, with the Northeastern states having the worst dental health.

Comparison with the WWII-Korea data in Table 16 shows that the DMFT score for the total group of naval enlistees is closer to that of the WWII-Korea sample than seen in the related study by Massler, Ludwick, and Schour (1952).

Rovelstad et al.

Rovelstad et al. (1959) present data that was compiled in 1956 from young adult male naval recruits at the U.S. Naval Training Center, Bainbridge, Maryland. Most individuals were from the eastern third of the United States. These results were also summarized in a later article (Rovelstad 1966). The results are from initial examinations of new recruits prior to receiving any dental care by the Navy and radiographs were used in the analysis. Furthermore, third molars were not considered in the DMFT scores. The total sample size was 2,027, but no information is given regarding the demographics (no breakdown by race or age). Rovelstad et al. refer to the sample as young male adults (they state that half the group had no third molars because of lack of eruption and less than one tenth had all third molars). They state that the overall average DMFT score was 13.6, but the data presented indicate a score of 15.4 (missing teeth=2.4, carious teeth=7.0, restored teeth=6.0), excluding third molars. The exact manner that the average DMFT value was derived is not outlined in the article, so if deviations from the standard technique (summation of the Decayed, Missing, and Filled teeth) were employed, it is unclear. Based on the results of their study, Rovelstad et al. conclude that, "The state of dental health of young men reporting for military duty is deplorable" (1959:60).

The results provided in Table 17 indicate that there is a large discrepancy between the data provided by Rovelstad et al. and both the WWII-Korea and Southeast Asia data. Besides the potential problems with some of the WWII-Korea records, additional variation may be attributed to the fact that Rovelstad et al. used radiographic examination to document decay and this will certainly increase the decayed value. Furthermore, most

Table 17. Comparison of Rovelstad et al. Results with WWII-Korea and Southeast Asia Data.

	Naval Recruits	WWII-Korea (White and Black males) n= 4,820	Southeast Asia (White and Black males) n=319
DMFT 17-22 years (28 teeth)	13.6 / 15.4*	7.82 (std dev= 6.3)	9.83 (std dev=5.60)

*There appears to be an error in the reporting of the DMFT, stated as 13.6 but raw numbers add to 15.4.

of the individuals in the study came from the eastern third of the United States, an area that has been shown to have notoriously high DMFT scores. The WWII-Korea and Southeast Asia data, on the other hand, are not regionally specific.

Stahl and Morris

Stahl and Morris (1955) provide results from a Korean War era study that looks at tooth loss. This research did not observe the overall caries situation and did not present DMFT results. Their sample population was composed of 1,153 White males 17-49 years of age. The group consisted of officers and enlisted men at the Army Engineer Center, Fort Belvoir, Virginia having six or more natural teeth. As a smaller study they looked at 150 Black males between 20-39 years of age. This study does not specifically state if third molars were included.

Stahl and Morris found that less teeth had been lost in officers than enlisted (Table 18), tooth loss increased with age (average of 6.0 teeth at the age of 17-19 to an average of 8.0 teeth at the age of 40-49), and there was no geographic influence to tooth

Table 18. Tooth Loss in Officer and Enlisted Personnel from Stahl and Morris Study.

Age	Enlisted sample size	ENLISTED Avg Number Missing (±S.E.)	Officer sample size	OFFICER Avg Number Missing (±S.E.)
17-19	26	6.0 (± .42)	0	N/A
20-29	664	5.8 (± .08)	110	4.0 (± .18)
30-39	66	7.0 (± .28)	206	6.3 (± .16)
40-49	24	9.9 (± .53)	57	7.3 (± .31)

loss. In their study of 150 Black individuals, they found no racial difference in regard to tooth loss in comparison with White individuals.

As the study by Stahl and Morris does not specifically state if third molars were considered, it is difficult to interpret the results when compared with the generic WWII-Korea data (Table 19). The WWII-Korea data does not include third molars. The fact that it was not specifically stated that the third molars were excluded might suggest that they were in fact considered. Furthermore, the fact that there is a decrease in the average number of teeth missing in the 17-19 year old group and the 20-29 year old group could be due to the fact that many third molars may not have been erupted in the younger age group (Table 19). This variation could also be due to the small sample size of the younger individuals.

Table 19. Comparison of Tooth Loss from Stahl and Morris Results with WWII-Korea Data.

Age	Army Engineers Avg Number Missing (±S.E.)	WWII-Korea White males (standard dev)
17-19	n=26 6.0 (± .25)	n=1,774 2.25 (2.94)
20-29	n=774 5.5 (± .15)	n=4,806 2.97 (3.98)
30-39	n=272 6.1 (± .25)	n=916 4.80 (6.13)
40-49	n=81 8.0 (± .50)	n=68 11.34 (9.73)

Arnold et al.

Arnold et al. (1944) provide results from a 1942 population of U.S. Coast Guard cadets at the U.S. Coast Guard Academy, New London, Connecticut. The ages of the cadets ranged from 17-23 years. It is not specifically mentioned if third molars are included, but based on the age of the sample it is likely that they would not have been erupted in many cases and would not have been included in the study. The study was based on a clinical examination only and radiographs were not used. The main goal of this research was to document the effect of fluoride on caries, although DMFT data was also provided. The study found that a single application of fluoride did not decrease the rate of caries after one year. They still found that, on average, the cadets developed 0.65 new carious teeth per person per year.

Comparison of the Coast Guard cadets with the WWII-Korea data shows that while the overall DMFT scores are similar for the two datasets, the individual components are variable, especially in regard to the missing and filled values (Table 20). It is unclear why this discrepancy is present, unless the WWII-Korea sample does not

Table 20. Comparison of Arnold et al. Results with WWII-Korea Data.

age	Coast Guard cadets (n=258)				WWII-Korea (all races included) N=5,592			
	D	M	F	total	D	M	F	Total (std dev)
17-23 years	.84	.48	8.64	9.97	1.98	2.62	3.38	7.98 (6.3)

fully document the actual number of restorations or is biased by the large number of records having a DMFT=0.

Hobson

Hobson (1956) provides some results from a dental needs study composed of 8,139 Army recruits during April and May 1955. Data was compiled from examination points throughout the United States. Of this group, 97% (n=7,889) were between the ages of 17 and 26 years. There is no mention of racial composition or whether third molars were included in the study. He found that 3% of the recruits already had dental bridges prior to enlistment, but an additional 25% of all recruits were found to need bridgework. In addition, over 25% of all individuals either had some type of denture or required some type of denture. For the individuals aged 17-26 years, the average recruit was missing 3.87 teeth. Comparison with the WWII-Korea generic dataset showed that of the males between 17 and 26 years of age (n=6,726), there was an average of 2.65 missing teeth and 9.98% of the individuals had some form of dental prosthesis. These results are less than those reported by Hobson and may reflect a slight bias towards better dental health in the WWII-Korea dataset resulting from incomplete documentation in some records.

Senn

Senn (1943) conducted a study on 18-27 year old White aviation cadets of San Antonio Aviation Cadet Center, San Antonio, Texas. The study consisted of over 7,000 cadets from all 48 of the continental United States. Radiographs were not used in this study. The data in this study were compiled from Dental Identification Charts, which is an individual record of carious, filled, and missing teeth, in addition to dental prostheses and anomalies. This chart would have been used for identification purposes and the fact that it is being used for dental health studies is support that it would have been completed accurately and with attention to detail regarding existing conditions as well as new treatment. The question remains whether greater attention was given to accurate charting of pilots as opposed to other military personnel. Senn provides DMFT scores by state, with a low score of 9 in Texas and Oklahoma to a high of 21 in Washington state (Maryland, Massachusetts, and Vermont had a score of 20). The average DMFT from all states combined was 15. He discusses the theory at the time that sunlight is a contributing factor to inhibiting caries development. In opposition to this theory, he finds high caries incidence on the Atlantic and Pacific coasts in areas of high sunlight. Senn finds more support that water content (fluorine and hardness) is related to caries. He states, "…the caries incidence is definitely lower in fluorine areas than it is in other parts of the country" (Senn 1943:464).

The fact that Senn used dental charts for his study is encouraging since these were considered to be accurate accounts of dental health. Comparison with the generic WWII-Korea dataset shows that 18-27 years old white males, n=6,002, had an average DMFT score of only 8.68 (std dev=6.48). This large difference between the score observed by Senn (average of 15) is likely due to the accuracy of the some of the dental charts used in the WWII-Korea sample. The majority of the charts used in the WWII-Korea dataset were derived from Army personnel, while the sample used in Senn's study was based on aviation cadets. Variation in the time invested in initial dental charting of recruits may have been related to their area of service. Furthermore, as previously stated it is suspected that there is an overabundance of records in the WWII-Korea dataset with a DMFT=0 and this would tend to lower the overall value for the sample.

Fanning

Fanning (1952) completed a study of men drafted into the U.S. Army between the ages of 20-26 who were residents of Hawaii. A total of 3,346 men were part of this study and the purpose was to examine the racial variation in DMFT scores from the Hawaii inductees. All were residents of Hawaii and had not served during WWII. Radiographs were not used and all 32 teeth were considered for the study. All missing teeth were assumed to be the result of caries. The average DMFT for the entire sample was 14.79. Several of the racial groups presented by Fanning are presented in Table 21.

Table 21. DMFT Results of Fanning.

DMFT Scores by race for MALE inductees in Hawaii during the Korean War	
Race	**DMFT**
Hawaiian (n=52)	13.17
Japanese (n=1,917)	17.41
Chinese (n=190)	15.18
Filipino (n=562)	6.55
Caucasian (n=126)	15.77

Based on Fanning's study, Japanese were found to have the worst dental health and Filipinos the best (note the small sample size for the Hawaiian group). Results from the WWII-Korea dataset with 4,091 white males between the ages of 20 and 26 showed a DMFT of 9.26 (std dev=6.55). It should be noted that this figure is based on only 28 teeth, excluding third molars, and as such will result in a lower score than if 32 teeth were considered. Even accounting for this effect, the difference between Fanning's results and the WWII-Korea data is quite drastic. Several factors may account for this discrepancy. One reason may be due to the suspected inaccuracy of a portion of the records in the WWII-Korea dataset. Another consideration is the small sample size of Caucasians in Fanning's study (n=126). Finally, possible geographic factors need to be considered since all of the individuals in his study were residents of the Hawaiian Islands and the WWII-Korea data is not regionally specific.

Deatherage

Deatherage (1943a) presents a study regarding the relationship of caries rates and naturally occurring fluoride in the public water supply. This study was an early investigation into the benefits of fluoride and was completed on a group of 2,026 White men from the Selective Service in Illinois between the ages of 21 and 37 years. He divided the sample into groups based on the fluoride content of the water where they lived. It should be noted that the participants in this study were examined prior to the relaxed dental requirements for admittance into the military. Missing teeth were only considered if they had been lost due to decay and third molars were excluded from the study. Deatherage found that individuals who had lived their lives entirely in fluoride-free areas had an average DMFT of 10.79 (n=286), individuals from areas with over 1.0 part per million (p.p.m.) fluoride had an average DMFT of 6.21 (n=454), and those who had lived their lives with intermediate levels of fluoride (0.5-0.9 p.p.m.) had an average DMFT of 7.88 (n=169). He states that the difference between the group that lived their entire lives in fluoride-free areas in comparison with the individuals from areas with at least 1.0 p.p.m. fluoride is over 24.92 times the standard error, and that anything over three times the standard error is considered significant. Another study performed by Deatherage (1943b) explored the caries rates of individuals who grew up in fluoride-free areas and then moved to optimal fluoride areas after calcification of their permanent teeth. He found that these individuals had significantly fewer caries than individuals who had lived their entire lives in fluoride-free areas. Both of the studies by Deatherage conclude that fluoride has an inhibitory effect on dental caries, even after calcification of the permanent teeth.

Comparison with the WWII-Korea dataset for White males between the ages of 21 and 37 years revealed a DMFT score of 10.27 (Table 22). As this sample is composed

Table 22. Comparison of Deatherage Results with WWII-Korea Data.

	Deatherage Results			WWII-Korea (n=4693)
	Fluoride-free	Intermediate Fluoride	Over 1.0 p.p.m Fluoride	
21-37 years (White males)	10.79	7.88	6.21	10.27 (std dev=6.69)

of individuals from across the United States, without regard to the fluoride content of the water supply, the results are very consistent with those reported by Deatherage. The WWII-Korea DMFT score is nearly the same as the results presented by Deatherage for those individuals who lived in fluoride free areas. It is worth restating that Deatherage's study was composed of military individuals who were subject to higher dental standards for acceptance into the military, while the WWII-Korea sample individuals were not subject to the same standards. This may account for the higher DMFT score resulting from the WWII-Korea sample compared with Deatherage's results.

Shannon et al.

The data presented by Shannon et al. (1966) were derived from a sample of 5,298 male U.S. Air Force enlistees between the ages of 17-22 years drawn from all areas of the U.S. during 1963 and 1964. Only individuals with more than 20 teeth were included in the study and third molars were not considered. They state that the exclusion of subjects who possessed less than 20 teeth produced a final result that was definitely conservative and would certainly not be an overestimate of the magnitude of caries experience found in the average recruit. There is no reference as to the racial composition of the study. Radiographic analysis was also conducted in order to find caries.

Comparison with the Southeast Asia data in Table 23 shows that the M component is generally similar, but there is a large discrepancy with the D component and a smaller discrepancy with the F component. This produces vastly different average DMFT scores, with Shannon et al. reporting a value of 14.6 and the Southeast Asia data

Table 23. Comparison of Shannon et al.'s Results with the Southeast Asia Data.

Age Range	Shannon N=5,298				Southeast Asia generic N=319			
17-22	D	M	F	Total	D	M	F	Total
	6.8 (4.9)	1.3 (1.75)	6.5 (5.92)	14.6	0.02 (0.19)	1.24 (1.86)	8.57 (4.94)	9.83 (5.60)

producing a value of 9.83. The study by Shannon et al. used radiographs to document caries, while the Southeast Asia data also was largely based on radiographs. It is possible that Shannon et al. considered small, incipient decay, while the Southeast Asia data would have ignored this type of minor decay. As the Southeast Asia data has a higher value for the Filled component, this may reflect that active decay had been treated (since the data was derived from treatment records), as opposed to the study of Shannon et al. in which active decay was noted prior to treatment. Furthermore, a tooth with both decay and a filling would only be recorded as filled in the Southeast Asia dataset, but would likely be recorded as decayed by Shannon et al. These reasons may partially explain the difference between the DMFT values.

USAF Dental Investigation Service

A study completed by the USAF Dental Investigation Service (1982) consisted of data derived from two samples of active duty U.S. Air Force personnel, one group from 1977 and one from 1982. The 1977 data were originally presented by Christen et al. (1979), but the USAF Dental Investigation Service found numerous discrepancies in the results and reanalyzed the data (USAF Dental Investigation Service 1982). The results presented here were derived from the USAF Dental Investigation Service instead of the Christen et al. study.

The sample for the 1977 data consisted of 5,805 active duty Air Force personnel, of which 92% were men, 8% women, 86% white, 14% minorities, and all individuals were between 17 and 57 years of age with a mean age of 27.83 (Christen, et al. 1979). The 1982 sample was composed of 5,483 individuals, of which 4,825 were males and 658 females (88% and 12% respectively), of these 4,441 were Caucasian and 1,042 minorities (81% and 19% respectively) (USAF Dental Investigation Service 1982). Total sample size for the generic Southeast Asia data was 1,824 males between the ages of 17 and 63 years (96% Caucasian and 4% minorities). DMFT results presented in Table 24 were calculated for 28 teeth only, excluding third molars.

Comparison of the 1977 and 1982 results with the Southeast Asia data shows that the DMFT values are very similar and actually exceed the 1977 and 1982 values in most instances (Table 24). This is not overly surprising if there is a general trend towards improved dental health. The Southeast Asia data would generally predate the 1977 and 1982 results by at least several years. The comparison with these published results supports the contention that the Southeast Asia data is an accurate reflection of the population at that time.

Table 24. Comparison of the USAF Dental Investigation Service Results with the Southeast Asia Data.

Age Range	Southeast Asia Data	1977	1982
17-19	N=73 8.30 (5.49)*	9.82	7.95
20-24	N=477 11.53 (5.80)	10.22	9.87
25-29	N=594 14.16 (5.80)	11.77	11.71
30-34	N=332 15.40 (5.97)	13.72	13.0
35-39	N=232 16.61 (5.75)	15.36	15.29
Over 40	N=116 17.25 (5.51)	15.62	16.38

*Number in parenthesis is the standard deviation

Keene and colleagues

Keene has published numerous articles in collaboration with his colleagues concerning dental health of naval recruits, and specifically the effect of fluoride on caries rates (e.g. Keene 1974, Keene and Catalanotto 1974, Keene, et al. 1973a, Keene, et al. 1969, Keene, et al. 1971, Keene, et al. 1973b). These studies took place at the Great Lakes Naval Training Center, Great Lakes, Illinois. Correlation analysis indicated that geographic variation was related to the availability of fluoride in the water. In a closer look at the regional variation of the naval recruits Keene et al. (1971) found the worst dental health to be associated with the New England states (a trend that has been observed in many other studies). In reference to the studies performed between 1960 and 1972 Keene states, “In terms of DMFT scores, recruits from the 35 Fluoridated cities were found to have approximately 50 per cent less dental caries experience than recruits from the 43 Non-fluoridated cities" (1974:906).

Keene et al. (1969) reported on a nine-year survey of 500,000 naval recruits from Great Lakes and found that only 2 men per 1,000 (0.2%) had no previous history of dental caries at the time of entrance into the Navy. The annual incidence ranged from a low of 1.3 per 1,000 in 1967 to a high of 3.1 per 1,000 in 1963. In a later article (Keene and Catalanotto 1974) it was reported that the number of caries-free recruits at Great Lakes had increased from 2 per 1,000 (0.2%) in 1960 to 9.5 per 1,000 (0.953%) in 1972. It is interesting to note that a radiographic survey of 1,059 Air Force recruits (17-25 years of age) conducted by Burgess (1985) found that 110 out of 1,059 individuals were free of restorations, decay, and missing teeth (10.4%) excluding third molars. This figure is quite distinct from that found by Keene on naval recruits 10 years previous. From the datasets used in this dissertation, including all races and sexes if available, it was found that the following frequencies of perfect teeth were observed for 17-25 year old individuals, excluding third molars: WWII-Korea generic= 11.67% (n=6,788), Southeast Asia generic= 2.91% (n=757), Modern Civilian=16.16% (n=3,064), and Modern Military= 10.31% (n=11,052).

Keene (1974) provides a good overview of Navy and Marine dental health studies that were conducted between 1935 and 1972 (Table 25). He states that most of these results would have excluded third molars, so the maximum DMFT score would be 28. Comparison of the results with the WWII-Korea and Southeast Asia databases (Table 26) shows that the overall DMFT scores are very similar, although the frequency of caries-

Table 25. Summary of Military Dental Health Studies Presented by Keene (1974).

Training center	Year	Number recruits	Mean DMFT
Norfolk, Va	1935	4,745	6.6
Great Lakes, Ill	1952	2,368	9.9
Bainbridge, Md	1956	2,027	13.6
Parris Is., SC	1965	350	13.6
San Diego, Ca	1965	373	10.3
Great Lakes, Ill	1966	2,168	12.3
San Diego, Ca	1967	300	11.2
Parris Is., SC	1968	360	11.4
San Diego, Ca	1969	400	9.7
Great Lakes, Ill	1970-72	762	11.2

Table 26. Dental Health Results from the WWII-Korea and Southeast Asia Datasets for 17-22 Year Old Males.

17-22 year old males (excludes 3rd molars; all races included)			
Dataset	DMFT	Std Dev	DMFT=0
WWII-Korea generic (n=4,983)	7.79	6.27	13.41%
Southeast Asia generic (n=319)	9.83	5.60	4.70%

free individuals (DMFT=0) is higher than the results presented by Keene et al. (1969), especially in regard to the WWII-Korea sample. Comparison of the WWII-Korea and Southeast Asia DMFT scores with those provided by Keene (1974) lends support that they are an accurate reflection of the overall dental health of that period, although the high incidence of DMFT=0 in the WWII-Korea data is suspect.

Brown and Swango

Brown and Swango (1993) compare the data from the First National Health and Nutrition Examination Survey (NHANES I) and the National Institute of Dental Research (NIDR) studies. These are two large dental health studies composed of the civilian population from across the United States. The data from NHANES I correspond to a timeframe of 1971-1974, while the NIDR data were collected from 1985-1986.

The original NHANES I data were composed of approximately 13,670 adults aged 18 to 74 years who received dental examinations as part of the study. The sample population was both employed and unemployed adults in the United States. All 32 teeth were considered with this study (National Center for Health Statistics 1979, National Center for Health Statistics 1981).

