J Forensic Sci, May 2003, Vol. 48, No. 3
Paper ID JFS2002226_483
Available online at: www.astm.org

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

ABSTRACT: The primary goal of this research is to examine the overall utility of nonradiographic dental records for the establishment of individual identifications. 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. Based on an analysis of two large datasets, individual dental patterns were determined to be generally unique, or at least very uncommon. Through this type of empirical comparison, it is possible to establish a strong, quantifiable association with a missing individual. The results of this research 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 dental comparisons. This research has proposed a new method of empirical comparison that allows forensic odontologists to derive objective frequency information regarding the occurrence of specific dental patterns in the general population. The method is similar to that used for mtDNA casework, and a computer program (OdontoSearch) has been developed to make the technique accessible. It was found that even a small number of common dental characteristics may produce a very rare dental pattern, a point that may be counterintuitive to many forensic odontologists.

KEYWORDS: forensic science, forensic odontology, diversity, dental patterns, empirical comparison, human identification, personal identification, concordance, NHANES III, TSCOHS, OdontoSearch

Teeth are the hardest structures of the human body and, as such, represent an ideal means of identification in situations of advanced decomposition, fire, or massive trauma (1). Studies at the University of Tennessee, Knoxville, have shown that soft tissue decay can be complete in as short as two weeks after death (2), making visual identification or fingerprint comparison impossible. Regardless of the condition of the body, it is very likely that the teeth will be preserved, and it is this line of evidence that oftentimes proves to be the most reliable comparative tool.

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 thorough dental comparison. Although other forms of dental graphics are sometimes used, 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.

Few, if any, forensic odontologists would question the validity of radiographic congruence between antemortem and postmortem evidence, but less certainty is associated with situations where only dental charts or notes are available from a missing individual's health record. 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 health status 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 results presented in this study are primarily applicable to situations in which antemortem radiographic evidence is not available.

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. Through an empirical analysis of large reference datasets, research has demonstrated the high diversity present in dental patterns (3). In fact, dental pattern diversity was shown to be comparable to the diversity seen in mitochondrial DNA sequences (3). The use of dental patterns was validated as an excellent means of personal identification. The goals of the present paper are to address the various techniques for interpreting antemortem/postmortem dental congruence, to explore the diversity of specific dental patterns, and to introduce a new computer program that can be used for dental identification based on patterns of missing, filled, and unrestored teeth.

Materials and Methods

Two modern datasets were used for this research, both of which were originally compiled as part of large-scale dental health studies. The first sample is comprised of a large number of adults from the U.S. civilian population. This dataset was originally compiled as part of the Third National Health and Nutrition Examination Survey (NHANES III). The NHANES III study is a multifaceted

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Received 29 June 2002; accepted 24 Nov. 2002; published 12 Mar. 2003.

health examination survey that was conducted between 1988 and 1994 in the United States to collect data on the civilian, noninstitutionalized population (4). As the NHANES III dataset contains dental information on a range of individuals from infants to the elderly, a subset of data was extracted in order to observe the diversity of adult dental patterns (this entire dataset is available to the general public for research purposes via a website at http://www.cdc. gov/nchs/about/major/nhanes/datalink.htm). A sample of 9730 individuals was selected that consisted of only individuals between the ages of 17 and 50 years. The demographic composition of this sample is presented in Table 1.

The second dataset is composed of a modern sample of 19 422 U.S. military personnel. The data were originally collected in 1994 and 2000 as part of two phases of the Tri-Service Comprehensive Oral Health Survey (TSCOHS). The raw data from this study were originally gathered by the Tri-Service Center for Oral Health Studies as part of an ongoing project to observe dental health throughout the active duty and recruit population of the U.S. military. The 1994 data are composed of detailed dental conditions of active duty and recruits from all branches of the service and from different military installations across the continental United States. The year 2000 phase of TSCOHS considered all branches of the military, but only in regard to recruits. The study design was created to be comparable to large-scale civilian dental health studies, such as NHANES III. The data were 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 TSCOHS data are listed in Table 2.

Coding Formats

All of the dental codes used in the NHANES III and TSCOHS studies were converted to a consistent set of codes for the purposes of the present research. In general, the coding systems that were originally used in the NHANES III and TSCOHS studies were much more extensive than was necessary for the goals of this study. In order to explore the effect of different coding strategies on the identification process, the data were converted into two formats: *detailed* and *generic.* The only difference between the two formats is the manner in which restorations were documented.