The original NIDR sample consisted of 15,132 persons aged 18 to 64 years who were examined in their workplace. The individuals that were part of the study were selected from across the 48 contiguous United States. Individuals that could be considered under the categories of Agriculture and Mining, the military, the permanently unemployed, and persons not employed outside the home were excluded from the sample. Third molars were not considered in this study. Furthermore, the NIDR study did not consider missing teeth for their dental health index since caries could not be confirmed to be the cause of tooth loss. The results were presented as a DFT index (National Institute of Dental Research (U.S.). Epidemiology and Oral Disease Prevention Program 1987).

Due to variability between the two studies, Brown and Swango adjusted the datasets in order to maximize the comparability of the two studies. For example, they only selected similarly employed individuals since one study was explicitly concerned with employed adults and the other was not. Also, since the individual tooth and surface calls were available, they could make relevant adjustments to the components of the DMF indices. As such, the data presented by Brown and Swango varies from the original studies. The results presented by Brown and Swango are DMFT scores that are based on 28 teeth and exclude third molars.

Although Brown and Swango were examining racial differences between the two studies, only the data pertaining to White individuals is reproduced in Table 27. As the sample of Black individuals is very small for the Southeast Asia dataset, comparison of only the White individuals was the most informative for use in this dissertation. The results presented by Brown and Swango include males and females, while the Southeast Asia dataset is composed of only males. As can be seen in Table 27, the DMFT values for the Southeast Asia dataset are nearly identical to those reported by Brown and Swango for the NHANES I study. Since the NHANES I and the Southeast Asia datasets originate from the same temporal period, this lends strong support to the reliability of the

Table 27. Comparison of NHANES I and NIDR (as presented by Brown and Swango) with the Southeast Asia Data.

Age	NHANES I (White males and females)	NIDR (White males and females)	Southeast Asia (White males only)
18-24	11.1	8.9	N=524 11.2 (5.77)*
25-29	13.4	10.5	N=583 14.1 (5.74)
30-34	15.8	12.0	N=316 15.6 (5.93)
35-39	16.9	14.6	N=222 16.73 (5.67)
40-44	17.7	16.5	N=87 16.87 (5.03)
45-49	18.1	18.1	N=19 18.52 (6.60)

* number in parentheses is the standard deviation

Southeast Asia dataset. The lower values in the NIDR study may support the contention that dental health has been gradually improving over time.

NHES I

A total of 6,672 men and women aged 18-79 years from the noninstitutionalized civilian population were examined for this study from 1960-1962 by the National Center for Health Statistics. The dental health results are a single component of the National Health Examination Survey (NHES I). This first phase of the study was conducted by direct examination of a sample of the U.S. population. Radiographs were not used in this study and questionable or borderline conditions were not recorded. Each dental examination was completed in approximately 10 minutes (National Center for Health

Statistics 1965). Filled or crowned teeth with new or recurrent decay were scored only as decayed. In addition, filled teeth that were not carious, but were defective (e.g. loose or fractured restoration) were recorded as decayed only. Permanent teeth missing for any reason and non-restorable/non-functional teeth in need of extraction were scored as missing. The findings from this study are based on 32 teeth and unerupted third molars were scored the same as extracted. This means that third molars that were extracted (not due to caries) or were unerupted were included in the counts of total missing teeth. This will have the effect of overestimating the DMFT, especially in younger adults who have unerupted third molars. Teeth with satisfactory fillings were scored as filled.

Comparison of the results from the NHES I study with those from the Southeast Asia dataset shows that the values from the Southeast Asia data are consistently lower than the NHES I values (Tables 28-30). In particular there is a large discrepancy between the average number of missing teeth between the two samples. Since the NHES I data included third molars into their results and did not discriminate for third molars missing due to impaction or other reasons, this will explain a significant amount of the variation. As was previously shown with the Modern Military dataset (Table 13), the difference in average DMFT scores by including third molars as opposed to excluding third molars is over three points. Furthermore, the decayed component shows variation stemming from the fact that the Southeast Asia data is virtually free of active decay. This likely occurred since the Southeast Asia data was collected from treatment records. The records would commonly chart the work that had been completed, as opposed to active decay that needed attention. This may also be attributed with the finding in the Southeast Asia

Table 28. Overall DMFT Results of the NHES I 1960-1962 Study (32 teeth considered).

Age	Total male	White Male (S.E.)*	Black Male (S.E.)*
18-24 (n=411)	13.6	14.4 (.43)	8.3 (1.05)
25-34 (n=675)	16.2	17.3 (.38)	8.4 (.92)
35-44 (n=703)	18.1	19.3 (.36)	9.4 (.85)

*S.E. data from Decayed, Missing, and Filled Teeth in Adults, U.S. 1960-62

Table 29. Individual Components of the DMFT Index from the NHES I 1960-1962 Study (32 teeth considered).

	Total males			White males			Black males		
Age	D	M	F	D	M	F	D	M	F
18-24	2.2	5.0	6.5	2.1	5.0	7.2	2.6	4.9	0.8
25-34	1.7	6.9	7.6	1.7	7.3	8.3	1.9	4.8	1.8
35-44	1.2	9.5	7.4	1.2	10.0	8.1	1.7	6.4	1.3

Table 30. DMFT Results from the Southeast Asia Data (28 teeth considered) for Comparison with the NHES I Data.

	White males (n=1,732)			
age	D	M	F	DMFT (std dev)
18-24 (n= 524)	0.05	1.37	9.78	11.20 (5.8)
25-34 (n= 899)	0.03	1.84	12.75	14.63 (5.8)
35-44 (n= 309)	0.03	2.94	13.80	16.77 (5.5)

dataset that the filled component in consistently higher than the NHES I data. If these considerations are noted, in addition to the slight temporal variation, then the results from NHES I and the Southeast Asia sample are very similar.

Conclusions

Overall, the comparisons of the WWII-Korea and Southeast Asia datasets with published military and civilian dental health studies show good correspondence. Clearly the correspondence is much better with some studies than others and numerous factors can be presented to explain the variation. The main difference found with the WWII-Korea dataset was that the number of individuals with "perfect" teeth (DMFT=0) was found to be quite high. It is believed that this is a result of induction records in the dataset that do not document existing dental treatment, in turn falsely registering the individual as caries-free. This bias will tend to reduce average DMFT values. This problem does not appear to have been an issue with the Southeast Asia data. While it appears that there may be some bias built into the WWII-Korea dataset due to the presence of induction records that do not accurately document existing dental conditions, it is not believed that this will be a significant factor for the forensic comparisons and that the overall effect on the DMFT scores was only slight. The sample size is large enough to produce a representative sample of dental patterns that will provide an indication of the variability in the dataset. In order to take a closer look at the accuracy of dental records from the WWII, Korea, and Southeast Asia time periods, a sample of antemortem and postmortem dental charts from forensic identification cases was selected and a comparison was performed to observe their overall correspondence in regard to dental characteristics. This is described in the next chapter.

CHAPTER 8: ANTEMORTEM-POSTMORTEM COMPARISON OF DENTAL CHARTS FROM WWII, KOREA, AND SOUTHEAST ASIA

Introduction

Civilian dentists generally maintain high standards in regard to the accuracy of dental records, although this is not always the case. A recent survey by Delattre and Stimson (1999) asked two groups of dentists to self-assess the forensic value of their dental charts and notes. The vast majority of the respondents felt that their records would be of at least moderate forensic value (56% felt they would be extremely valuable). The majority of the participants were general dentists and not forensic odontologists, so it is difficult to judge the appreciation that these individuals had for the degree of documentation necessary for forensic identification. In Delattre and Stimson's study the utility of the records was self-assessed, while it would have been perhaps more informative to have had a forensic odontologist's perception. A dentist unfamiliar with forensic identification may feel that the level of precision present within his or her records is insufficient for identification purposes, when in reality it would prove to be extremely useful. Overall, it appears that most dentists have an appreciation of the utility of dental records for forensic identification purposes and all efforts are made to accurately document treatment and abnormalities.

In principal, all attempts are made by military dentists to accurately document the dental health conditions in a servicemember's records. A quote regarding the Navy and Marine Corps protocol states that, "Upon entry into the Navy or Maine Corps each person receives a dental examination, and all missing teeth, existing restorations, dental caries, and abnormalities are recorded in duplicate on Standard Form 603-Dental Record" (Wyckoff 1957:503). Each dental treatment during service is then added to the individual's file. It seems reasonable to assume that the other branches of the service would also follow these standards. Whether due to the physical loss of records over time or simply incomplete recording, this high degree of attention to existing dental conditions is not always observed in past military dental records. Recent military records, on the other hand, are expected to contain a thorough account of dental treatment in the form of at least radiographs, charts, and notes.

As the accuracy of past military dental records is critical to many forensic identifications, as well as the goals of the research contained in this dissertation, it was necessary to observe a sample of cases in order to assess the correspondence between actual dental status and documented records. In order to gather a sufficient number of representative examples, a random sample of cases was drawn from archived identification files curated at the CILHI. From these identification packets it was then possible to compare the dental condition at the time of death with the most current treatment record contained within the personnel files. Specifically, comparisons were performed on individuals who died during WWII, the Korean War, or the Southeast Asia Conflict and whose records are not part of the datasets used in this dissertation.

The selected files consisted of identifications that were made between 1972 and 1975 at the CILTHAI and between 1976 and 2001 at the CILHI. Files selected for the study had to fulfill several requirements to be considered: 1) in order to allow for cases with postmortem loss, a minimum of 10 teeth or tooth locations (in the case of numerous antemortem extraction sites) must have been present, 2) some form of antemortem treatment record must have been available for comparison, and 3) a positive identification must have been established between the set of remains and the missing individual, but not necessarily from dental comparison. Since WWII and the Korean War were temporally similar, the records from these two conflicts were combined into a WWII-Korea dataset. This combined dataset was compared to records from the Southeast Asia Conflict. In total, data were compiled for 64 WWII-Korea cases and 48 Southeast Asia identification cases.

Although most antemortem records provided detailed surface information in regard to the location of restorations, a minority of records only documented that a tooth was filled and provided a generic code for this state. When considering the correspondence of specific states between the antemortem and postmortem records, a tooth was only considered to be filled, missing, virgin, or missing but replaced with a prosthesis (these are the codes used in the generic datasets). The specific surfaces involving a restoration were not considered. The comparison was completed in this manner in order to accommodate all antemortem records. In addition the designation of restored surfaces can be subjective and variation between dentists may occur regarding the same restoration. For example, although the antemortem records may document an **MOD** amalgam, the postmortem examiner may record only an **MO** amalgam. This variation would not be considered an exclusionary discrepancy and may be only a difference of interpretation. Furthermore, active caries were not considered during the antemortem-postmortem comparison since they would have developed since the last dental examination in many instances.

For comparison of charting accuracy, a score was assigned to each of the antemortem-postmortem comparisons that was calculated as a ratio of the number of correctly annotated teeth over the total number of observed teeth (or tooth locations in the case of antemortem extraction). Third molars were not considered. For example, consider an individual who had not lost any teeth in the postmortem interval, allowing for all 28 teeth/tooth locations to be observed. During the postmortem analysis four restorations were discovered that were not documented in the antemortem records, so this comparison would receive a score of 24/28, or .857. Perfect correspondence would result in a value of 1.

It is worth noting that this value is somewhat inflated, simply because all teeth are considered but some are more frequently affected than others. For example, if an antemortem record does not show any restorations although the individual is found to have all his molars filled, this will result in a correspondence of 20/28, or .714. The fact that 20 teeth match in the antemortem and postmortem comparison is not due in any part to charting accuracy, rather it is a result of the tendency of anterior teeth to be unaffected.

Another potential bias to this analysis occurs since some of the selected cases may have had their identifications based on favorable dental comparisons and the fact that detailed antemortem documentation was available. Other cases where the dental records were unreliable or incomplete may not have resulted in an identification and, as such, would not have been potential candidates for inclusion into the sample unless DNA or other evidence was used. This point is important to keep in mind, but is not likely to have had a substantial effect on the results.

Results

Although the correspondence between antemortem and postmortem records was high for both samples, in most cases the dental records from the Southeast Asia Conflict were much more detailed and accurately charted than those from the WWII-Korea timeframe. Reasons for this discrepancy may include the fact that less time has passed since the Southeast Asia Conflict as opposed to WWII and the Korean War. Many dental records that may have initially been present from the 1940s and 1950s could have been lost or damaged since that time. More likely, other reasons account for the differences. An important point to consider is that there were a large number of individuals entering the military during WWII and dental standards for enlistment had just been essentially repealed. This overwhelming influx of people, often with very poor dental health, made detailed documentation of all dental conditions very difficult during initial induction periods. Furthermore, the military was understaffed with dentists during this time and could not adequately handle the large numbers and the substantial dental needs (Hellman, et al. 1957). It is quite likely that pre-existing dental treatment may not have always been charted during these initial induction phases and individuals were only assessed as to their immediate needs. A review of numerous induction records from WWII showed that dental records from the induction period were very sparsely filled out, generally only noting active decay and missing teeth. Subsequent records were found to be much more thorough and complete. A similar trend is also observed with the Korean War records, likely because many soldiers participated in both conflicts. During the Southeast Asia Conflict the number of soldiers was not as great as during WWII, so the dentists would have had more time to thoroughly document dental treatment. More importantly, there was likely a greater appreciation of the identification potential of dental information during this time, resulting in more attention to accurate documentation. Furthermore, the use of radiographs was more common during the Southeast Asia Conflict, which aided in more precise documentation and facilitated the identification process.

An indication of the variability in accuracy between the WWII-Korea and Southeast Asia records comes from the average percentage of matches found in the two samples (Figure 15 and Table 31). It was found that 50% of the cases considered from the WWII-Korea sample had exact correspondence between all antemortem and postmortem comparisons, while the Southeast Asia data showed exact correspondence in 65% of the cases. Figure 15 clearly shows that the average value derived from the Southeast Asia era records was higher than that derived for the WWII-Korea records. This difference was found to be statistically significant (Table 32). While there is a significant difference between the two data sets, the overall values exceed 0.91 and indicate that the dental records are generally accurate (a value of 1 indicates exact correspondence between antemortem and postmortem records).

In general there were two sources of variation noted between the WWII-Korea records and the Southeast Asia records: 1) the presence of restorations or extractions in the postmortem record that were not annotated in the antemortem records, and 2)

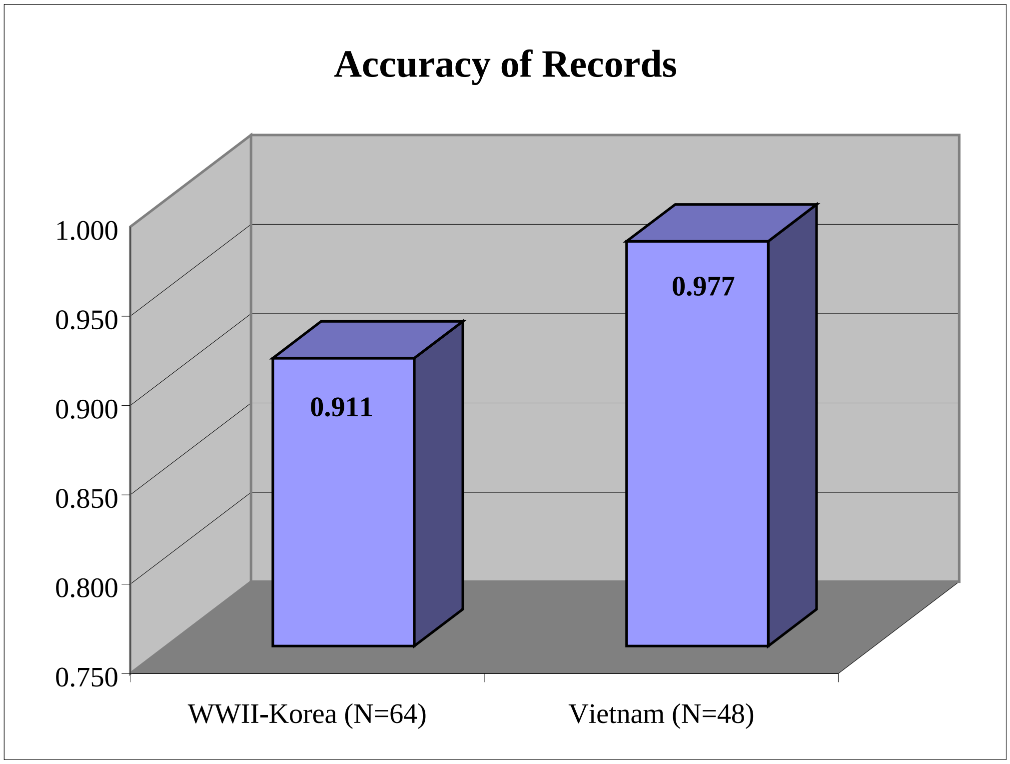


Figure 15. Accuracy between antemortem and postmortem records from WWII-Korea and Southeast Asia identification cases.

Table 31. Group Statistics for the Antemortem-Postmortem Comparison of Records.

	N	Mean	Std. Deviation	Std. Error Mean
WWII-Korea	64	.911	.1285	.0161
Southeast Asia	48	.977	.0360	.0052

Table 32. Independent Samples T-test Results Comparing the Accuracy of WWII-Korea Records to Southeast Asia Records.

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	33.33	.000	-3.42	110	.001	-.0654	.0191	-.1032	-.0275
Equal variances not assumed			-3.87	75.76	.000	-.0654	.0169	-.0990	-.0318

restorations or extractions were present in the antemortem record but were not observed postmortem.

By far the most frequently observed discrepancies involved the presence of postmortem findings that were not documented in the antemortem records. This was most frequently observed in the induction records from the WWII-Korea sample. It is hypothesized that the role of the dentists during induction was primarily to document required treatment and, in some cases, extracted teeth. Subsequent dental records provided more detailed documentation of all conditions, but for various reasons these records are not always available or the individual may have been killed prior to additional examinations. Other potential reasons may be that the record of additional treatment was lost, or the individual received treatment from a source outside of the military.

It was only very rarely observed that treatment noted in the antemortem records was not present postmortem. In most cases this type of discrepancy could be readily explained as a charting error caused by misidentification of a tooth. This type of antemortem-postmortem charting error usually involved the molars or premolars since extractions and subsequent dental drift can at times make specific tooth identification difficult. While this type of charting error was found to be infrequent, it still represented a source of discrepancy.

Overall, the accuracy of the dental records from both the WWII-Korea sample and the Southeast Asia sample was found to be good. When the records were found to correspond poorly, it was usually because only minimal documentation was present in the antemortem records (mainly a problem with the WWII-Korea records). When detailed antemortem documentation was present it was usually found to be nearly identical to the postmortem condition regardless of the sample considered. In many instances it was a case of “all or nothing.”

CHAPTER 9: PATTERNS OF DECAY AND TOOTH LOSS

Improvements in dental health over the past decades may be due to several factors, including improved access to fluoride, better access to dental care, and changing public and personal attitudes about the importance of the dentition. Although dental health appears to be improving in the United States, tooth loss and caries are still ever-present and are critical features utilized in forensic identifications and exclusions. The hypotheses regarding the primary reasons for tooth loss will be briefly addressed. In addition, patterns of tooth decay will be analyzed. Specifically, it is important to recognize the forensic implications of bilateral expression of decay and the effect that decay on one tooth has on its neighboring teeth. If, for example, caries are always expressed bilaterally, then this will be an important factor for understanding patterns of missing, filled, and unrestored teeth.

Tooth Loss

There has been a steady decline in the prevalence of tooth loss over the past several decades (Marcus, et al. 1996). Reasons for tooth loss of the permanent dentition are numerous and may include trauma, aesthetic reasons, caries, periodontal disease, and orthodontics. The causes of tooth loss have been studied, and debate usually revolves around whether it is caries or periodontal disease that is responsible for tooth loss later in life. Perhaps one of the most notorious instances of tooth loss in American history surrounds George Washington, who is believed to have suffered from gum disease and periodontal bone loss as opposed to caries (Sognnaes 1976a). Overall, numerous studies have investigated the causes of tooth loss and based on the results of these studies, researchers have come to differing opinions. Regardless of the causes of tooth loss, documentation of the condition may be critical to forensic identification. A brief overview of tooth loss follows.

Weyrauch and coworkers (1995) discuss the reasons for tooth loss and the debate over whether caries are the main cause in youth and periodontal disease later in life. Their study was based on Air Force records from all 50 states for active duty military personnel and included 1,462 records collected from 1987-1992. Their sample includes both sexes, and all races, with an age range of 18-53 years. They support the traditional model that the frequency of tooth loss related to caries decreases with age and that loss related to periodontitis increases with age. Their research shows that the change in cause occurs at about age 35-39. They also found that officers generally showed a lower caries rate than enlisted personnel and cite socio-economic reasons. An earlier study of military personnel (Rovelstad, et al. 1959:60) found similar results that indicate caries are responsible for tooth loss under 35 years and periodontal disease over 35 years.

A study by Bailit et al. (1987) came to conclusions that contradict those of Weyrauch et al. (1995). Although it is commonly assumed that periodontal diseases are the primary cause of tooth loss after age 35, they found that advanced periodontal disease is not a major cause of tooth loss. They state that caries continue to be the most frequent cause for tooth loss later in life. Similarly, a study by Chauncey et al. (1989) points to the cause of tooth loss to be predominately a result of caries. They studied a total of 736 dentulous male veterans between the ages of 28 and 80 years and found that dental caries were the prime cause of tooth extraction, followed by preparation for a prosthesis, and then periodontal disease. They found that only 18.7% of the extractions in this population were a result of periodontal disease.

A study by Niessen and Weyant (1989) also investigated the cause of tooth loss in the permanent dentition. They looked at a veteran population (average age of 57.7 years) and found that 63% of extractions were due to caries, while only 33% were due to periodontal disease. The results of their study contradict the claim that periodontal disease is the primary cause of tooth loss later in life and caries earlier life. They found that caries remain the primary cause of tooth loss throughout life.

Bilateral Symmetry

Literature Review

Homologous teeth (i.e. antimeres) develop and enter the oral environment at about the same time and the gross morphology of one tooth is the approximate mirror of the other. It is for these reasons that it is often assumed that the cumulative assault by extrinsic cariogenic factors will lead to decay patterns that closely resemble each other across antimeres. Bilateral caries refers to the destruction of identical surfaces of corresponding (i.e. homologous) teeth situated on opposite sides of the mouth. Unilateral caries refers to a situation in which identical surfaces of homologous teeth express different caries patterns.

Bilateral symmetry is an important factor to consider not only for dental health studies, but also for forensic identification purposes. If it is determined that teeth are genetically predisposed to decay in equal fashions on opposite sides of the mouth, this will impact how dental patterns are viewed. Dahlberg (1957) addresses the use of frequency information in regard to dental characteristics such as fillings, dentures, and other dental appliances. He states that for determining probabilities from several defects they must be from different causes. For example, he states that a defect on the mesial surface of a lower right canine is present at 0.5% (proportion of 1:200). The frequency for the same surface on the lower left canine is also 0.5%. The frequency of a missing lateral incisor is 2% (proportion of 1:50). In determining the probability of duplication, the combination of the lateral incisor event with the right canine event would be 1:10,000. However, since the right and left canines are likely to have the same cause, it is not acceptable to use both for determining the probability. He states that finding one or both canines involved would not alter the probability unless there was positive evidence of different causes. The reason for this is that he states features are almost universally bilateral, so they cannot be treated independently. Later in this dissertation it will be shown that even treating non-homologous teeth independently, as recommended by Dahlberg, is of questionable validity.

Studies of the symmetrical occurrence of dental caries have reached conflicting conclusions and this may be due in part to how symmetry is defined. If the population is viewed as a whole, then symmetry of caries patterns is likely to be nearly identical, but this may not be a reflection of the patterns observed in specific cases. For example, take a population where 50% of the individuals have caries clustered only on the right side of their mouths, while the remainder of the population has caries clustered only on the left side of their mouths. Despite the extreme clustering, the population as a whole would exhibit mean caries scores for the right and left sides that are identical and it would be feasible to conclude that the caries pattern was symmetrical. Another consideration is that in studies of the bilateral expression of caries it is often impossible to determine when the decay occurred. Two homologous teeth may both have identical decay patterns, but the carious lesions may have occurred years apart.

A study by Scott (1944) found remarkable uniformity in the occurrence of carious lesions on the left and right homologous teeth. Scott (1944) looked at the incidence of bilateral lesions in the posterior teeth as observed radiographically. He used the bite-wing radiographs from 300 individuals compiled from files at the Department of Oral Roentgenology of the Baltimore College of Dental Surgery. A total of 4,800 teeth were observed, 2,400 pairs of bilaterally situated teeth. No specific age ranges were considered in his study and all missing and filled teeth were considered to have resulted from caries. Without regard to pairs, he found that 60.2% of the total number of posterior teeth were carious. Scott found that the mandibular first molar was most frequently affected. Slightly more teeth were carious in the maxillary teeth than the mandibular. Scott found that a total of 300 teeth were missing: 142 teeth were bilaterally missing, 126 were unilaterally missing opposite a carious tooth, and 32 were missing unilaterally opposite a normal tooth. Considering the posterior teeth, 73.1% of the teeth that exhibited any carious state (decayed, missing, or filled) expressed some form of bilateral condition. The remaining 26.9% of the posterior teeth were affected unilaterally. Considering the individual (not the tooth), some degree of bilateral caries was found in

95.3% of the individuals, while only 2% revealed purely unilateral caries, and less than 3% were caries-free on the posterior teeth. The study concludes that there is a marked tendency toward bilateral symmetry in carious lesions of the posterior teeth. Scott attributes the marked symmetry to anatomic features of the teeth, such as grooves, pits, and fissures.

In another study, Jackson et al. (1979b) found results contrary to those of Scott (1944). They looked at the occurrence of caries between the right and left homologous canines, premolars, and molars in a sample of individuals from England. They observed only the mesial and distal sites on permanent teeth. Jackson et al. (1979b) claim that the common belief that caries occur bilaterally is not valid. Their results support the contention that the distribution of caries between right and left homologous sites is more commonly asymmetrical than symmetrical. As an example they discuss the results from another article concerning the mesial surface of the right and left maxillary incisors. They found that 1,810 persons had caries on only the right side and 1,643 individuals had caries on only the left side (a total of 3,453 individuals with asymmetrical attacks). In regard to the symmetrical attacks, there were only 2,158 individuals with attacks on both the right and left homologous tooth surfaces. They state, "In the great majority of persons, attacks of caries at R/L homologous sites are asymmetrical" (Jackson, et al. 1979b:239). They found similar results supporting asymmetrical caries in the canines, premolars and molars. They interpret this asymmetry to be evidence for a genetic (biological) cause of caries as opposed to extrinsic cariogenic factors such as acid and acid-producing microorganisms. They believe that extrinsic factors would not discriminate one side from another, but genetic factors would.

Hujoel et al. (1994) looked at coronal caries patterns in a study that utilized the data from the 1985-86 NIDR report, which is composed of employed adults in the United States. They observed caries patterns in regard to both the tooth as a whole and tooth surfaces. They define three possible patterns of caries distribution on homologous teeth: *random*, *aggregated*, or *regular*. A *random* caries pattern has lesions that are randomly distributed among homologous teeth or surfaces. The caries pattern does not vary in a systematic way from the mouth's left to right side and homologous teeth (or surfaces) have the same probability of developing caries. With an *aggregated* caries pattern, there is aggregation of lesions on one side of the mouth or the other to a greater extent than would be expected by chance. The carious lesions tend to be located predominately on one side of the mouth and homologous teeth have unequal probabilities of developing caries. With a *regular* caries pattern the lesions are distributed more symmetrically between the left and right sides of the mouth than would be expected on the basis of chance alone.

Hujoel et al. (1994) looked only at discordant homologous pairs, defined as a pair of teeth having the same relative anatomical position in the maxilla or mandible with one tooth (or surface) being sound and the other either carious or filled. For example, the upper right first molar and upper left first molar are a homologous pair, and if the upper right is sound and the upper left is carious then they form a discordant homologous pair. In essence, bilateral caries were not tested, the authors were strictly interested in observing whether unilateral caries were randomly distributed in the mouth or were concentrated on one side. For their sample they selected 6,493 subjects who had at least two homologous discordant tooth pairs (mean age=39 years; 52% male). They state that only the discordant pairs will provide information on the pattern of caries expression, as subjects with zero or one lesion cannot carry information about caries patterns and at least two lesions are required to make a pattern. Similarly, if two homologous pairs both express caries then no information on caries patterns can be extracted since it cannot be tested whether the homologous surfaces were at equal risk and if the pattern was random or not. They found that the distribution of carious lesions among homologous discordant tooth pairs was not random with respect to the midline ($p < 0.0001$), regardless of whether the tooth as a whole was observed or the individual surfaces. The *random* and *regular* caries patterns were rejected in favor of caries *aggregation* in which carious teeth tended to aggregate on the right or left side of a subject's mouth more than would be expected by chance. They interpret this as evidence that causal factors of caries are not homogeneously distributed within a subject's mouth and may be attributed to genetic, infectious, or environmental factors. Hujoel et al. support the hypothesis that chewing patterns influence caries distribution. They suggest that a right or left side chewing preference may be at least partially responsible for the observation that caries patterns are not random and tend to cluster on one side of the mouth. Although they do not discuss it in this article, it is worthwhile to consider handedness since differential brushing patterns could also lead to differential decay patterns.

A study by Losee (1947) was based on 580 radiographs of Marine Corps recruits from 1946 at the U.S. Marine Base, San Diego, California. The median age was 21.23 and all were from states west of the Mississippi. Most of the data were derived from the premolars and the first and second molars. Of the 6,411 bilaterally corresponding surfaces (e.g. occlusal surfaces of upper left and right first molars) that had one or both surfaces carious, 61.9% involved both surfaces and 38.1% involved only one surface. Although he does not specifically state how missing teeth were handled (i.e. were they considered to be carious or excluded from consideration), he concludes that the bilateral caries expression occurs more frequently than if the distribution were determined solely by chance. Worth consideration is that the premolars and molars exhibit the majority of caries, simply due to their morphology. With these teeth it is difficult to determine if the observed bilateral conditions occurred simultaneously or at very different times.

A study by Bertram and Brown (1943) looked at the bilateral caries expression in the permanent teeth of children aged 6 to 18 years in Oklahoma during 1941. Bertram and Brown treated the caries expression in bilateral teeth like a probability experiment with coin flipping and the probability of getting two heads. As an example they observed 432 pairs of maxillary second molars and found that 349 pairs were non-carious, 14 molar pairs were carious only on the right side, 20 pairs were carious only on the left side, and 49 pairs showed both teeth to be carious. The total percentage of right molars that were carious is 15% (49+14=63, 63/432=.15), the percentage of left molars that were carious is 16% (49+20=69, 69/432=.16). They use the product of these two percentages (0.024) as the expected frequency in which both molars should be carious. The observed frequency in which both second molars were carious was 0.11 (49/432) and the difference between the two numbers was found to be very significant statistically. They conclude that bilateral caries occur more frequently than would be expected by chance alone.

Current Research

The patterns of decay on homologous teeth in the permanent dentition were observed using the Modern Military dataset. The sample size utilized was 19,422 individuals between the ages of 17 and 61 years (see Table 6 for a demographic profile). The specific surface information for all caries locations was ignored for this analysis and each tooth was treated as a whole (e.g. a tooth with an **MOD** amalgam would be considered equal to a tooth with an **O** amalgam). Furthermore, all decay was considered in the same manner, regardless of whether it was restored decay or an active carious lesion. As there was no way to account for the temporal occurrence of the decay, it was not possible to differentiate bilaterally expressed caries that occurred at the same time from those that may have resulted at vastly different times. Missing teeth were considered separately from carious teeth.

In order to observe a representative sample of homologous teeth with variable frequencies of decay, the maxillary first molars, mandibular second molars, maxillary lateral incisors, and mandibular first premolars were analyzed.

The maxillary first molars and the mandibular second molars are frequently attacked by caries. It is quite common to discover active or restored decay and tooth loss

Table 33. Bilateral Expression of Maxillary 1st Molars.

Modern Military sample (N=19,422)	
Condition	Frequency observed
Both carious (n= 10,845)	55.84%
Both noncarious (n= 4,332)	22.30%
One noncarious and one carious (n= 2,977)	15.33%
One missing and one carious (n= 864)	4.45%
Both missing (n= 334)	1.72%
One missing and one noncarious (n= 70)	0.36%

Table 34. Bilateral Expression of Mandibular 2nd Molars.

Modern Military sample (N=19,422)	
Condition	Frequency observed
Both carious (n= 9,886)	50.90%
Both noncarious (n= 4,857)	25.01%
One noncarious and one carious (n= 3,433)	17.68%
One missing and one carious (n= 796)	4.10%
Both missing (n= 349)	1.80%
One missing and one noncarious (n= 101)	0.52%

at these locations. As these teeth are frequently found to be carious or missing , it was determined that they would be adequate examples for observing homologous conditions. The frequencies of occurrence seen in the maxillary homologues are similar to the mandibular homologues (Tables 33 and 34). In approximately half of the cases, caries are present on both teeth, approximately one quarter of the cases are noncarious in both teeth, and approximately one quarter of the cases have a mixed condition. In only less than 2% of the cases were both homologues missing. While bilateral symmetry is observed more frequently (approximately 80% of the individuals), asymmetric patterns still occur in approximately 20% of the individuals.

In order to observe the bilateral expression of teeth that are less frequently attacked by caries, the mandibular first premolars and maxillary lateral incisors were examined. As these teeth are less frequently attacked by caries, bilateral expression may be more indicative of an interrelated cause as opposed to a random event. While it was found that the homologues of these teeth were most frequently noncarious (approximately 78% of the cases), when caries were present they were found to be more frequently in a mixed condition as opposed to bilaterally carious (Tables 35 and 36). The results of this analysis suggests that, while the overall frequency of caries is nearly identical on the right and left sides of the mouth, bilaterality is not expressed to this extent when individual cases are considered.

Overall, bilateral caries appear to occur frequently on the posterior teeth. Based on the high prevalence of decay in this area of the mouth, it is difficult to determine if the decay occurring on one tooth is dependent on the condition of its antimere. The fact that unilateral conditions occur in the population with any frequency indicates that *all* teeth provide valuable information regarding the overall dental pattern expressed in an individual and none should be excluded from consideration during a forensic comparison. The simple fact that variation occurs within the oral cavity in regard to decay patterns is critical to forensic identification and the individuality of the dental pattern.

Table 35. Bilateral Expression of Maxillary Lateral Incisors.

Modern Military sample (N=19,422)	
Condition	Frequency observed
Both carious (n= 1,749)	9.01%
Both noncarious (n= 15,240)	78.47%
One noncarious and one carious (n= 1,841)	9.48%
One missing and one carious (n= 107)	0.55%
Both missing (n= 258)	1.33%
One missing and one noncarious (n= 227)	1.17%

Table 36. Bilateral Expression of Mandibular 1st Premolars.

Modern Military sample (N=19,422)	
Condition	Frequency observed
Both carious (n= 1,050)	5.41%
Both noncarious (n= 15,178)	78.15%
One noncarious and one carious (n= 1,783)	9.18%
One missing and one carious (n= 87)	0.45%
Both missing (n= 1,130)	5.82%
One missing and one noncarious (n= 194)	1.00%

Effect of Caries on Neighboring Teeth

Due to their location within the mouth, it is often considered likely that the caries susceptibility of adjacent, or neighboring, teeth is interrelated. It is generally assumed that all sites are at risk to dental caries, but that there is a varying degree of vulnerability or resistance from site to site, depending in part on the condition of the adjacent teeth. Obviously it is important to dental health studies to determine if caries on one tooth predisposes its neighboring teeth to decay as well. This information could also be useful from a forensic identification standpoint, as deviations from “common” decay patterns can be noted as such. Several studies have examined the relationship of decay occurring in neighboring teeth, but the conclusions are not always in agreement.

Literature Review

Certainly the most prolific researchers to address the question of caries on neighboring teeth are Jackson, Fairpo and Burch (1972a, 1972b, 1979a, 1979b, 1981, 1972c, 1973a, 1973b, 1973c, 1973d, 1975). Their articles are based on populations in England and Ireland and are commonly concerned with the distribution of caries (decayed and filled) in adjacent surfaces of the maxillary and mandibular incisors, although canines, first and second premolars, and first and second molars were also studied. They found that the prevalence of caries in mandibular incisors is lower than in maxillary incisors and that there is a bias towards attacks in one side of the mouth in both maxillary and mandibular incisors (asymmetric decay). The main goal of their articles is to tests their hypothesis “…that each site on each tooth is genetically endowed with a characteristic that determines whether or not, in a given environment, it is at risk to caries attack” (Jackson, et al. 1972a:1343). Their genetic hypothesis is contrary to what they refer to as the “acid theory” of decay. With the acid theory all teeth are susceptible to caries development at varying degrees due to an ongoing battle with acid and acid-producing microorganisms and the tooth surface. With the acid theory there is no such thing as a caries-immune tooth, only a caries-susceptible tooth that will succumb quickly and a caries-resistant tooth that will succumb slowly. Based on the results of their studies they conclude that distributions of attacks of caries are highly non-random and they believe that the distribution of caries-vulnerable sites is genetically determined. They believe that their research shows that the status of an affected mesial or distal site on one tooth (decayed or restored) has no detectable influence on the risk or the timing of attack on the neighboring mesial or distal surface of the adjacent tooth. Due to the genetic factors, some sites are totally caries-resistant and will never develop caries regardless of extrinsic factors. They find the acid theory to be seriously deficient and perhaps wholly fallacious.

A study by Losee (1947) was based on 580 radiographs of Marine Corps recruits in 1946 at the US Marine Base, San Diego, California. The median age was 21.23 and all were from states west of the Mississippi. Part of his study was concerned with data collected from the distal surface of the canine and the mesial, distal, and occlusal surfaces of the posterior teeth. He found 3,688 pairs of abutting surfaces (e.g. distal canine and mesial aspect of the adjacent first premolar) that had one or both surfaces carious. Of these teeth, 75.4% involved both surfaces and 24.6% involved only one surface. He concludes that adjacent surfaces are affected more frequently than if the distribution were determined solely by chance. His research supports that caries development is at least partially dependent on the condition of the neighboring teeth.

Bodecker (1937) found that decay on one tooth does not necessarily predispose its neighboring teeth to decay. Excluding cavities on the mesial surface of first molars, Bodecker found that out of 516 full mouth radiographs there were 179 lesions in which the closely contacting neighbor was unaffected.

Current Research

In order to examine the patterns of decay observed in the Modern Military dataset, the maxillary right first molars and mandibular left first molars were observed. All individuals with carious maxillary right first molars (n=12,871) and carious mandibular left first molars (n=12,503) were selected from the dataset. Surface information was not considered in regard to the specific location of decay for this analysis (i.e. each tooth was considered as a whole). The patterns of decay observed with the neighboring teeth (second molars and second premolars) are outlined in Tables 37 and 38. In approximately 20% of the cases both of the neighboring teeth were noncarious, and in roughly 80% of the cases at least one of the neighboring teeth was also affected by caries. As this area of the mouth is commonly attacked by caries it is difficult to conclude that the condition of one tooth was reliant on the condition of another.

In order to observe the condition of teeth that are not as frequently attacked by caries, the maxillary right central incisor was selected for analysis. All individuals with a carious maxillary right central incisor were selected from the Modern Military dataset (n=2,769). The condition of the neighboring teeth (left central incisor and right lateral incisor) was examined and the results are presented in Table 39. The frequency that both neighboring teeth were affected is higher for the incisors than was seen in the molars, although the frequency that neither neighboring tooth was affected was approximately the same. As the decay on the incisors is most likely to occur on the mesial or distal interproximal areas (as opposed to occlusal), it would be expected that there would be more of a chance for neighboring teeth to be affected. Overall, the frequencies observed

Table 37. Decay on Neighboring Teeth Surrounding a Carious Maxillary 1st Molar.

Modern Military sample (N=12,871)	
Condition	Frequency observed
One neighbor carious, one noncarious (n= 5,669)	44.04%
Both neighbors carious (n= 3,876)	30.11%
Both neighbors noncarious (n= 2,727)	21.17%
One neighbor missing, one carious (n= 384)	2.98%
One neighbor missing, one noncarious (n= 189)	1.47%
Both neighbors missing (n= 28)	0.22%

Table 38. Decay on Neighboring Teeth Surrounding a Carious Mandibular 1st Molar.

Modern Military sample (N=12,503)	
Condition	Frequency observed
One neighbor carious, one noncarious (n= 6,295)	50.35%
Both neighbors carious (n= 3,157)	25.25%
Both neighbors noncarious (n= 2,303)	18.42%
One neighbor missing, one carious (n= 470)	3.76%
One neighbor missing, one noncarious (n= 250)	2.00%
Both neighbors missing (n= 28)	0.22%

Table 39. Decay on Neighboring Teeth Surrounding a Carious Maxillary Central Incisor.