The *detailed* format provides specific surface information concerning the location of a restoration on any combination of the mesial, occlusal, distal, facial, or lingual tooth surfaces (M, O, D, F, L). Multiple restorations on a single surface (e.g., two distinct occlusal restorations on the maxillary right 1st molar) were assigned only a single code (in this case O). Furthermore, there is no differentiation between a single restoration that affects multiple surfaces or distinct restorations on different surfaces of the tooth. For example, in the database 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) the occlusal surface was not considered and only four surface codes were assigned (any combination of M,

TABLE 1—*Sample size and demographic composition of the detailed and generic NHANES III data.*

NHANES III Dataset ($N = 9730$)						
	White		Black		Other	
Age	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	2813	3231	1453	1847	196	190

TABLE 2—*Sample size and demographic composition of the detailed and generic TSCOHS data.*

TSCOHS Dataset ($N = 19\,422$)						
	White		Black		Other	
Age	Male	Female	Male	Female	Male	Female
17–19	2116	474	521	192	468	119
20–24	3652	673	980	281	642	123
25–29	2137	331	562	133	294	43
30–34	1736	171	416	85	218	18
35–39	1230	143	297	42	135	11
40–61	799	77	154	26	112	11
Total	11 670	1869	2930	759	1869	325

TABLE 3—*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	V	V

D, F, or L). As the NHANES III and TSCOHS studies did not provide codes for the occlusal surface of the anterior teeth, this format was unavoidable. Unique codes were not utilized for teeth with crowns. Posterior teeth with crowns were 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. Missing teeth were designated by an X, while missing teeth that were replaced by a prosthesis (denture or bridge) were designated as XP. Teeth with no decay or fillings (i.e., virgin teeth) were scored V. Teeth with only active caries were also coded as V. 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. Other researchers (5) have also recommended the exclusion of unrestored decay from consideration in forensic dental comparisons. 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.

In the *generic* (i.e., simplified) datasets all filled surfaces were condensed into a single code, R, and the surface information was ignored. Similarly, teeth with crowns were coded only 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 (Table 3).

Interpretation of Dental Pattern Congruence and the Issue of Concordance

Currently, in situations where individualistic antemortem evidence is not present (e.g., radiographs are lacking) it is often a challenge for forensic odontologists to assess the strength of a specific antemortem-postmortem dental match. Judgments of this type are most commonly based on the subjective opinion of the odontologist, usually derived from their clinical experience. As another alternative some authors have recommended that an arbitrary number of points of concordance should be utilized. Both of these techniques have serious deficiencies, and an improved method is needed that allows for the strength of a dental match to be appropriately quantified.

Historically, the number of points of concordance necessary to establish a positive identification has never been universally agreed upon within the field of forensic odontology (6–8). Stimson (6) states that, as a rule of thumb, eight points of concordance would be the minimum number, although Sognnaes and Keiser-Nielsen (9–11) prefer a dozen concordant features unless the material is extraordinarily characteristic. Although the American Board of Forensic Odontology provides guidelines for body identification (12), it does not provide a discussion behind the rationale for "positive identification," "possible identification," "insufficient evidence," or "exclusion." The current criteria relating to dental identification are vague and subjective, depending primarily on the experience and confidence of the odontologist.

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 nonradiographic 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 (Ref 13, p. 146).

Similarly, Gustafson (14) 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 characteristics without radiographic evidence.

Sognnaes (15,16) and Keiser-Nielsen (11) 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. This technique is based on a gradient system ranging from a possible identification to a certain identification. Many of Sognnaes' articles concern the dental identifications of Adolf Hitler, Eva Braun, and Martin Bormann (15–18). Using guidelines concerning the number of points of concordance needed for an identification, 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, Sognnaes and Keiser-Nielsen refer to the number of "ordinary" and "extraordinary" characteristics, and the assessment is weighted based on the perceived rarity of the treatment. For example, twelve ordinary characteristics or six extraordinary characteristics would be needed to fall into the category of a certain identification. Further breakdown of this strategy and its application in case examples is presented in numerous articles by Sognnaes and Keiser-Nielsen (10,11,15–17,19).

While the concordance guidelines proposed by Sognnaes and Keiser-Nielsen remove much of the subjectivity from the identification process, numerous drawbacks exist with their protocol. One obvious problem with these guidelines is that they are vague concerning what will be considered "extraordinary" versus "ordinary." Ordinary characteristics are loosely defined as routine fillings and extractions, while extraordinary characteristics include such treatment as elaborate crowns and bridges (15). Keiser-Nielsen (11) defines extraordinary characteristics as features that occur in less than 10% of all cases. Apparently no value is given to unrestored (virgin) teeth in this scheme, even though if commonly restored teeth that are found to be unaffected this may still provide important comparative evidence. As a result, this technique requires that a large number of teeth are available for observation, a luxury that is not always afforded to forensic investigations.