Modern Military sample (N=2,769)	
Condition	Frequency observed
One neighbor carious, one noncarious (n= 976)	35.25%
Both neighbors carious (n= 1,147)	41.42%
Both neighbors noncarious (n= 509)	18.38%
One neighbor missing, one carious (n= 81)	2.93%
One neighbor missing, one noncarious (n= 54)	1.95%
Both neighbors missing (n= 2)	0.07%

on all the examined teeth are similar and show that if one tooth is carious, it is very likely that one of the neighboring teeth will also be affected. With all three of the teeth examined, it was found that if one tooth is carious, at least one of the neighboring teeth will be affected approximately 80% of the time.

Clearly there is variation in the expression of bilateral symmetry and the condition of neighboring teeth, much of which will contribute to the observed uniqueness of dental patterns.

CHAPTER 10: STATISTICAL BASIS FOR THE UNIQUENESS OF DENTAL PATTERNS

There are a huge number of possible combinations of missing, filled, restored, and unrestored teeth that can be charted from the permanent dentition. This fact is the main basis for the entire realm of personal identification by forensic odontologists. While dental radiographic evidence is preferable, the number of possible dental characteristics that can be derived from non-radiographic lines of evidence (e.g. charts and notes) still provide a wealth of evidence for establishing identifications. This method of comparison from non-radiographic evidence has been used to establish dental identifications in the U.S. military since at least WWII (e.g. Levine 1972, Snow 1948) and much earlier in the civilian realm (e.g. Amoedo 1898).

Several quotes from various researchers will elucidate the general perception by forensic odontologists, and those working in the forensic sciences, concerning the uniqueness of dental evidence:

> "Saferstein indicates the existence of several billion different fingerprint combinations which assures the uniqueness of establishing identification by this method. Fortunately, the same uniqueness exists in the oral cavity. With each tooth having five visible surfaces there can be a total of 160 surfaces if all 32 teeth are present. If one now considers the various combinations of decayed, missing and restored teeth, prosthetic appliances, root morphology, boney defects and trabeculi patterns, again several billion different combinations exist" (Myers and Mirchandani 1986:514).

> "…I venture to say that far more identifications are clinched by dental evidence than by skeletal evidence. Details of the teeth, especially the combinations of dental restorations and replacements, are unique to the individual in much the same way as are his fingerprint patterns and are much more permanent" (Stewart 1963:265).

> "If the same individual characteristics have been recorded in both sets of information, identity can be directly established. From personal experience covering more than two hundred cases, I feel justified in stating that dental characteristics may

lead to a speedy direct identification in a considerable percentage of cases, which is of particular value in mass disasters, where time is so important" (Keiser-Nielsen 1963:309).

"The science of dental identification is based on the astronomical number of different combinations possible in the dental charting of the human mouth" (Luntz and Luntz 1973:122).

"…the astronomical figure resulting would make it obvious that there is almost no chance of two dentitions being alike and that if the chart of an unknown matches that of a known, even though not completely, there is no doubt that the charts were made from the same dentition" (Wyckoff 1957:501).

"The number of different dental combinations in a person's mouth is astronomical. The likelihood of the same combinations appearing in any two individuals is virtually nil, and this is the principle on which dental identification is based" (Chrobak and Frasco 1983:17).

"It has in fact, been established by computer that the chances of two people having identical teeth are not less than two BILLION to one!" (Furness 1972:14 emphasis in original text).

"The sixteen different opposing teeth of the human dentition offer-in their variables of kind, position within the jaw, and states of health, disease, and repair-an astronomical number of combinations which can be compared to the combinations of positions possible for the sixteen opposing pieces of a chess set" (Sognnaes 1976b:370).

The number of theoretically possible combinations of filled, missing, and unrestored teeth can be calculated as $\mathbf{C}^{\mathbf{n}}$, where **C** is the number of possible characteristics and **n** is the number of teeth considered. If only four possible characteristics for each tooth are utilized (unrestored, filled, missing, or missing/replaced with prosthesis) the number of possible combinations with 28 teeth would be 4^{28}, or 72,057,594,037,927,940 different patterns. If the possible combinations of filled surfaces are considered (mesial, occlusal, distal, facial, and/or lingual), then the number of possible characteristics for each tooth is 34 since there are 31 possible combinations of filled surfaces for each tooth (see Table 40) in addition to the categories of unrestored, missing, and missing/replaced with prosthesis. The expression would be 34^{28}, or about 7.61×10^{42} different combinations. The possible number of combinations of missing and filled teeth is stressed by Keiser-Nielsen and Sognnaes (Keiser-Nielsen 1977, Keiser-Nielsen 1980, Sognnaes 1975).

Perhaps a more accurate statistical look at the number of possible combinations would involve consideration of only the posterior teeth, since this is where most of the modifications resulting from decay (fillings or extractions) will occur. Furthermore, this would also approximate situations of postmortem loss since the anterior teeth are most

Table 40. Possible Combinations of Filled Surfaces (M, O, D, F, L).

31 Possible Combinations of Surface Fillings				
M	O	D	F	L
MO	OD	DF	FL	
MD	OF	DL		
MF	OL	DFL		
ML	OFL			
MOD	ODL			
MOF	ODF			
MOL	ODFL			
MDF				
MDL				
MFL				
MODF				
MODL				
MDFL				
MOFL				
MODFL				

commonly missing in the postmortem interval. Using the same criteria as above, the number of possible combinations considering only the first and second premolars and the first and second molars with four possible characteristics is 4^{16}, or 4,294,967,296 different combinations. If the 34 possible characteristics are considered, the expression is 34^{16}, or about 3.19×10^{24} different possibilities. Obviously the statistical values generated for the posterior teeth alone present sufficient numbers of possible variations to be of discriminating value if, indeed, this variation is truly expressed in the population.

Sognnaes (1975) discusses the uniqueness of the individual human dentition and the possible combinations. He provides an example in which he states that four missing teeth create 35,960 combinations in the mouth. Of the 28 remaining teeth, he states that four of these have fillings, which creates an additional 20,475 combinations. Sognnaes treats these characteristics independently and multiplies the values to arrive at a figure of 730,281,000 possible combinations of four missing and four filled teeth. A very similar example is also provided by Keiser-Nielsen (1977, 1980). Furthermore, it is recommended by Keiser-Nielsen (1977, 1980) that the frequencies of individual characteristics can assumed to occur independently, and that these values can be multiplied in order to produce an expected frequency for a combined occurrence. There are serious flaws with these types of statistical assessments, some of which have been mentioned by Lorton and Langley (1986a).

The main flaw of the statistical computations presented above is that they incorrectly apply the law of independence and assume that treatment occurs randomly throughout the mouth. While the number of combinations presented in these articles is theoretically plausible, some are, in actuality, unlikely to ever be found in an individual. (The number of possible combinations is more realistic if only the posterior teeth are considered, as opposed to consideration of all 28 teeth, but even this is problematic.) Each of the possible dental patterns is not equiprobable, otherwise there would not be any patterns that occur more frequently than others. If all patterns were equiprobable then the expected frequency of any dental pattern would be (1/total number of possibilities), in the case of 28 teeth with four possible characteristics the expected frequency would be 1/72,057,594,037,927,940, which is certainly not valid. For example, while it is theoretically possible for an individual to have an alternating pattern of missing and filled teeth throughout the oral cavity, this would be unlikely to ever occur (other more far-fetched examples could easily be imagined). Individuals with all unrestored teeth, or perhaps only filled molars, are likely to occur more frequently in the overall population. As such, the theoretical values do not represent a valid number of dental patterns that can be expected to be found in the population as a whole, and use of these figures in a court of law could be difficult to defend and potentially misleading. This said, it is still believed that the number of dental patterns present in the population is sufficient to be of use for forensic identification purposes, a point which will be developed further through an empirical approach.

Besides being invalid to treat dental patterns as equiprobable, it is inappropriate to treat each tooth in the permanent dentition as being at the same risk of treatment. If this was the case, the law of independence could be used and the frequencies of certain characteristics could be multiplied together to arrive at the overall frequency that a certain pattern would be expected to be observed in the population. This type of calculation is recommended by Keiser-Nielsen (1980), who states that it is valid to treat the frequency of occurrence independently and multiply the values of numerous teeth together in order to derive an expected frequency. He states (Keiser-Nielsen 1980:69) that when considering six features with a frequency of 10 percent that this combination "…would make the person in question one out of at least 1 million people, all of them missing and all of them with a physical possibility of ending up at the site of recovery." A method similar to this is recommended by Dahlberg (1957). The data in Table 41 represent the overall frequency of missing, filled and unrestored teeth in two large samples of individuals. (Note that the values for unrestored teeth were calculated by adding the number of decayed and virgin teeth together.) Either of the samples provided in Table 41 could be used as a source of frequency data, they only differ in that one is composed of civilians and one is composed of military personnel. Both military and civilian data are provided as these figures may be of interest to other researchers. If teeth could truly be treated independently, then it should be possible to select a dental pattern and multiply the probability of observing a certain characteristic for each tooth together to obtain the frequency that the overall pattern would be expected to be observed in the population.

In order to observe the variation between an observed frequency of a specific dental pattern and the expected frequency calculated by treating each tooth independently, two of the most commonly encountered dental patterns were selected from the generic Modern Military dataset (Patterns 1 and 2: Table 42). In addition, one

Table 41. Frequencies of Characteristics by Tooth for a Military and a Civilian Sample (all values are percentages).

	Modern Military (n=19,422)			**Modern Civilian** (n=9,730)		
Tooth No.	**Missing**	**Filled**	**Unrestored***	**Missing**	**Filled**	**Unrestored***
2	3.20	47.60	49.21	12.59	36.70	50.71
3	4.19	60.38	35.43	17.85	42.96	39.19
4	2.18	23.00	74.82	11.92	22.99	65.09
5	8.98	17.15	73.87	14.39	18.64	66.97
6	1.12	5.89	92.99	6.16	6.05	87.79
7	2.16	11.45	86.39	8.35	10.81	80.84
8	1.47	12.01	86.52	8.02	11.27	80.71
9	1.55	11.66	86.79	8.05	11.76	80.20
10	2.21	11.41	86.37	8.67	11.74	79.59
11	1.06	5.68	93.26	6.15	6.12	87.74
12	8.67	16.79	74.55	14.36	18.36	67.29
13	2.41	22.30	75.29	12.06	22.50	65.45
14	4.06	59.46	36.48	17.77	42.92	39.31
15	3.06	46.91	50.03	13.04	35.85	51.11
18	4.31	52.39	43.30	18.07	40.02	41.91
19	7.88	58.54	33.58	27.77	40.54	31.69
20	3.00	19.66	77.35	8.46	21.61	69.93
21	6.61	8.61	84.77	7.46	10.78	81.76
22	0.31	2.22	97.47	2.46	2.05	95.50
23	0.58	1.34	98.08	3.37	1.39	95.24
24	0.76	1.51	97.73	3.62	1.11	95.27
25	0.70	1.52	97.78	3.78	1.31	94.91
26	0.71	1.23	98.07	3.36	1.51	95.13
27	0.32	2.31	97.37	2.32	2.28	95.40
28	6.47	8.67	84.86	7.90	10.98	81.12
29	2.89	20.27	76.84	9.31	21.47	69.22
30	6.98	59.80	33.23	26.55	41.37	32.09
31	3.90	51.84	44.25	18.51	40.30	41.19

**Unrestored* contains teeth with untreated decay and virgin teeth

Table 42. Three Dental Patterns Used in Comparison of Observed and Expected Frequencies.

	Tooth No.	Pattern # 1	Pattern # 2	Pattern # 3
maxilla	2	V	R	R
	3	V	R	R
	4	V	V	R
	5	V	V	R
	6	V	V	V
	7	V	V	V
	8	V	V	V
	9	V	V	V
	10	V	V	R
	11	V	V	V
	12	V	V	R
	13	V	V	R
	14	V	R	R
	15	V	R	R
mandible	18	V	R	R
	19	V	R	R
	20	V	V	R
	21	V	V	V
	22	V	V	V
	23	V	V	V
	24	V	V	V
	25	V	V	V
	26	V	V	V
	27	V	V	V
	28	V	V	V
	29	V	V	R
	30	V	R	R
	31	V	R	R

dental chart was randomly selected from personnel files from the Southeast Asia Conflict (Pattern 3: Table 42). The dental patterns from these records were empirically observed against the Modern Military dataset (generic format) to derive the observed frequency of occurrence. The values in Table 41 for the Modern Military (generic format) were used to calculate the expected frequency of occurrence treating each tooth independently. Values for the Modern Civilian (generic format) are also provided in Table 41 so that similarities and differences between the two can be viewed. The observed and expected values were calculated for all 28 teeth, and they were also calculated only considering teeth that had received treatment (extracted or restored).

Pattern # 1 (all unrestored teeth) was found to occur 2,397 times in the Generic Modern Military database if all 28 teeth are considered. The observed frequency can then be considered to be 12.34% of the total sample (n= 19,422). If all teeth are treated independently and the observed frequencies are multiplied for each tooth, the expected frequency is 0.00004 (0.004% of the population should express this pattern if independence was valid). Obviously there is a very large discrepancy between the empirically observed frequency and that derived by assuming independence.

Pattern # 2 (all molars restored) was found to occur 581 times in the Generic Modern Military database if all 28 teeth are considered. The observed frequency can then be considered to be 2.99% of the total sample (n= 19,422). If all teeth are treated independently and the observed frequencies are multiplied for each tooth, the expected frequency is 0.0004 (0.04% of the population should express this pattern if independence were valid). If only the teeth with treatment are considered (all molars) then the observed frequency is 3,870 occurrences, or 19.93% of the total sample (n=19,422). Assuming independence and multiplying the frequency of restorations for the molars only, an expected value of 0.0076 is derived (only 0.76% of the sample should have these teeth filled). Again, comparison of the empirically derived frequencies versus those derived under the assumption of independence shows that the differences are extreme.

For Pattern # 3 (randomly selected from a Southeast Asia era personnel file) the pattern was found to occur one time in the Modern Military database. The expected frequency assuming independence was equally rare and multiplication of the values produced a figure less than 10^{-8}. The observed frequency can be considered to be 1 out of 19,422, or 0.00005. If only the teeth with treatment are considered, then the observed frequency is 186 out of 19422, or 0.0096, while the expected value is still <.00000001. In this case the empirically derived values are more similar to those calculated under the assumption of independence, but are still not appropriate.

Overall, it is clear that it is clear that it is not valid to assume independence or equiprobability when considering dental patterns and that the statistical recommendations of Keiser-Nielsen and Sognnaes (Keiser-Nielsen 1977, Keiser-Nielsen 1980, Sognnaes 1975) are not valid and are potentially misleading. The most accurate manner to quantify the frequency of occurrence in the population is by empirical comparison. In order to derive accurate values, it is essential to have large, reliable comparative datasets, such as those compiled as part of this dissertation.

Conclusions

While some researchers have cited the large number of possible dental patterns based on combinations of missing, filled, and unrestored teeth, most of these studies assume independence or equiprobability in the calculation of the values. This type of statistical treatment has been shown to be invalid based on the empirical observation of a large sample of individual dental patterns. While it has been shown to be statistically inaccurate to treat teeth independently, the question of the uniqueness of dental patterns in the population still arises. Since it has been shown that the theoretically calculated number of dental combinations is not realistic, then it becomes essential to determine if there is sufficient diversity in dental patterns to be used for identification purposes. The most appropriate method to assess the diversity question is by empirical comparison with a large reference population. In order to confirm the utility of non-radiographic evidence for identifications, it was necessary to discover if there are common decay patterns that are frequently observed in the general population, or whether most observed patterns are unique. Furthermore, it was necessary to determine if there is a minimum number of teeth needed to create a distinctive pattern.

CHAPTER 11: DIVERSITY OF DENTAL PATTERNS AND THEIR COMPARISON TO MITOCHONDRIAL DNA

Dental Patterns and mtDNA Sequences

In many respects it is appropriate to compare the diversity of dental patterns formed by combinations of missing, filled, and unrestored teeth with the diversity of mtDNA sequences formed by combinations of variants at multiple polymorphic sites within the mtDNA sequence. The comparison of these techniques is relevant because many properties of mtDNA variation are similar to dental pattern variation, and the relatively well-developed system for assessing the significance of mtDNA matches provides an excellent frame of reference for considering the discrimination provided by dental data. Several points show that dental information and mtDNA share some of the same strengths and weaknesses.

Unlike nuclear DNA, neither the character states comprising a dental pattern nor the various nucleotide positions comprising a mtDNA sequence can be considered to occur independently. The entire mtDNA molecule is a single non-recombining locus, so that any single mutation/polymorphism is permanently associated with other mutations on the molecule. Similarly, decay on teeth is not a random event that occurs equally throughout the mouth. This means that dental patterns and mtDNA sequences must be evaluated in relation to the frequency of the patterns/sequences in the population (not all dental patterns or mtDNA sequences are equiprobable in the population and random matches may occur). Some mtDNA sequences and some dental patterns are more likely to occur than others.

Depending on the format considered, dental variants are at least as abundant as the number of mtDNA variants. If detailed surface information is utilized for dental fillings, in combination with missing and unrestored conditions, each tooth will express one of 34 variable states (X, XP, V and any combination of M,O,D,F,L). Consideration of strictly generic dental codes, including only a single code for fillings, provides four variable states for each tooth (V, R, X, XP). With mtDNA there are four possible nucleotide bases (A, T, C, G) for each polymorphism. Clearly the detailed dental characteristics provide a vast range of possible combinations that surpass mtDNA, although if all 610 positions of HV1 and HV2 are considered then the theoretical variation possible with mtDNA still exceeds that of the teeth.

MtDNA is maternally inherited and, as such, is passed on through the family line. It is actually this very fact that allows for mtDNA to be of great use in many forensic comparisons since the sequence derived from a set of remains believed to be a specific individual can be compared to a family reference sample. Sometimes the donor may be a distant relative. Dental patterns of offspring, on the other hand, cannot be accurately predicted based on the dental health of their parents, although some degree of genetic influence may be present. In essence, the family reference sample used for mtDNA comparison can be considered to be analogous to an antemortem dental record, and problems locating a family reference sample are comparable to the difficulty of locating antemortem dental records. Dental identification is therefore useful if there are antemortem records available, while mtDNA can be used even in the absence of samples from the decedent (provided they are available from maternally related individuals).

Both mtDNA and dental pattern comparison are limited in their utility for forensic identification when common sequences/patterns are encountered. This problem has been addressed by sequencing outside of the hypervariable regions with mtDNA (Parsons and Coble 2001). Edentulous individuals and those with perfect teeth present the greatest challenges to non-radiographic dental identification.

It is possible for the mtDNA sequences of maternal relatives to differ slightly from each other due to a mutation event, and it is possible for more than a single mtDNA type to occur within an individual (a condition known as heteroplasmy) as a result of a recent mutation event in the individual or the individual's matriline. For dental patterns it is possible for dental conditions to be present in the postmortem record that are not expressed in the antemortem files due to undocumented treatment (e.g. a tooth was filled subsequent to the date of the available documentation, so the files show the tooth to be unrestored but the postmortem analysis shows the tooth to be filled). With both mtDNA and dental patterns it is possible for these types of "explainable discrepancies" to exist. In both instances it is important to acknowledge that these slight variations may occur and that they are not evidence for exclusion. Perhaps the greatest danger in either mtDNA or dental comparisons is a false exclusion due to contamination. For mtDNA the contamination may result from the introduction of exogenous DNA, while serious charting errors may inadvertently "contaminate" a dental comparison.

Through the use of large, representative datasets it is possible to assess the overall diversity of dental patterns and mtDNA sequences for identification purposes. By performing all pairwise comparisons of the sequences/patterns, it is possible to present the overall frequency that they match one another in a database. From these comparisons it is possible to derive an assessment of the overall diversity of the sequences/patterns, as well as the probability of a random match between two individuals. These statistics provide the framework for empirical observation of dental patterns and mtDNA sequences and are an indication of their overall utility for personal identification. This type of analysis has been utilized in support of the high population diversity observed for mtDNA sequences (Holland and Parsons 1999, Melton, et al. 2001), and it is very appropriate for the analysis of dental patterns.

Overall Diversity of Dental Patterns

In order to test the overall diversity of dental patterns, a FORTRAN program written by Dr. Lyle Konigsberg at the University of Tennessee, Knoxville performed pairwise comparisons of all dental patterns present within all of the datasets compiled for this dissertation and generated the total number of matches. This analysis was performed for all the datasets in both their detailed and generic formats. In addition, all of the datasets were pooled and the same pairwise comparisons were performed. Based on the values derived from this program, it was possible to calculate Diversity and Random Match Probability values. Both of these values are related to each other and can be used for comparison to diversity figures used in the discussion of mtDNA studies (e.g. Holland and Parsons 1999, Melton, et al. 2001).

Two different criteria were used for the Diversity values, one based on the total sample (Total Diversity) and one that is conditional upon having some substantive dental states other than perfect teeth or no teeth (Conditional Diversity). In both instances, the numerator reflects the number of mismatches encountered during the pairwise comparisons. The larger the numerator, the closer the diversity value is to 1 (an overall value of 1 would indicate that all patterns present within the data are distinct, a value of 0 would indicate that all are the same). The Total Diversity measure was calculated as:

$$\frac{\sum_{i>j} \delta_{ij}}{\left(\frac{N(N-1)}{2}\right)},$$

where δ_{ij} =1 when individuals *i* and *j* have different patterns.

For the Conditional Diversity measure, matches based on individuals with MF=0 or individuals with M=28 were not considered since those conditions ("perfect teeth" and edentulousness) represent an acknowledged problem for dental identification. The frequencies of individuals with perfect teeth and edentulous individuals are presented in Table 43 for each of the datasets. Although these individuals represent an identification

Table 43. Frequency of Individuals with Perfect Teeth and Edentulous Individuals.

Forensic Dataset	Total Number	Perfect Teeth	Edentulous
WWII-Korea Detailed	7,920	1,355 (17.11%)	70 (0.88%)
WWII-Korea Generic	9,102	1,371 (15.06%)	70 (0.77%)
Southeast Asia Detailed	1,852	36 (1.94%)	15 (0.81%)
Southeast Asia Generic	1,854	36 (1.94%)	15 (0.81%)
Modern Military (Detailed and Generic)	19,422	2,397 (12.34%)	2 (0.01%)
Modern Civilian (Detailed and Generic)	9,730	1,325 (13.62%)	161 (1.65%)

problem, based on the frequency information in Table 43, it can be seen that if an unidentified individual is encountered with perfect teeth then a substantial percentage of the population can be excluded and this may still be useful information. Clearly the individuals with perfect teeth will have a larger effect on the diversity estimate than the edentulous ones simply due to the sample size. The Conditional Diversity was calculated as:

$$\frac{\left(\sum_{i>j}\delta_{ij}\right)+XY}{\left(\frac{Y(Y-1)}{2}+XY\right)},$$

where $\delta_{ij}=1$ when individuals *i* and *j* have different patterns and *ij* is the set of all pairwise comparisons for Y individuals, X= Number of individuals with MF=0 or M=28 (i.e. individuals without any missing or restored teeth, and edentulous individuals), and Y= Number of individuals with MF≥1 and M<28 (i.e. individuals with at least one missing or filled tooth, excluding edentulous individuals). Therefore, X+Y=N of the Total Diversity Index. The denominator used in the calculation of the Conditional Diversity measure accounts for the fact that all individuals with MF=0 or M=28 would be a mismatch to all other individuals in the dataset with MF≥1 and M<28.

The Random Match Probabilities are derived by either forming a ratio of the number of pattern matches encountered during the pairwise comparisons (as opposed to mismatches) to the total number of pairwise comparisons, or by subtracting the Diversity estimate from 1. This Random Match Probability value reflects the probability that two individuals drawn at random (without replacement) from the population would share the same dental pattern.

It can be seen in Table 44 that the Total Diversity values (which include matches between individuals with perfect teeth and matches between edentulous individuals) are high for all of the datasets, greater than or equal to 0.97 in all instances. The Random Match Probability values are low, generally less than 2% with the exception of the WWII-Korea data. It is equally important to notice that there is very little difference in either the Total Diversity or Random Match Probability values based on the generic or detailed formats of the data. This shows that even dental patterns formed with only basic dental codes can be very diagnostic.

Most of the Total Diversity values derived from the dental patterns show that mtDNA sequences are more diverse than dental patterns, but are similar. Melton et al. (2001) report a pooled diversity of 0.998 for mtDNA sequences derived from contemporary North American populations. (This diversity measure is based on variation as detected by sequence-specific oligonucleotide, SSO, probes. This manner of typing only captures a small portion of the total sequence variation in the hypervariable control region. This is not representative of the diversity that would be seen in the entire hypervariable region, which would result in a higher figure.) This would correspond to a Random Match Probability of 0.002. Holland and Parsons (1999) performed pairwise comparisons of all the sequences in their database of 604 Caucasian individuals and found that there were 669 instances of a match out of the 182,106 separate pairwise comparisons. They report an empirically determined Random Match Probability of

Table 44. Total Diversity of Dental Patterns Based on Pairwise Comparisons.

	N	Pairwise comparisons N*(N-1)/2	Matches	Random Match Probability	Total Diversity Estimate
Detailed WWII-Korea	7,920	31,359,240	943,327	0.03008	0.9699
Generic WWII-Korea	9,102	41,418,651	968,216	0.02338	0.9766
Detailed Southeast Asia	1,852	1,714,026	761	0.00044	0.9996
Generic Southeast Asia	1,854	1,717,731	1,917	0.00112	0.9989
Detailed Modern Military	19,422	188,597,331	2,906,151	0.01541	0.9846
Generic Modern Military	19,422	188,597,331	3,246,590	0.01721	0.9828
Detailed Modern Civilian	9,730	47,331,585	898,859	0.01899	0.9810
Generic Modern Civilian	9,730	47,331,585	925,489	0.01955	0.9804
Detailed All Datasets	38,924	757,519,426	13,228,058	0.01746	0.9825
Generic All Datasets	40,108	804,305,778	16,552,379	0.02058	0.9794

0.0037 (i.e. two randomly selected individuals from the population will match once in approximately 270 times), which would correspond with a Diversity estimate of 0.9963. Most of the values presented in Table 44 indicate that the diversity observed in dental patterns is slightly less than the values presented for mtDNA, but they are comparable and indicate overall high diversity.

Comparison of the Conditional Diversity values in Table 45 provides different results that show dental patterns to be more diverse than mtDNA. By removing the matches formed by edentulous individuals and individuals with perfect teeth, the diversity values become even more impressive. (It should be noted that a similar improvement would be accomplished with mtDNA if the most common sequence was removed from consideration.) When the detailed formats of the datasets were used (34 possible codes for each tooth), Conditional Diversity was always greater than .999 in all four of the datasets (Table 45). When the generic datasets were analyzed (only four possible codes), Conditional Diversity was usually the same and never dropped below .997 in any of the datasets (Table 45). As stated previously, mtDNA diversity for North American populations has been calculated to be .998 (Melton, et al. 2001), indicating that in most instances the Conditional Diversity estimates for dental patterns are superior to the reported mtDNA diversity. Similarly, the Random Match Probability values are very close to zero, indicating that the chance of randomly selecting two individuals with the same dental pattern is almost non-existent when edentulous individuals and individuals with perfect teeth are removed from consideration. These findings indicate that the lower values expressed by the Total Diversity (Table 44) are primarily a result of individuals

Table 45. Conditional Diversity (MF≥1 and M<28) of Dental Patterns Based on Pairwise Comparisons.

	X*	Y**	Pairwise comparisons [Y*(Y-1)/2]+XY	Matches	Random Match Probability	Conditional Diversity Estimate
Detailed WWII-Korea	1,425	6,495	30,344,640	23,961	0.00079	0.99921
Generic WWII-Korea	1,441	7,661	40,381,131	27,050	0.00067	0.99933
Detailed Southeast Asia	51	1,801	1,712,751	26	0.000015	0.999985
Generic Southeast Asia	51	1,803	1,716,456	1,182	0.00069	0.99931
Detailed Modern Military	2,399	17,023	185,720,930	34,544	0.00019	0.99981
Generic Modern Military	2,399	17,023	185,720,930	374,983	0.00202	0.99798
Detailed Modern Civilian	1,486	8,244	46,228,230	10,617	0.00023	0.99977
Generic Modern Civilian	1,486	8,244	46,228,230	37,247	0.00081	0.99919
Detailed All Datasets	5,361	33,563	743,151,946	135,697	0.00018	0.99982
Generic All Datasets	5,377	34,731	789,296,706	803,690	0.00102	0.99898

*X= Number of individuals with MF=0 or M=28 (i.e. individuals without any missing or restored teeth, and edentulous individuals)

**Y= Number of individuals with MF≥1 and M<28 (i.e. individuals with at least one missing or filled tooth, excluding edentulous individuals) with MF=0. When at least one dental characteristic is present, the overall diversity of dental patterns is very high. The values presented in Table 44 for the Total Diversity can be considered to be a conservative estimate, while the values presented in Table 45 for the Conditional Diversity reflect the strong effect that primarily individuals with perfect teeth have on the overall diversity of dental patterns. Clearly dental patterns provide an excellent comparative tool for assisting in personal identification, on a scale that is very similar to mtDNA.

CHAPTER 12: INTERPRETATION OF DENTAL PATTERN CONGRUENCE AND THE ISSUE OF CONCORDANCE

The previous section has established the empirical basis for the high diversity present in dental patterns and their utility for identification purposes. While this is an important step in the validation of the technique, for forensic comparisons it becomes critical to be able to quantify the strength of a specific antemortem-postmortem dental comparison. Previous attempts have been made by forensic odontologists to assign an arbitrary number of points of concordance to establish an identification. Depending on the number of matching points, a gradient classification scale has been recommended in regard to the strength of the comparison (Sognnaes 1977a, Sognnaes 1977b). Based on the research presented in this dissertation, it is now clear that it is not important to have a set number of matching points. The best method for quantifying the rarity of a dental pattern match is to empirically compare the observed pattern to a large reference population. With this technique, dental patterns based on the characteristics of any number of teeth can still be assessed and an accurate sense of the rarity of the pattern can be derived. Both issues (points of concordance and empirical comparison with a reference sample) will be addressed in this section.

Points of Concordance

The number of points of concordance necessary to establish a positive identification has never been formally agreed upon within the field of forensic odontology (Mertz 1977, Sognnaes 1975, Stimson 1975). Stimson (1975) states that, as a rule of thumb, 8 points of concordance would be the minimum number, although Sognnaes (1976a, 1976b) prefers a dozen concordant features unless the material is extraordinarily characteristic. Although the American Board of Forensic Odontology provides guidelines for body identification (anonymous 1994), they do not provide a discussion behind the rationale for a “positive identification,” a “possible identification,” “insufficient evidence,” or an “exclusion.” The criteria relating to dental identification are vague and subjective, depending primarily on the experience and confidence of the odontologist.

Dahlberg (1957:389) believes that for an identification to be beyond reasonable doubt the statistical proportion should be at least a ratio of 1:total number of missing individuals. Dahlberg bases this proportion on the probability of discovering an individual with certain dental characteristics and draws his frequency data from empirical studies (e.g. the probability of having a filled incisor multiplied by the probability of having a filled molar, etc.). While Dahlberg states that it is incorrect to treat homologous teeth independently, it has been shown in this study that it is also inappropriate to treat characteristics on non-homologous teeth independently as he proposed. The more appropriate technique is to empirically compare the overall dental pattern to the reference data in order to derive the expected frequency.

Mertz (1977:64) writes that “Many forensic odontologists believe mathematical theories on variable probabilities could be questioned in a court of law.” In reference to situations in which there are only a few points of concordance, he goes on to state (Mertz 1977:65) “Perhaps in the future, as the state of art improves, a well trained biostatistician will be able to provide weighted values for each identifying characteristic and help to clear up some of these problem areas." This attitude is echoed by Sognnaes (Sognnaes 1977a) who believes that future research will provide more sophisticated quantitative techniques to address the issues involved with antemortem-postmortem concordance. This dissertation is intended to resolve these concerns.

Part of the difficulty in applying a uniform standard regarding points of concordance with dental evidence is that it is inappropriate to consider radiographic and non-radiographic dental evidence in the same manner. One unique radiographic feature is all that may be necessary in order to establish a positive identification, while multiple corresponding characteristics within an odontogram may remain inconclusive. It is certainly preferable to have numerous points of concordance (regardless of the type of dental evidence), but it is difficult to set a fixed number as each case presents its own unique set of circumstances. Luntz and Luntz state, "Unlike fingerprint identification, dental identification cannot be based on a predetermined number of comparative points, inasmuch as in dental identification certain coincident characteristics are accorded more weight than others. A single antemortem x-ray of a tooth compared with a postmortem x-ray could be the basis for an identification, whereas antemortem and postmortem dental charts showing three or four matching restorations might be regarded as containing insufficient criteria for an identification" (1973:146). Similarly, Gustafson (1966) believes that it would be unlikely for any two individuals to have identical dental characteristics, but it is quite possible for two people to have similar data on their dental charts. Based on this perception, a significant problem facing forensic odontologists has been to establish standards for an identification based solely on dental charts without radiographic evidence.

Sognnaes (1977a, 1977b) and Keiser-Nielsen (1980) have addressed the topic of points of concordance based on dental characteristics and have proposed guidelines for assessing the overall power of the comparison for establishing an identification. It should be noted that Sognnaes references an unpublished presentation by Keiser-Nielsen entitled "Proposed minimum requirements for establishing identity by teeth" from the Fifth International Meeting on Forensic Sciences, Toronto, 1969, but the same guidelines are outlined in (Keiser-Nielsen 1980). Many of Sognnaes' articles concern the dental identifications of Adolf Hitler, Eva Braun, and Martin Bormann (e.g. Sognnaes 1977a, Sognnaes 1977b, Sognnaes 1980, Sognnaes and Strom 1973). Using guidelines concerning the number of points of concordance needed for an identification (as recommended to him by Keiser-Nielsen) he was able to conclusively identify Hitler and Bormann, but determined that there was not enough evidence to identify Eva Braun. In order to quantify the number of points of concordance, he refers to "ordinary" and "extraordinary" characteristics and provides the identification guidelines presented in Table 46.

Numerous drawbacks exist with the guidelines recommended in Table 46. One obvious problem with these guidelines is that they are subjective, specifically in regard to what will be determined to be "extraordinary" versus "ordinary." Ordinary characteristics are vaguely defined as routine fillings and extractions, while extraordinary characteristics include such treatment as elaborate crowns and bridges (Sognnaes 1977a).

Table 46. Sognnaes' Recommended Points of Concordance (Based on Keiser-Nielsen (1980)).

	Total	Ordinary Characteristics	Extraordinary Characteristics
Possible ID	1	1	0
	4	1	3
	4	4	0
	7	7	0
Probable ID	4	0	4
	5	2	3
	6	4	2
	8	8	0
Certain ID	6	0	6
	7	2	5
	8	4	4
	9	6	3
	10	8	2
	12	12	0

Keiser-Nielsen (1980) loosely defines "extraordinary" characteristics as features that occur in less than 10 percent of all cases. Apparently no value is given to unrestored (virgin) teeth in this scheme. Another problem is that this technique requires a large number of teeth to be available for observation, a luxury that is not always afforded to forensic investigations.

Another serious flaw with Sognnaes' technique is that it is incorrect to view the characteristics of each tooth separately. Several "ordinary" restorations in combination with other "ordinary" missing teeth may represent a very unique pattern as a whole, a point that these guidelines ignore. With the method endorsed by Sognnaes and Keiser-

Nielsen it is necessary to have at least 12 “ordinary” points of concordance to establish what he refers to as a “Certain Identification.” In other words, if unusual dental treatment is not present, it is necessary for 43% of all teeth (excluding third molars) to be missing or filled before a match can be established with certainty. Other possible combinations require a mixture of “ordinary” and “extraordinary” characteristics to achieve the same result. There is no consideration of the overall pattern formed by the combination of either “ordinary” or “extraordinary” characteristics. Although this method provides a technique of quantifying the strength of an antemortem-postmortem match between records that removes some of the subjectivity, it is unlikely that many cases will meet the necessary requirements to fall into the “Certain Identification” status.

A final problem with the scheme recommended by Sognnaes and Keiser-Nielsen is that only teeth that have suffered some type of insult are considered. There is no significance given to unrestored teeth, even though this may be an important characteristic in itself. The fact that commonly restored teeth may be found to be unaffected can provide important comparative evidence. Overall, it is important to consider the dental treatments (extractions and restorations) in association with the unrestored teeth. In most instances the combination of unrestored, missing, and/or restored teeth can be extremely individualistic and provide strong evidence for establishing an identification.

Empirical Comparison with a Reference Dataset

The research presented in this dissertation indicates that it is inappropriate to use a fixed number of points of concordance for non-radiographic dental evidence. A more valid alternative utilizes a large, representative dataset in order to empirically determine the expected frequency of occurrence. The strength of a match to a specific dental pattern can be assessed based on an empirical comparison with the reference data. Relatively rare patterns will be recognized as such and an objective value can be associated based on the data. Furthermore, all dental characteristics should be considered, including unrestored teeth. It is important to remember that this evidence alone cannot constitute a definitive identification, but when used in conjunction with other supporting evidence it can provide a very strong correlation to a specific individual that is beyond reasonable doubt.

The technique recommended as part of this dissertation is nearly identical to the reporting procedures utilized by mtDNA experts. Initially it is necessary to establish the overall diversity of dental patterns to justify the power of the technique (as presented in Chapter 11). This is true for both dental patterns and mtDNA sequences. For personal identification cases it is more useful to consider the relative rarity of specific dental patterns (or mtDNA sequences). Given a specific pattern/sequence, the probability that another individual randomly selected from the population will match depends on the relative rarity of the pattern/sequence (Holland and Parsons 1999). It is important to note that the Diversity and Random Match Probability measures presented in the previous chapter do not say anything about specific dental patterns. These statistics are primarily a reflection of the most common patterns in the databases and, as such, provide only a general indication of the overall sample diversity.

It has been found that with mtDNA there are a small number of common sequences and a larger number of rare types. For example, Holland and Parsons (1999) report that out of a sample of 604 Caucasian individuals, 390 types occur in only a single individual, while the most common type occurs in 26 individuals (4.3%). The same has also been observed with dental patterns, but to a greater degree since a larger percent of the population is found to have "perfect teeth." Comparison of Total Diversity and Conditional Diversity in the previous chapter indicates that a few common dental patterns are present, while the majority of the patterns are rare.

Unless there is a way to quantify the match between antemortem and postmortem dental records, congruence between the two cannot be adequately interpreted. The most straightforward way to present frequency information for a specific pattern is to simply count the number of times the pattern occurs in the reference data. For very large sample sizes the counting method should provide a reasonable estimate of the expected population frequency. Holland and Parsons (1999) outline statistical modifications to the counting technique used to establish confidence limits on the frequency estimates derived for mtDNA sequences, especially for instances when the sample sizes are limited.

Clearly the best manner of quantifying the strength of a dental match is by empirical comparison to a reference dataset, not an arbitrary number of matching points. Several examples will help elucidate this point.

Non-radiographic Dental Identification Considering Complete Sets of Teeth

Three dental records were selected from the files of personnel killed during the Southeast Asia Conflict who were subsequently identified and whose records are housed at the CILHI. The antemortem dental records consist of the most recent dental chart from the individual's personnel file. These antemortem records provided examples of actual dental patterns of military individuals and, furthermore, these individuals would not be part of the reference datasets used in this dissertation. For these three examples, varying degrees of dental treatment were present in the antemortem records and all 28 teeth (excluding third molars) were considered to be present in the postmortem interval and to show exact correspondence with the antemortem data. In these examples it is important to keep in mind that there exists an exact correspondence between the postmortem chart and the antemortem records of a missing individual, and it is the strength of this match that needs to be quantified. While additional circumstantial evidence may be present in this type of situation (personal effects or archaeological provenience), only the strength of the dental evidence is considered here.

If explainable discrepancies were noted between the antemortem and postmortem records, then it is recommended that these teeth be excluded from the comparison and that they be treated as though they were missing postmortem. By treating the teeth in this fashion, any character state is accepted in the comparison allowing for the most conservative comparison and the most conservative frequency value for the overall pattern. None of the examples presented in this dissertation contain explainable discrepancies.

The strength of the match was quantified in two fashions: 1) using the method proposed by Sognnaes and Keiser-Nielsen,, and 2) through empirical comparison with a representative data set. Using Sognnaes and Keiser-Nielsen's guidelines, the observed match is determined to be a "Possible Identification," a "Probable Identification," or a "Certain Identification" based on the number of characteristics (Table 46). With the empirical comparison, the number of dental characteristics is not important and the strength of the match is assessed as the frequency that the dental pattern under consideration (including all teeth regardless of their condition) is observed in the reference datasets. This value is expressed as: $\left(\frac{X+1}{N+1}\right)*100$, where X is the number of pattern matches and N is the sample size. If, for example, the pattern is found to be unique in the reference dataset, then the number of matches should be considered to be 1/(N+1). In some instances this value can then be assessed in relation to the number of individuals considered to be possible candidates. For example, if the antemortem-postmortem match is believed to be a U.S. soldier missing from a certain province during the Southeast Asia Conflict this figure can be compared to the total number of missing individuals (prior odds for identification). Given statistical inference derived from other lines of evidence, it would then be possible integrate this new information to produce a posterior odds estimate or likelihood ratio.

Example 1

In the first example the records show that there are five matching restorations, six matching extraction sites, and 17 matching unrestored teeth (Table 47). This would

Table 47. Case Example 1 with Antemortem-Postmortem Matches for all 28 Tooth Locations (Universal Charting).

	Tooth No.	Unidentified Individual	Antemortem Records of John Doe
maxilla	1	-	-
	2	DO	DO
	3	OL	OL
	4	X	X
	5	X	X
	6	V	V
	7	V	V
	8	V	V
	9	V	V
	10	V	V
	11	V	V
	12	X	X
	13	X	X
	14	V	V
	15	MO	MO
	16	-	-
mandible	17	-	-
	18	X	X
	19	V	V
	20	DO	DO
	21	V	V
	22	V	V
	23	V	V
	24	V	V
	25	V	V
	26	V	V
	27	V	V
	28	V	V
	29	V	V
	30	X	X
	31	O	O
	32	-	-

likely be viewed as 11 “ordinary” characteristics by Sognnaes and Keiser-Nielsen’s criteria. None of the characteristics would be considered “extraordinary” and all are present on the molars and premolars, a common location for fillings to occur. By Sognnaes and Keiser-Nielsen’s criteria this correspondence would be considered as a “Probable Identification” (12 ordinary characteristics are needed for a “Certain Identification”).

Empirical comparison of the overall dental pattern (considering all 28 teeth) with both the Detailed and Generic Southeast Asia datasets (sample sizes are 1,852 and 1,854, respectively) shows that it is unique to both formats. It can then be stated that the observed dental pattern can be expected to occur in the population with a frequency of 1/1,855 or 0.05%. In other words, approximately one in 1,855 randomly selected individuals could be expected to have this dental pattern. Furthermore, when the pattern is compared to the Detailed and Generic Modern Military datasets (n=19,422) it was found to be unique in both formats. By calculating the frequency of occurrence from this larger sample, the strength of the match between antemortem and postmortem records can be increased to 1/19,423 individuals or 0.005% of the population. This example provides very strong evidence that the overall observed pattern is very rare in the population and the match to a missing individual is very significant. Clearly the empirical comparison provides a much more accurate assessment of the overall strength of the dental match.

Example 2

The second example consists of a dental pattern composed of 14 restored teeth and 14 unrestored teeth (Table 48). All of the fillings would be considered "ordinary" under Sognnaes and Keiser-Nielsen's standards. The fact that 14 characteristics are present and correspond exactly to the antemortem record indicates that, by Sognnaes' guidelines, a "Certain Identification" is formed.

Empirical comparison of all 28 teeth to the reference data confirms that the observed dental pattern is very uncommon. In the Detailed Southeast Asia dataset the pattern was found to be unique, while in the Generic Southeast Asia dataset it was found to occur only once (2/1,855 or 0.11%). In the Modern Military dataset (n=19,422) the pattern was found to be unique in both the detailed and generic formats for a frequency of only 1/19,423 or 0.005%. Once again the cumulative pattern of ordinary restorations produces a configuration that is very individualistic. The significance of the dental pattern match is reflected much more accurately by the empirical comparison than by the arbitrary criteria.

Example 3

The final example consists of a dental pattern in which there are only a few restorations present. This individual has six restored teeth and 22 unrestored teeth (Table 49). Furthermore, all of the fillings are confined to the molars, the most common location for decay to occur. Overall, there is nothing unusual about the restorations or

Table 48. Case Example 2 with Antemortem-Postmortem Match for all 28 Tooth Locations (Universal Charting).

	Tooth No.	Unidentified Individual	Antemortem Records of Billy Zoom
maxilla	1	-	-
	2	DOL	DOL
	3	MOD	MOD
	4	V	V
	5	DO	DO
	6	V	V
	7	L	L
	8	V	V
	9	V	V
	10	L	L
	11	V	V
	12	DO	DO
	13	O	O
	14	MOD	MOD
	15	MODL	MODL
	16	-	-
mandible	17	-	-
	18	O	O
	19	MODF	MODF
	20	V	V
	21	V	V
	22	V	V
	23	V	V
	24	V	V
	25	V	V
	26	V	V
	27	V	V
	28	V	V
	29	DO	DO
	30	MODF	MODF
	31	DOF	DOF
	32	-	-

Table 49. Case Example 3 with Antemortem-Postmortem Match for all 28 Tooth Locations (Universal Charting).

	Tooth No.	Unidentified Individual	Antemortem Records of Jacob Jimboy
maxilla	1	-	-
	2	V	V
	3	O	O
	4	V	V
	5	V	V
	6	V	V
	7	V	V
	8	V	V
	9	V	V
	10	V	V
	11	V	V
	12	V	V
	13	V	V
	14	O	O
	15	O	O
	16	-	-
mandible	17	-	-
	18	O	O
	19	OF	OF
	20	V	V
	21	V	V
	22	V	V
	23	V	V
	24	V	V
	25	V	V
	26	V	V
	27	V	V
	28	V	V
	29	V	V
	30	V	V
	31	O	O
	32	-	-

their location within the dental arcade and they would be considered to be "ordinary." Based on the points of concordance table provided by Sognnaes and Keiser-Nielsen (Table 46), this would only be regarded as a "Possible Identification," the weakest type considered.

Empirical comparison of the 28 teeth with the reference datasets provides quite a different perspective. The Detailed and Generic Southeast Asia datasets (n=1,852 and 1,854, respectively) show that even this simple pattern is unique in both formats and produces a frequency of 1/1,855 or 0.05%. When the overall pattern is compared with the Modern Military datasets (n=19,422), it was found to be unique in the detailed format and to only occur three times (4/19,423 or 0.02%) in the generic format. As with the other examples, the overall pattern is found to be extremely rare in the two datasets, indicating that the correspondence is very significant for identification. In this example an apparently "common" dental pattern was found to be very individualistic when considered in relation to all the teeth.

These three examples show that only a few common dental characteristics are needed to create an overall dental pattern that is relatively unique to the general population. Furthermore, when entire sets of teeth are available for observation, it is unlikely that detailed surface information regarding the location of restorations will significantly add to the comparison. If all of the teeth are available for comparison, correspondence with antemortem records forms a very strong line of evidence for identification and the results can be quantified in order to provide a greater appreciation for the strength of the match.

Non-radiographic Dental Identification Considering Extensive Postmortem Loss

A valid concern with forensic identification is that there is not always a full complement of teeth present for comparison. Due to various taphonomic factors, it is very common for the forensic odontologist to only have partial dental remains recovered for comparison with the antemortem records. While it has been readily shown in the previous examples that dental patterns based on complete complements of teeth are likely to be rare in the overall population, situations need to be explored when only incomplete remains are recovered. In order to test this, two additional examples from Southeast Asia identification cases were randomly selected in which there had only been the recovery of a limited number of teeth. The antemortem and postmortem charts selected for the following examples correspond exactly to real identification cases from the Southeast Asia Conflict. In this respect the antemortem records provide realistic dental patterns and the postmortem charts represent actual taphonomic loss so that there has not been any attempt to modify the comparison. These examples can be considered to be representative of what might be present concerning antemortem and postmortem evidence in a forensic case.

Example 1

In this first example it was only possible to determine the postmortem status of four teeth due to extensive postmortem loss (Table 50). One tooth was found to be missing antemortem and replaced with a prosthesis (#9), two teeth were virgin (#s11 and 28), and one tooth had a three surface restoration (#31). Based on the criteria of

Table 50. Case Example 1 with Antemortem-Postmortem Match for Only 4 Tooth Locations. Postmortem Loss Designated by Shaded Cells (Universal Charting).

	Tooth No.	Unidentified Individual	Antemortem Records of Spencer Gibblet
maxilla	**1**		-
	2		O
	3		MO
	4		DO
	5		V
	6		V
	7		V
	8		MDFL
	9	**XP**	**XP**
	10		MDFL
	11	**V**	**V**
	12		DO
	13		DO
	14		MO
	15		O
	16		-
mandible	**17**		-
	18		MOFL
	19		MODF
	20		DOL
	21		V
	22		V
	23		V
	24		V
	25		V
	26		V
	27		V
	28	**V**	**V**
	29		DO
	30		MOD
	31	**MOF**	**MO**
	32		-

Sognnaes and Keiser-Nielsen, this would correspond to one “ordinary” characteristic and one “extraordinary” characteristic. Using the guidelines from Table 46, this match between antemortem and postmortem records would only be considered as a weak “Possible Identification.” Since a minimum of six teeth are needed to establish a “Certain Identification,” all of which must have “extraordinary” characteristics, it would be impossible to ever identify an individual with any degree of certainty when this degree of loss occurs.

Empirical comparison of the dental pattern from the four teeth present in this case produced very different results from Sognnaes’ technique. When compared against 1,852 records from the Detailed Southeast Asia dataset, this pattern was found to be unique (1/1,853 or 0.05%). When the pattern is compared to the Detailed Modern Military dataset it was found to occur only three times (4/19,423 or 0.02%). Consideration of the same four teeth using the generic data format for the restoration on tooth #31 did not significantly change the outcome. The pattern was observed in the Generic Southeast Asia dataset only 10 times (11/1,855 or 0.59%), while the pattern only appeared 66 times in the Generic Modern Military dataset (67/19,423 or 0.34%). In this case only four teeth were sufficient to establish a very strong correlation with a missing individual, a point that would have been missed without empirical comparison. Primarily due to the combination of a filling and a prosthesis, only a very small number of teeth were needed to form a very rare dental pattern. Obviously, as the number of teeth present for consideration grows, so does the probability that very individualistic dental patterns will emerge.

Example 2

A second case example is presented to demonstrate the type of results that can be expected when only partial dental remains are represented. In this example eight teeth were recovered, all from the mandible (Table 51). Restorations are present on both first and second molars, while the remainder of the recovered teeth are unrestored. Overall there are only four "ordinary" characteristics as outlined by Sognnaes and Keiser-Nielsen and a match between the antemortem and postmortem records would merely be considered as a weak "Possible Identification."

Empirical comparison of the eight teeth with the reference populations from the Southeast Asia and Modern Military datasets produced quite different conclusions from those derived by points of concordance. As it is very common for the mandibular molars to be filled it would be of considerable interest to the forensic odontologist to be able to objectively quantify how common the observed pattern of filled and unrestored teeth would be in the general population. Comparison of the dental pattern with the Detailed Southeast Asia dataset (n=1,852) indicates that this pattern created by only eight teeth is unique to the dataset (1/1,853 or 0.05%). Comparison of this dental pattern to the Detailed Modern Military dataset (n=19,422) shows that, again, this pattern is unique to the dataset (1/19,423 or 0.005%). If the detailed surface information is removed concerning the four restorations and is replaced with the generic format, drastically different results are attained. The frequency that the pattern is observed jumps to 525 matches in the Generic Southeast Asia dataset (526/1,855 or 28.36%), and 4,184 matches in the Generic Modern Military dataset (4,185/19,423 or 21.55%). Using the generic

Table 51. Case Example 2 with Antemortem-Postmortem Match for Only 8 Tooth Locations. Postmortem Loss Designated by Shaded Cells (Universal Charting).

	Tooth No.	Unidentified Individual	Antemortem Records of Buzz McCracken
maxilla	1		-
	2		O
	3		V
	4		V
	5		V
	6		V
	7		M
	8		V
	9		V
	10		V
	11		V
	12		V
	13		V
	14		OL
	15		OL
	16		-
mandible	17		-
	18	MODF	MODF
	19	MODF	MODF
	20		V
	21	V	V
	22	V	V
	23	V	V
	24		V
	25		V
	26		V
	27		V
	28	V	V
	29		V
	30	MO	MO
	31	OF	OF
	32		-

format of the data, approximately one in four randomly selected individuals could have this dental pattern. Comparison with the Generic datasets does not provide strong evidence to associate the eight teeth with a specific individual. It is clear from this example that in situations of extensive postmortem loss of teeth, the use of detailed surface information in regard to restorations may be critical to the strength of the comparison. This is especially true in regard to molars due to their tendency to be frequently restored. Again, as the number of teeth available for observation grows, even generic codes regarding restoration locations can be very discriminating and provide frequencies that are nearly equal to the detailed format in their overall rarity.

Detailed versus Generic Restoration Designations

This research has shown that detailed documentation of surface location for restorations does not significantly add to the discriminating power of an antemortem-postmortem comparison when sufficient dental remains are present. Patterns formed by consideration of only generic designations (i.e. filled) are nearly as individualistic as those formed by detailed criteria (i.e. mesial, distal, occlusal, facial, and/or lingual). With a complete set of dentition and several characteristics (i.e. missing or filled teeth), dental patterns are formed that are very infrequently encountered in the population.

As the degree of detail provided within antemortem dental records is variable, this discovery will greatly facilitate many dental comparisons. For example, it is common to encounter antemortem dental records from soldiers during WWII or the Korean War that only list a tooth as "filled" and do not provide specific surface information. While in the past this level of detail may have been considered to lack sufficient information to be used in an identification, the overall pattern can now be assessed in comparison to the reference datasets to quantify the strength of a match and provide an objective manner of interpretation.

In their study of the selectivity of dental records from a large sample of military individuals, Friedman et al. state that they consider detailed surface information for the location of fillings during the sorting because "…earlier studies have showed that the only dental characteristics that significantly affected computer sorted matches lists were restored surfaces, missing, or unrestored teeth…" (1989:1359). While it is unlikely that Friedman and colleagues tested this statement by performing the same experiment with generic codes for fillings, the results of this dissertation indicate that the use of generic restoration codes does not, in fact, hinder the identification process. Quite the contrary, very little discriminating power is lost by simplifying the codes and it is hypothesized that generic codes may greatly assist investigators during the identification of individuals from a mass disaster. An obvious challenge for odontologists working on a mass disaster is to compile all of the antemortem data and postmortem data into a format that facilitates comparison. Often the data is transcribed to a computer program (e.g. CAPMI or WinID) and sorts are performed mechanically to provide best-match scenarios. It is essential that all the antemortem and postmortem data are accurately transcribed (Bell 2001). Based on this initial records sort, the odontologists can take a more detailed look at the overall correspondence between the antemortem records and dental remains to determine if an identification is warranted. As the documentation of surface locations for restorations can be ambiguous, subjective, and time-consuming, these types of initial sorts may best be handled with only generic codes.

A study performed in Sweden (Rasmusson and Borrman 1992) tested the charting ability of 12 fourth year dental students using five macerated maxillae and five macerated mandibles without the aid of radiographs. They found that the most common error was the incorrect registration of restorations (n=87), followed by confusion between the identification of molars and premolars (n=50). Many of the errors regarding restorations stemmed from confusion about the extension of a filling from the occlusal surface onto either a facial or lingual surface (Rasmusson and Borrman 1992).

Antemortem records can be quickly converted into a generic format since it is usually clear whether a tooth has been filled or not, the difficulty may concern the specific location of the restoration on the tooth. Furthermore, a postmortem examination can be rapidly completed by stating simply whether a tooth is unrestored, filled, missing, or missing/replaced with a prosthesis. As long as the antemortem dental records are accurate, the dental patterns created by simply using the generic codes should be sufficient to easily differentiate several hundred adults and correlate to a specific individual. The benefit of this recommendation is that initial comparisons can be performed rapidly, after which the odontologist will be able to take a more detailed look at all of the available evidence. Overall, the research conducted as part of this dissertation revealed that very little power is gained by using the surface codes for recording the location of fillings unless postmortem loss or fragmentation is extensive.

Conclusions

An arbitrary number of dental points of concordance may be uninformative and misleading to the identification process. This research has demonstrated that the best method for assessing the diversity of dental patterns formed by missing, filled, and unrestored teeth is through frequency information derived from empirical comparison with representative databases. It has been shown in the previous chapter that diversity values are high and random match probabilities are low for dental patterns. The values were found to be comparable to those presented for mtDNA, indicating that dental patterns can be as informative as mtDNA sequences for identification purposes.

It is important to consider not only the missing and restored teeth during a dental comparison, but also the unrestored dentition. The overall patterns created by the tooth conditions may provide strong evidence that can be used to establish an identification. The preceding examples clearly show that the empirical comparison technique outlined in this dissertation provides the best method of quantifying antemortem-postmortem dental comparisons. Arbitrary and subjective criteria are removed from the process and easily intelligible statistics can be calculated in order to assess the overall strength of a match. Furthermore, this technique is much more amenable to situations in which postmortem loss is extensive. These examples have also shown that detailed surface information is not necessary for restorations when ample teeth are present for observation. The opposite will usually be true if the number of teeth is small.

Forensic odontologists should not be concerned with a specified number of points of concordance when considering dental evidence. When comparing non-radiographic lines of evidence, the dental pattern created by several teeth may be sufficient to provide a conclusive link to a missing individual. This pattern does not need to be based on unusual characteristics, since the combination of several common conditions may produce a pattern that is very rare in the overall population. Empirical comparison utilizing reference data as described in this research provides the best method of quantifying the strength of a dental match, removing the need for arbitrary standards relating to a specified number of concordant points.

CHAPTER 13: VARIABILITY OF SPECIFIC DENTAL PATTERNS

Introduction

The previous chapter has adequately shown that a strong correlation to a missing individual can be established based on the combinations of missing, filled, and unrestored teeth. Whether a full complement of teeth is present or there has been extensive postmortem loss, observed dental patterns from the case examples were shown to be relatively infrequent in the overall population. This quantitative information can then be used to attach a degree of certainty to the match (the likelihood that two individuals would share the same dental pattern). The five examples presented in the preceding chapter show that these cases were relatively unique in the datasets that they were compared to, but another question arises as to the overall variability of specific dental patterns within the datasets compiled for this study.

While it has been established that the overall diversity observed in the datasets is high, it was of interest to take a closer look at the frequency that specific patterns occur. Primarily, are there numerous patterns that are commonly encountered, or are most individuals that comprise the datasets relatively unique in their overall dental patterns? Furthermore, it is necessary to observe whether there a significant difference between the frequency of occurrence between the generic and detailed formats of the data. For this part of the analysis, all dental records were considered, including individuals with perfect teeth and edentulous individuals.

Variability of Dental Patterns Considering 28 Teeth

In order to observe the dental patterns created by the 28 teeth in each of the datasets compiled for this study, the 20 most frequently observed dental patterns are presented in Tables 52-59 along with their frequency of occurrence. Results are provided for each of the four datasets (WWII-Korea, Southeast Asia, Modern Military, and Modern Civilian) in both their detailed and generic formats. Decayed teeth were considered to be unrestored for this phase of the research due to the fact that the criteria used for identifying active decay (e.g. size of a lesion) is subjective and may vary between observers. Furthermore, it is possible that the deterioration of the tooth occurred post-examination and would not be documented on a dental chart.

From the following tables it is clear that most dental patterns are very uncommon in all datasets, regardless of whether the detailed or generic format is considered. With the exception of those individuals who have no fillings or extractions (i.e. "perfect teeth") the specific pattern frequencies of occurrence quickly fall below 1% of the sample. Most patterns are found to be unique or only very infrequently observed. While it should not be surprising that individuals with "perfect teeth" present an identification challenge, the preceding tables clearly show that there are not common dental patterns observed in the population and most individuals will possess a combination of dental characteristics that is relatively individualistic when at least one dental characteristic is present. Even when "perfect teeth" are observed, this still allows for the exclusion of a significant number of the population.

Table 52. The 20 Most Frequent Dental Patterns from the Detailed WWII-Korea Data.

Detailed WWII-Korea with 28 Teeth N=7,920				
Dental Pattern (Universal Charting excluding 3rd molars)			Number	Percent
RIGHT	V V V V V V V V V V V V V V V V V V V V V V V V V V V V	*LEFT*	1355	17.109
	V V V V V V V V V V V V V V V X V V V V V V V V V V X V		125	1.578
	V V V V V V V V V V V V V V V V V V V V V V V V V V X V		105	1.326
	V V V V V V V V V V V V V V V X V V V V V V V V V V V V		99	1.250
	XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP		64	0.808
	V X V V V V V V V V V V V V V V V V V V V V V V V V V V		40	0.505
	V V V V V V V V V V V V X V V V V V V V V V V V V V V V		38	0.480
	V V V V V V V V V V V V V V V V V V V V V V V V V V V X		37	0.467
	V V V V V V V V V V V V V V X V V V V V V V V V V V V V		34	0.429
	V X V V V V V V V V V V V V V V V V V V V V V V V V X V		25	0.316
	V V V V V V V V V V V V X V V X V V V V V V V V V V V V		21	0.265
	V V V V V V V V V V V X V V V V V V V V V V V V V V V V		21	0.265
	V V V V V V V V V V V V V V X V V V V V V V V V V V V X		17	0.215
	V X V V V V V V V V V V X V V X V V V V V V V V V V X V		17	0.215
	V V V V V V V V V V V V V V X X V V V V V V V V V V X X		16	0.202
	V V X V V V V V V V V V V V V V V V V V V V V V V V V V		16	0.202
	V V V V V V V V V V V V X V V X V V V V V V V V V V X V		15	0.189
	V X V V V V V V V V V V V V V X V V V V V V V V V V X V		15	0.189
	V V V V V V V V V V V V V X V V V V V V V V V V V V V V		14	0.177
	X V V V V V V V V V V V V V V V V V V V V V V V V V V V		14	0.177
Unique Dental Patterns			5,030	63.51

Table 53. The 20 Most Frequent Dental Patterns from the Generic WWII-Korea Data.

Generic WWII-Korea with 28 Teeth N=9,102				
	Dental Pattern (Universal Charting excluding 3rd molars)		Number	Percent
RIGHT	V V V V V V V V V V V V V V V V V V V V V V V V V V V V	*LEFT*	1,371	15.063
	V V V V V V V V V V V V V V V X V V V V V V V V V V X V		127	1.395
	V V V V V V V V V V V V V V V V V V V V V V V V V V X V		107	1.176
	V V V V V V V V V V V V V V V X V V V V V V V V V V V V		99	1.088
	XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP		64	0.703
	V X V V V V V V V V V V V V V V V V V V V V V V V V V V		40	0.439
	V V V V V V V V V V V V V V V V V V V V V V V V V V V X		38	0.417
	V V V V V V V V V V V V X V V V V V V V V V V V V V V V		38	0.417
	R R V V V V V V V V V V R R R R V V V V V V V V V V R R		37	0.407
	V V V V V V V V V V V V V V X V V V V V V V V V V V V V		35	0.385
	V X V V V V V V V V V V V V V V V V V V V V V V V V X V		26	0.286
	V V V V V V V V V V V V V V R V V V V V V V V V V V V V		25	0.275
	V V V V V V V V V V V V V V V V V V V V V V V V V V R V		21	0.231
	V V V V V V V V V V V V V V V R V V V V V V V V V V V V		21	0.231
	V V V V V V V V V V V V X V V X V V V V V V V V V V V V		21	0.231
	V V V V V V V V V V V X V V V V V V V V V V V V V V V V		21	0.231
	V V V V V V V V V V V V V V V V V V V V V V V V V V V R		18	0.198
	V V V V V V V V V V V V V V V R V V V V V V V V V V R V		18	0.198
	V V V V V V V V V V V V V V X V V V V V V V V V V V V X		17	0.187
	V V V V V V V V V V V V X V V X V V V V V V V V V V X V		17	0.187
Unique Dental Patterns			5,621	61.76

Table 54. The Only 14 Repeated Dental Patterns from the Detailed Southeast Asia Data.

Detailed Southeast Asia with 28 Teeth N=1,852				
Dental Pattern (Universal Charting excluding 3rd molars)			Number	Percent
RIGHT	V V V V V V V V V V V V V V V V V V V V V V V V V V V V	***LEFT***	36	1.944
	X X X X X X X X X X X X X X X X X X X X X X X X X X X X		15	0.810
	O O V V V V V V V V V V O O O O V V V V V V V V V V O O		4	0.216
	V O V V V V V V V V V V O O O O V V V V V V V V V V O O		4	0.216
	V O V V V V V V V V V V O V V V V V V V V V V V V V V V		3	0.162
	V V V V V V V V V V V V V V V V V V V V V V V V V V V X		3	0.162
	O O V V V V V V V V V V O O V O V V V V V V V V V V O O		2	0.108
	V O V V V V V V V V V V O O O O V V V V V V V V V V OF O		2	0.108
	V O V V V V V V V V V V O V O O V V V V V V V V V V O O		2	0.108
	V OL V V V V V V V V V V O V V O V V V V V V V V V V O V		2	0.108
	V V V V V V V V V V V V MO V V V V V V V V V V V V V V V		2	0.108
	V V V V V V V V V V V V V V O O V V V V V V V V V V V O		2	0.108
	V V V V V V V V V V V V V V V F V V V V V V V V V V F V		2	0.108
	V V V V V V V V V V V V X V V V V V V V V V V V V V V V		2	0.108
Unique Dental Patterns			1,771	95.63

Table 55. The 20 Most Frequent Dental Patterns from the Generic Southeast Asia Data.

Generic Southeast Asia with 28 Teeth N=1,854				
	Dental Pattern (Universal Charting excluding 3rd molars)		Number	Percent
RIGHT	R R V V V V V V V V V V R R R R V V V V V V V V V V R R	***LEFT***	37	1.996
	V V V V V V V V V V V V V V V V V V V V V V V V V V V V		36	1.942
	R R R R V V V V V V R R R R R R R V V V V V V V V R R R		17	0.917
	X X X X X X X X X X X X X X X X X X X X X X X X X X X X		15	0.809
	V R V V V V V V V V V V R R R R V V V V V V V V V V R R		9	0.485
	R R R R R R R R R R R R R R R R R R V V V V V V R R R R		7	0.378
	R R R V V V V V V V V V R R R R V V V V V V V V V V R R		7	0.378
	R R V V V V V V V V V R R R R R V V V V V V V V V V R R		7	0.378
	R R V V V V V V V V V V R R R R R V V V V V V V V V R R		7	0.378
	R R V V V V V V V V V V R R V R V V V V V V V V V V R R		7	0.378
	V R V V V V V V V V V V R V R R V V V V V V V V V V R R		7	0.378
	R R R V V V V V V V V R R R R R R V V V V V V V V R R R		6	0.324
	R R R R R V V V V R R R R R R R R R V V V V V V V R R R		5	0.270
	R R R R V R R R R R R R R R R R R R V V V V V V R R R R		5	0.270
	R R R R V V V V V V R R R R R R V V V V V V V V V V R R		5	0.270
	R R V V V V V V V V V V R V R R V V V V V V V V V V R R		5	0.270
	R R R R R R R R R R R R R R R R R R V V V V V V V R R R		4	0.216
	R R R R V V V V V V R V R R R R R V V V V V V V V R R R		4	0.216
	R R R V V V V V V V R R R R R R R V V V V V V V V R R R		4	0.216
	R R V V V V V V V V R R R R R R V V V V V V V V V V R R		4	0.216
Unique Dental Patterns			1,457	78.59

Table 56. The 20 Most Frequent Dental Patterns from the Detailed Modern Military Data.

Detailed Modern Military with 28 Teeth N=19,422				
	Dental Pattern (Universal Charting excluding 3rd molars)		Number	Percent
RIGHT	V V V V V V V V V V V V V V V V V V V V V V V V V V V V	*LEFT*	2,397	12.342
	V O V V V V V V V V V V V V V V V V V V V V V V V V V V		95	0.489
	V V V X V V V V V V X V V V V V V X V V V V V V X V V V		90	0.463
	V V V V V V V V V V V V V V V O V V V V V V V V V V V V		86	0.443
	V V V V V V V V V V V V O V V V V V V V V V V V V V V V		68	0.350
	V V V V V V V V V V V V V V V V V V V V V V V V V V O V		62	0.319
	V O V V V V V V V V V V O V V O V V V V V V V V V V O V		52	0.268
	V O V V V V V V V V V V O V V V V V V V V V V V V V V V		52	0.268
	V V V V V V V V V V V V V V V V V V V V V V V V V V V O		49	0.252
	V V V V V V V V V V V V V V V F V V V V V V V V V V F V		44	0.227
	V V V V V V V V V V V V V V V O V V V V V V V V V V O V		41	0.211
	O V V V V V V V V V V V V V V V V V V V V V V V V V V V		40	0.206
	V V V V V V V V V V V V V V O V V V V V V V V V V V V V		40	0.206
	O O V V V V V V V V V V O O O O V V V V V V V V V V O O		39	0.201
	V V V V V V V V V V V V V V V F V V V V V V V V V V V V		33	0.170
	V OL V V V V V V V V V V V V V V V V V V V V V V V V V V		31	0.160
	V V V V V V V V V V V V V V O V V V V V V V V V V V V O		31	0.160
	V V V V V V V V V V V V V V V V V V V V V V V V V V F V		31	0.160
	V OL V V V V V V V V V V OL V V OF V V V V V V V V V V OF V		29	0.149
	V V V V V V V V V V V V V O V V V V V V V V V V V V V V		28	0.144
Unique Dental Patterns			13,631	70.18

Table 57. The 20 Most Frequent Dental Patterns from the Generic Modern Military Data.

Generic Modern Military with 28 Teeth N=19,422		
Dental Pattern (Universal Charting excluding 3rd molars) — *RIGHT* … *LEFT*	Number	Percent
V V V V V V V V V V V V V V V V V V V V V V V V V V V V	2,397	12.342
R R V V V V V V V V V V R R R R V V V V V V V V V V R R	581	2.991
V R V V V V V V V V V V R V V R V V V V V V V V V V R V	293	1.509
V V V V V V V V V V V V V V V R V V V V V V V V V V R V	173	0.891
V V V V V V V V V V V V V V V R V V V V V V V V V V V V	165	0.850
V R V V V V V V V V V V V V V V V V V V V V V V V V V V	161	0.829
V V V V V V V V V V V V V V V V V V V V V V V V V V R V	133	0.685
V R V V V V V V V V V V R V R R V V V V V V V V V V R R	126	0.649
V R V V V V V V V V V V R V V V V V V V V V V V V V V V	124	0.638
V V V V V V V V V V V V R V V V V V V V V V V V V V V V	119	0.613
R R V V V V V V V V V V R V R R V V V V V V V V V V R R	96	0.494
V R V V V V V V V V V V R R R R V V V V V V V V V V R R	93	0.479
V V V X V V V V V V X V V V V V V X V V V V V V X V V V	90	0.463
V V V V V V V V V V V V V V V V V V V V V V V V V V V R	79	0.407
V V V V V V V V V V V V V V R R V V V V V V V V V V R R	78	0.402
V R V V V V V V V V V V V V V R V V V V V V V V V V R V	77	0.396
V V V V V V V V V V V V R V V R V V V V V V V V V V R V	76	0.391
R R V V V V V V V V V V R R R R R V V V V V V V V V R R	75	0.386
V R V V V V V V V V V V R V V R V V V V V V V V V V R R	75	0.386
R R R V V V V V V V V V R R R R V V V V V V V V V V R R	67	0.345
Unique Dental Patterns	7,471	38.47

Table 58. The 20 Most Frequent Dental Patterns from the Detailed Modern Civilian Data.

Detailed Modern Civilian with 28 Teeth N=9,730				
	Dental Pattern (Universal Charting excluding 3^{rd} molars)		Number	Percent
RIGHT	V V V V V V V V V V V V V V V V V V V V V V V V V V V V	LEFT	1,325	13.618
RIGHT	XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP	LEFT	149	1.531
RIGHT	V V V V V V V V V V V V V V V V V V V V V V V V V V X V	LEFT	67	0.689
RIGHT	V V V V V V V V V V V V V V V X V V V V V V V V V V X V	LEFT	62	0.637
RIGHT	V V V V V V V V V V V V V V V X V V V V V V V V V V V V	LEFT	58	0.596
RIGHT	V V V V V V V V V V V V X V V V V V V V V V V V V V V V	LEFT	33	0.339
RIGHT	V V V V V V V V V V V V V V V V V V V V V V V V V V O V	LEFT	29	0.298
RIGHT	V V V V V V V V V V V V V V X V V V V V V V V V V V V V	LEFT	28	0.288
RIGHT	V V V V V V V V V V V V V V V V V V V V V V V V V V V X	LEFT	22	0.226
RIGHT	V OL V V V V V V V V V V OL V V OF V V V V V V V V V V OF V	LEFT	21	0.216
RIGHT	V X V V V V V V V V V V V V V V V V V V V V V V V V V V	LEFT	21	0.216
RIGHT	V V V V V V V V V V V V V V V O V V V V V V V V V V V V	LEFT	20	0.206
RIGHT	V X V V V V V V V V V V V V V V V V V V V V V V V V X V	LEFT	19	0.195
RIGHT	V O V V V V V V V V V V V V V V V V V V V V V V V V V V	LEFT	17	0.175
RIGHT	V V V X V V V V V V X V V V V V V X V V V V V V X V V V	LEFT	17	0.175
RIGHT	V V V V V V V V V V V V V V X V V V V V V V V V V V V X	LEFT	15	0.154
RIGHT	V O V V V V V V V V V V O V V O V V V V V V V V V V O V	LEFT	14	0.144
RIGHT	V O V V V V V V V V V V O V V V V V V V V V V V V V V V	LEFT	14	0.144
RIGHT	V X V V V V V V V V V V X V V V V V V V V V V V V V V V	LEFT	14	0.144
RIGHT	V V V V V V V V V V V V O V V V V V V V V V V V V V V V	LEFT	13	0.134
Unique Dental Patterns			6,873	70.64

Table 59. The 20 Most Frequent Dental Patterns from the Generic Modern Civilian Data.

Generic Modern Civilian with 28 Teeth N=9,730				
Dental Pattern (Universal Charting excluding 3rd molars)			Number	Percent
RIGHT	V V V V V V V V V V V V V V V V V V V V V V V V V V V V	***LEFT***	1,325	13.618
	R R V V V V V V V V V V R R R R V V V V V V V V V V R R		149	1.531
	XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP		149	1.531
	V R V V V V V V V V V V R V V R V V V V V V V V V V R V		93	0.956
	V V V V V V V V V V V V V V V V V V V V V V V V V V X V		67	0.689
	V V V V V V V V V V V V V V V X V V V V V V V V V V X V		62	0.637
	V V V V V V V V V V V V V V V V V V V V V V V V V V R V		58	0.596
	V V V V V V V V V V V V V V V R V V V V V V V V V V V V		58	0.596
	V V V V V V V V V V V V V V V X V V V V V V V V V V V V		58	0.596
	V V V V V V V V V V V V V V V R V V V V V V V V V V R V		55	0.565
	V R V V V V V V V V V V R V R R V V V V V V V V V V R R		44	0.452
	V R V V V V V V V V V V V V V V V V V V V V V V V V V V		37	0.380
	V V V V V V V V V V V V X V V V V V V V V V V V V V V V		33	0.339
	V V V V V V V V V V V V V V R R V V V V V V V V V V R R		29	0.298
	V R V V V V V V V V V V R V V V V V V V V V V V V V V V		28	0.288
	V V V V V V V V V V V V V V X V V V V V V V V V V V V V		28	0.288
	V V V V V V V V V V V V R V V V V V V V V V V V V V V V		26	0.267
	R R V V V V V V V V V V R V R R V V V V V V V V V V R R		24	0.247
	R R V X V V V V V V X V R R R R V X V V V V V V X V R R		24	0.247
	R R R V V V V V V V V V R R R R V V V V V V V V V V R R		23	0.236
Unique Dental Patterns			5,210	53.55

Only a few other studies have researched the dental patterns of a large sample of individuals for the purpose of establishing identifications (e.g. Friedman, et al. 1989, Lorton and Langley 1986b). Lorton and Langley (1986b) used a database of 578 soldiers between the ages of 17 and 28 years in order to observe the selectivity of dental characteristics. This study was interested in the ability of a computer matching program (CAPMI) to correctly select a target individual from a database of "missing" individuals. While the goals of their research differ from that presented in this dissertation (selection of a specific individual versus general frequency information), some parallels are present. They found that when an individual possesses four or more characteristics (fillings or missing teeth) that the individual can be separated from the entire group of 578 soldiers. Furthermore, they tested the effect of errors in charting and found that even with error rates of 10 to 40%, the CAPMI system was still able to correctly select the proper individual in most instances. They found that, "If an unknown record had five or more dental characteristics, the chances of finding it in the top 5% of the sorted file were virtually 100% even with error rates up to 30% in the database" (Lorton and Langley 1986b:977). Similar to the results of this dissertation, Lorton and Langley found that certain combinations of teeth composed of only common restorations "…provide amazingly selective identification points" (1986b:976). Also, they found that individuals with no missing or filled teeth complicate identification issues, but when only individuals with at least one dental characteristic are considered, the diversity is vastly improved. The research by Lorton and Langley supports the contention that dental characteristics provide a diverse set of information valuable to the identification process, and that even when errors are present in the antemortem records, the variability contained within the accurately documented teeth will still be sufficient to match a specific individual.

Friedman and colleagues (1989) collected dental data on 7,030 soldiers between the ages of 17 and 49 (mean 24.4 years; 60% between 18 and 25 years) during the 1980s. They used the CAPMI program for their study in order to test the utility of dental patterns for selecting a missing individual from a dataset. They state that the number and complexity of dental restorations have decreased for younger Americans and the purpose of their study was to determine if an improvement in dental health was a hindrance to forensic identification. It is important to realize that Friedman, et. al were concerned with the selection of a specific missing individual from a database, as opposed to the research presented in this dissertation that is concerned with calculating frequency information after a match to a specific individual has been established.

The dental characteristics were recorded for each tooth, but only in regard to restored and missing teeth. Active decay was considered to be of questionable utility for sorting purposes and was not documented separately (i.e. a tooth with active decay would be considered only as unrestored). In reference to the CAPMI program, Friedman and colleagues state that "The system does not use decayed surfaces as sorting factors, as these are often subject to clinical and radiographic judgment calls, and have been shown in earlier studies to confound the matching process" (1989:1358). Detailed surface codes were used for recording the locations of restorations.

Friedman et al. found that the average subject had seven dental characteristics (MF=7), 75% had four or more, 9% had a full complement of unrestored teeth (including third molars), 3.6% had only one characteristic. Comparison with a sample of 17-49 year old individuals from the Modern Military dataset including third molars (n=19,381) showed that the average MF score was 10.53 (std dev=6.08) and only 1.90% had an MF score of zero. This variation may be due to differences within the age composition between the two samples (i.e. one sample may be more heavily weighted towards younger individuals).

Friedman et al. tested the uniqueness of various combinations of dental characteristics (considering 32 teeth) by running 363 simulations in the CAPMI computer program against the population of 7,030 records. Sample records (33 individuals per group) were randomly drawn from the population dataset based on their varying numbers of characteristics (eleven groupings were considered: 2, 3, 4, 5, 6, 7, 8, 9-11, 12-14, 15-18, and 19+ characteristics). The randomly selected individuals from each group were then compared against the 7,030 records. In this manner the 7,030 served as the antemortem records and the 33 randomly selected records served as the postmortem. They found that the variety of dental restorations was such that even the more common restorative situations (2, 3, or 4 characteristics) yielded only two to four identical records and 80% of all comparisons made with two or more characteristics gave a unique correct answer (Table 60). Of the remaining records, 13% matched three or fewer records. They state (Friedman, et al. 1989:1357) "…although dental restorations are diminishing in frequency in the younger population they still provide a high degree of selectivity for forensic science purposes."

Table 60. Results Presented by Friedman et al. (1989).

Sorting selectivity of 7,030 soldiers	
Number of characteristics per record	Percent of Unique Records
2	73
3	79
4	67*
5	73
6	88
7	91
8	91
9-11	90
12-14	100
15-18	100

*This value is less than others due in part to an individual missing only 3rd molars who matched 62 other records.

Variability of Dental Patterns with Postmortem Loss

While it is clear that a full complement of 28 or 32 teeth will generally produce a distinctive dental pattern, the effect of postmortem loss is worth consideration. In order to address this important issue, the Modern Military and Modern Civilian datasets were utilized. Only the first and second molars and premolars were considered (16 teeth total) since these teeth are most commonly recovered due to their root structure, and they are most commonly affected by decay. The 20 most frequently observed dental patterns created by consideration of only the molars and premolars from both the Detailed and Generic formats are presented in Tables 61-64.

Table 61. The 20 Most Frequent Dental Patterns from the Detailed Modern Military Data with only Molars and Premolars.

Detailed Modern Military with ONLY MOLARS and PREMOLARS N=19,422				
Dental Pattern (Universal Charting of posterior teeth)			Number	Percent
RIGHT	V V V V V V V V V V V V V V V V	LEFT	2,633	13.557
	V O V V V V V V V V V V V V V V		107	0.551
	V V V V V V V V V O V V V V V V		100	0.515
	V V V X X V V V V V V X X V V V		96	0.494
	V V V V V V O V V V V V V V V V		80	0.412
	V V V V V V V V V V V V V V O V		70	0.360
	V O V V V V O V V O V V V V O V		63	0.324
	V O V V V V O V V V V V V V V V		62	0.319
	V V V V V V V V V V V V V V V O		54	0.278
	V V V V V V V V O V V V V V V V		51	0.263
	O O V V V V O O O O V V V V O O		50	0.257
	V V V V V V V V V F V V V V F V		48	0.247
	O V V V V V V V V V V V V V V V		47	0.242
	V V V V V V V V V O V V V V O V		43	0.221
	V V V V V V V V V F V V V V V V		39	0.201
	V V V V V V V V O V V V V V V O		35	0.180
	V OL V V V V V V V V V V V V V V		34	0.175
	V V V V V V V O V V V V V V V V		34	0.175
	V V V V V V V V V V V V V V F V		33	0.170
	V OL V V V V OL V V OF V V V V OF V		30	0.154
Unique Dental Patterns			12,928	66.56

Table 62. The 20 Most Frequent Dental Patterns from the Generic Modern Military Data with only Molars and Premolars.

Generic Modern Military with ONLY MOLARS and PREMOLARS N=19,422				
Dental Pattern (Universal Charting of posterior teeth)			Number	Percent
RIGHT	V V V V V V V V V V V V V V V V	***LEFT***	2,633	13.557
	R R V V V V R R R R V V V V R R		761	3.918
	V R V V V V R V V R V V V V R V		348	1.792
	V V V V V V V V V R V V V V R V		191	0.983
	V V V V V V V V V R V V V V V V		189	0.973
	V R V V V V V V V V V V V V V V		180	0.927
	R R R R R R R R R R R R R R R R		153	0.788
	V V V V V V V V V V V V V V R V		149	0.767
	V R V V V V R V R R V V V V R R		146	0.752
	V R V V V V R V V V V V V V V V		140	0.721
	R R R R R R R R R R R V V R R R		136	0.700
	V V V V V V R V V V V V V V V V		135	0.695
	R R V V V V R V R R V V V V R R		121	0.623
	V R V V V V R R R R V V V V R R		118	0.608
	R R V V V V R R R R R V V V R R		109	0.561
	R R V V V V R R R R V V V R R R		97	0.499
	V V V X X V V V V V V X X V V V		96	0.494
	V R V V V V R V V R V V V V R R		90	0.463
	V V V V V V V V R R V V V V R R		90	0.463
	R R V X X V R R R R V X X V R R		87	0.448
Unique Dental Patterns			4,806	24.75

Table 63. The 20 Most Frequent Dental Patterns from the Detailed Modern Civilian Data with only Molars and Premolars.

Detailed Modern Civilian with ONLY MOLARS and PREMOLARS N=9,730				
	Dental Pattern (Universal Charting of posterior teeth)		Number	Percent
RIGHT	V V V V V V V V V V V V V V V V	LEFT	1,425	14.645
	XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP		170	1.747
	V V V V V V V V V V V V V V X V		80	0.822
	V V V V V V V V V X V V V V X V		76	0.781
	V V V V V V V V V X V V V V V V		64	0.658
	V V V V V V X V V V V V V V V V		38	0.391
	V V V V V V V V V V V V V V O V		29	0.298
	V V V V V V V V X V V V V V V V		29	0.298
	V V V V V V V V V V V V V V V X		29	0.298
	V X V V V V V V V V V V V V V V		22	0.226
	V OL V V V V OL V V OF V V V V OF V		21	0.216
	V X V V V V V V V V V V V V X V		21	0.216
	V V V V V V V V V O V V V V V V		20	0.206
	V V V V V V V V X X V V V V X V		19	0.195
	V O V V V V V V V V V V V V V V		18	0.185
	V V V X X V V V V V V X X V V V		17	0.175
	V V V V V V O V V V V V V V V V		16	0.164
	V V V V V V V V X V V V V V V X		16	0.164
	V O V V V V O V V O V V V V O V		15	0.154
	V O V V V V O V V V V V V V V V		15	0.154
Unique Dental Patterns			6,533	67.14

Table 64. The 20 Most Frequent Dental Patterns from the Generic Modern Civilian Data with only Molars and Premolars.

20 Most Frequent Dental Patterns (in order of occurrence) **Generic Modern Civilian with ONLY MOLARS and PREMOLARS** N=9,730				
Dental Pattern (Universal Charting of posterior teeth)			Number	Percent
RIGHT	V V V V V V V V V V V V V V V V	***LEFT***	1,425	14.645
	R R V V V V R R R R V V V V R R		182	1.871
	XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP XP		170	1.747
	V R V V V V R V V R V V V V R V		98	1.007
	V V V V V V V V V V V V V V X V		80	0.822
	V V V V V V V V V X V V V V X V		76	0.781
	R R R R R R R R R R R R R R R R		69	0.709
	V V V V V V V V V X V V V V V V		64	0.658
	V V V V V V V V V R V V V V V V		61	0.627
	V V V V V V V V V V V V V V R V		60	0.617
	R R R R R R R R R R R V V R R R		58	0.596
	V V V V V V V V V R V V V V R V		57	0.586
	V R V V V V R V R R V V V V R R		52	0.534
	V R V V V V V V V V V V V V V V		42	0.432
	V V V V V V X V V V V V V V V V		38	0.391
	V V V V V V V V R R V V V V R R		35	0.360
	R R R R R R R R R R R R V R R R		32	0.329
	V R V V V V R V V V V V V V V V		32	0.329
	R R R V V V R R R R V V V V R R		30	0.308
	R R V X X V R R R R V X X V R R		30	0.308
Unique Dental Patterns			4,181	42.97

The results presented in Tables 61-64 reveal that there is no real difference between the frequency of occurrence of the patterns formed with a full complement of teeth or the patterns formed by only the posterior teeth. Those individuals with no fillings or extractions are still the most prevalent, but the frequency rapidly drops to below 1%, with most individuals possessing patterns that are unique or only very infrequently observed. This similar frequency trend is graphically depicted in Figure 16. In this plot it can be seen that there is almost no difference between the pattern frequency considering complete sets of teeth or only the posterior teeth. Furthermore, the generic format of the data provides pattern frequencies that are nearly identical to the detailed format.

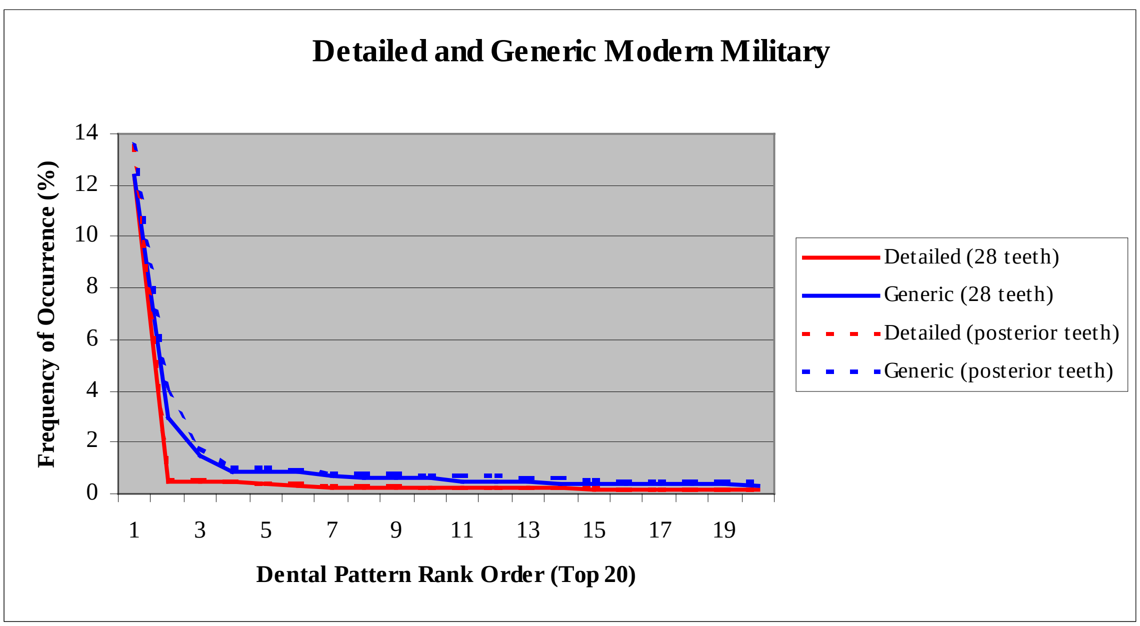


Figure 16. Rank order plot of the 20 most frequently observed dental patterns in the Modern Military data.

Two important facts have been elucidated from this analysis: 1) individualistic dental patterns can be produced with either complete or partially represented dental remains, and 2) in many instances the detailed surface codes for restorations are irrelevant for comparative purposes. The discovery that postmortem loss does not necessarily have a prohibitive effect on the identification process has an obvious benefit to forensic investigations. The fact that detailed documentation of restorations does not necessarily increase the uniqueness of dental patterns is encouraging for instances in which the antemortem data are limited. This should not necessarily be interpreted as though surface codes should never be utilized, but use of a generic system is likely to reduce subjectivity and decrease error rates. Overall, repetition of specific dental patterns was found to occur very infrequently in the datasets, regardless of the data format, and demonstrates that this line of evidence provides an excellent means of identification when the observed patterns are compared to the reference data.

CHAPTER 14: SUMMARY AND CONCLUSIONS

This dissertation has primarily addressed the topic of forensic dental identification, although a limited discussion of dental health was included. The comparison of antemortem and postmortem dental characteristics is a commonly employed technique to establish personal identification in the forensic sciences. The key pieces of evidence needed for a dental comparison are twofold, the presence of dental remains and accurate antemortem dental records. With the proper evidence, forensic odontologists can make dental identifications very rapidly and with a high degree of certainty due to the inherent variability within the human dentition. Typical antemortem dental records may include radiographs, dental charts (odontograms), both intra and/or extraoral photographs, dental casts, and notes. Certainly dental radiographs are the most desirable piece of antemortem evidence, but unfortunately, they are not always available and the comparison of antemortem and postmortem characteristics must be based on handwritten charts and notes. This dissertation is specifically concerned with non-radiographic dental comparison. Specifically, this research has explored the variability of post-developmental characteristics in the human dentition (combinations of missing, filled, and unrestored teeth) as noted and charted in non-radiographic formats. Although not repeatedly stated throughout this dissertation, the reader should realize that this research acknowledges the power of radiographic comparison, an area that does not need to be tested. The research presented in this dissertation concerns non-radiographic dental evidence and its utility in establishing personal identifications.

Few, if any, forensic odontologists would question the validity of radiographic congruence between antemortem and postmortem evidence, but less certainty is associated in situations when only dental charts or notes are available. In some instances, such as a plane crash, passengers may be from various countries. As dental records are collected for comparison, it may be possible to receive the dental charts and notes very rapidly (for example by fax), while the radiographs, if they exist, may take more time to arrive. While most contemporary dental records, civilian and military, are likely to include radiographs, investigations into individuals missing for many decades (e.g. WWII or the Korean War) may only have written documentation available.

The number of points of concordance needed to establish an identification has always been a topic of concern to forensic odontologists. The actual criteria for determining “unquestionable points of similarity” are not defined and this lack of standardization has been a concern of many forensic odontologists. Along this line, the determination that an observed dental pattern is either common or rare in the population has been a subjective judgment call of the odontologist based on their education, clinical experience, and forensic caseload. In order to remove the subjectivity of these determinations and quantify the variability of dental patterns, four datasets were compiled for this dissertation consisting of temporally and demographically distinct populations. Three of the four datasets were composed of dental records from U.S. military personnel, while the fourth dataset was composed of civilian dental records. The military samples were divided by time period and correspond to WWII-Korean War, the Southeast Asia Conflict, and a contemporary sample from 1994-2000. The civilian dataset is composed of a contemporary population from1988-1994. Large sample sizes for all the datasets ensured that the results were statistically valid and representative of the population as a whole.

In order for antemortem data to be useful for forensic purposes, accuracy is essential in regard to therapeutic dental treatment. Incomplete or inaccurate records will not assist in the identification process and could actually hinder the effort. In reference to written dental records and odontograms, Wyckoff states that "…it is not mandatory that the two records match perfectly in order to establish positive identification. It is mandatory, however, that there be unquestionable points of similarity between the two records with no existing impossibilities…" (1957:503-504). The accuracy of these data obviously has a profound impact on the identification potential of missing individuals and it was necessary to perform a test to determine if non-radiographic evidence is generally of a suitable caliber for this purpose. Specifically, the accuracy of military dental records from past U.S. conflicts was tested since these are often critical to the identification of U.S. servicemembers missing from past conflicts. The reliability of the two modern samples used in this dissertation was not tested since they were derived from detailed oral examinations as part of dental health studies and not patient records. For this reason the modern samples are considered to be very accurate. Two separate tests were performed to observe the overall accuracy of the military records representing the WWII-Korea sample and the Southeast Asia sample since these data are based strictly on dental charts derived from personnel files and are potentially subject to more error than the modern samples.

First, the Decayed, Missing, Filled Teeth (DMFT) index was used to compare the records of the missing U.S. service members from WWII-Korean War and those from the Southeast Asia Conflict with published results from temporally and demographically similar populations presented in the dental health literature. Although the DMFT index is used exclusively as a quantifier for dental health studies, it provides a method for comparing the dental health of two compatible populations. Distinct variation between the published DMFT scores (derived as part of a dental health study) and the DMFT scores calculated from the large samples of temporally compatible dental records (derived from missing soldiers) is likely indicative of incomplete/inaccurate treatment records within the soldiers' medical history. Similar results are interpreted as an indication that the charts accurately reflect the samples' dental status as a whole. The sample sizes of all the datasets used in this dissertation were sufficient to generate reliable DMFT scores that could, in turn, be statistically compared with temporally compatible studies that had been completed during actual oral examinations of military and civilian individuals.

It was initially suspected that the degree of agreement between DMFT scores derived from military dental charts and those derived from oral exams would improve over time as the importance of the data was understood for identification purposes. It was found that the records from the WWII-Korean War time frame had more variation than those from the Southeast Asia Conflict, but that neither was substantially different from the published results. This bias appears to be the result of induction records during WWII and the Korean War that did not fully document existing treatment and were primarily concerned with charting dental needs. As a result, there was a bias towards lower DMFT scores (i.e. better dental health) in the WWII-Korea dataset. This did not appear to be a problem with the Southeast Asia era records. It was found that, due to the large standard deviations associated with DMFT scores, there was seldom a statistically significant difference between the published results and those derived as part of this dissertation. This is interpreted as an indication that the WWII-Korean War records may be slightly biased due to the presence of incompletely documented conditions on induction records (an overabundance of individuals with DMFT=0), but that when dental information is present it is accurate.

A second test of the accuracy of the WWII-Korea and Southeast Asia dental records involved the comparison of a sample of identification cases from the CILTHAI and the CILHI. A sample of 64 cases was selected from WWII-Korean War era and 48 cases were selected from the Southeast Asia Conflict. The records selected for the study consisted of identification cases that were made at either CILTHAI or CILHI in which a postmortem analysis consisted of dental information for at least 10 teeth (missing antemortem, restored, or unrestored), and antemortem dental records were present for comparison. A ratio was established between the postmortem dental characteristics (the dental status of the individual at the time of death) and the most recent antemortem dental records. Overall correspondence between the antemortem and postmortem conditions was found to be good for both samples, but it was superior for the Southeast Asia era individuals. Again, the main problem noticed with the WWII-Korean War antemortem records was that often times the only available dental information was from induction records that contained only very minimal information, such as missing teeth or teeth with active decay. In some instances there was an apparent disregard for existing dental restorations. Although every case will have to be individually assessed, results indicate that sufficient data are typically present within the antemortem charts to be used in a comparison with the remains of an unidentified individual for personal identification. Although not specifically tested, it is hypothesized that modern civilian and military dental records will usually provide an accurate documentation of an individual's complete dental treatment.

While numerous researchers have pointed out that the possible number of combinations of dental characteristics in the human permanent dentition are astronomical, there has never been a large scale empirical test to determine if a small number of dental patterns are very common in the general population, or if an individual's combined dental characteristics are relatively unique. Statistically, there are billions of possible combinations of missing, filled, and unrestored teeth within the adult mouth. With this quantity of possibilities it would seem plausible that an individual's dental condition would be of sufficient uniqueness to be used for identification in a manner analogous to the variation observed with fingerprints or mtDNA. As the total number of possible dental combinations is theoretically accurate, many of these dental patterns are not realistic and it is inappropriate for forensic odontologists to cite these numbers as a justification for dental identification. Each of the 32 teeth in the adult dentition cannot be treated as independent of each other and at the same risk for loss or disease. Clearly not all dental patterns have the same chance of existing within the population, and the law of independence does not hold true for teeth. Dental morphology will dictate that molars, based on their large and complex surface area, will be more susceptible to decay than other teeth, such as canines or incisors. There are other factors such as the chronology of molar emergence, their ease of cleaning, and surface topography (such as pits and fissures) that make molars more susceptible to caries than the smooth surfaces on the anterior teeth. Furthermore, many of the statistically possible dental patterns are, in actuality, highly unlikely (e.g. an individual that has an alternating pattern of missing and filled teeth across their entire mouth).

The primary goal of this dissertation was to examine the overall utility of non-radiographic dental records for the establishment of individual identifications. In order to ascertain the true variability of the adult dentition within the U.S., an empirical look at a large sample of the population was determined to be the best way to quantify the diversity of dental patterns. It was found that while the number of theoretically possible dental patterns is an overestimate of the true diversity, individual variability of dental patterns was still found to exist to a degree that allows them to be an excellent source for forensic comparisons. Initially, the analogy between dental characteristics recorded on a chart and fingerprints or mtDNA might seem to be overstated since many people view these other types of evidence to be a superior form of identification, but the results presented by this dissertation would refute this claim. It was found that even without radiographic lines of comparison, charts and notes that accurately detail a missing individual's antemortem dental condition can be essential for establishing an identification and that individual dental patterns are generally unique, or at least very uncommon, within all samples tested. With this information, it is possible to establish a strong, quantifiable association with a missing individual.

In order to observe the variability of dental records based on their degree of detail regarding the documentation of restorations, the four datasets were converted into two formats, one with only *generic* codes for restorations (the tooth was coded simply as restored) and another with *detailed* surface information (i.e. mesial, occlusal, distal, facial, and/or lingual) for the specific location of restorations. A comparison was performed in which the *detailed* format of the dental records was judged against the *generic* form of the data. Although the use of the generic format greatly reduced the number of potential codes for each tooth from 34 to 4, it was found that very little power was lost and the dental patterns were still found to be relatively unique when ample numbers of teeth were available for comparison. In situations of extensive postmortem loss, the detailed format was found to be a much more valuable comparison tool.

The results of this dissertation indicate that a definitive number of points of concordance do not need to be established in dental identification cases. Each case must be assessed individually. The critical factor is to remove subjective judgment calls from comparisons of "common" or "extraordinary" dental characteristics. This research has proposed a new method of empirical comparison that allows forensic odontologists to derive objective frequency information regarding the occurrence of dental patterns in the general population. The method is similar to that used for mtDNA testing. It was found that a few common dental characteristics may produce a very rare dental pattern, a point that may be counterintuitive to many forensic odontologists. Recognition of the uniqueness of dental patterns will be essential for personal identification in many instances and will be easily defensible in a court of law.

The results may be surprising in that, although teeth cannot be viewed independently of each other, the overall variation observed is still at a level that makes most individuals' combined dental pattern unique or relatively unusual. In fact, the uniqueness of the dental patterns was found to be comparable to the rates reported for mtDNA. Furthermore, dental comparisons can be performed much more rapidly and economically than with mtDNA sequences. While individuals with "perfect" teeth and edentulous individuals will always be a challenge to the identification process, it was found that when only a few characteristics were present in the mouth, very individualistic patterns were created. This dental frequency information, especially when considered along with other evidence (e.g. anthropology and provenience), will greatly enhance personal identification.

Future Direction

Developed as part of this dissertation, an interactive computer program (OdontoSearch) was designed by Cheryl Shigeta and Amanda Drogosch at the CILHI that enables a forensic odontologist to input an observed dental pattern from a case, select the appropriate reference population for comparison, and generate the frequency that a specific pattern is found. This allows the analyst to quantify the relative uniqueness of the observed pattern. This removes the subjective aspect of dental match significance and facilitates an accurate assessment of the likelihood of having two missing individuals with the same dental characteristics. Obviously this program is not to be used to select a specific missing individual in the fashion of WinID or CAPMI, but is a simple tool for assessing the commonality of an observed condition. Although the datasets used in this program are large, the addition of other large reference datasets would be useful and would only strengthen the technique.

No consideration of deciduous teeth was presented in this dissertation, but this may be worth exploring in some capacity. Certainly the rapid loss and development of teeth in a mixed dentition will be problematic.

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