Another serious flaw with Sognnaes and Keiser-Nielsen's 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 twelve ordinary points of concordance to establish what is referred 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. Although this method provides an objective technique of quantifying the strength of an antemortem-postmortem match between records, there is still a need in the field of forensic odontology for an improved method of assessing dental pattern concordance.

In order to overcome the deficiencies present with arbitrary points of concordance and subjective judgment calls, it is recommended that a technique of empirical comparison to a large reference dataset should be utilized. Through this approach, an observed dental pattern can be compared to a reference dataset in order to determine its expected frequency in the population. This technique provides an objective method for quantifying the strength of a match formed by a consistent pattern of missing, filled, and unrestored teeth. Any dental pattern can be objectively assessed, regardless of the amount of existing dental treatment.

Empirical Comparison with a Reference Dataset

In order to accurately assess the significance of an antemortem/postmortem dental match, empirical comparison to a large, representative dataset provides the best method available. This technique is not dependent on a minimum number of characteristics since the strength of a match to a specific dental pattern can be assessed based on a comparison with a reference dataset. Relatively rare patterns in the population will be recognized as such, and this can be quantified with an objective value derived from the data. Furthermore, all dental characteristics should be considered, including unrestored teeth, when assessing an individual's overall dental pattern.

The technique recommended as part of this research is nearly identical to the reporting procedures utilized by mtDNA experts (20). To initially assess the power of the technique for use with teeth, it was necessary to explore the overall diversity of dental patterns. This procedure has already been completed and demonstrated that dental patterns provide an excellent means of personal identification (3). Regardless of whether mtDNA sequences or dental patterns are being considered, the probability that another individual randomly selected from the population will match depends on the relative rarity of their pattern/sequence. It is important to note that the diversity and random match probability measures presented by Adams (3) do not say anything about the frequency of 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 (20) 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%). A similar trend was also observed with dental patterns (3). Comparison of total diversity and conditional diversity presented by Adams (3) indicates that a few common dental patterns are present (e.g., individuals with "perfect" teeth), while the majority of the patterns are rare.

Through empirical comparison, a match between antemortem and postmortem dental records can be accurately quantified. 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 (20) 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. These guidelines are also applicable to dental patterns.

If explainable discrepancies are found between the antemortem and postmortem records, then it is recommended that these teeth should be excluded from the comparison and that they should be treated as though they were missing postmortem. By treating the teeth in this fashion, any character state is accepted in the comparison, which allows for the most conservative comparison and the most conservative frequency value for the overall pattern.

Previous Research

Only a few other studies have researched the dental patterns of a large sample of individuals for the purpose of establishing identifications (5,21). Lorton and Langley (21) 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 focused on 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 here (selection of a specific individual versus general frequency information), some parallels are present. They found that when an individual possessed four or more characteristics (fillings or missing teeth) that the individual could 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" (Ref 21, p. 977). Lorton and Langley also found that certain combinations of teeth with only common restorations ". . . provide amazingly selective identification points" (Ref 21, p. 976). Furthermore, they found that individuals with no missing or filled teeth complicate identification issues, but when only those 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 that is valuable to the identification process.

Friedman et al. (5) collected dental data on 7030 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 and colleagues were concerned with the selection of a specific missing individual from a database, as opposed to the research presented here that is concerned with calculating frequency information after a match to a specific individual has been established.

In their study, Friedman and colleagues recorded the dental characteristics 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, they 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" (Ref 5, p. 1358). Detailed surface codes were used for recording the locations of restorations.

Friedman et al. found that the average subject had seven dental characteristics composed of missing or filled teeth, 75% had four or more, 9% had a full complement of unrestored teeth (including third molars), and 3.6% had only one characteristic. Comparison with a sample of 17 to 49-year-old individuals from the TSCOHS dataset, including third molars ($N = 19\ 381$), showed that the average number of missing and filled teeth was 10.53 (with a standard deviation of 6.08) and only 1.90% had no missing or filled teeth. 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). Through their analysis they found that the variety of dental restorations was such that even the more common restorative situations (i.e., two, three, or four characteristics) yielded only two to four identical records, and 80% of all comparisons made with two or more characteristics gave a unique correct answer through a CAPMI comparison. They state (Ref 5, p. 1357) ". . . although dental restorations are diminishing in frequency in the younger population they still provide a high degree of selectivity for forensic science purposes."

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 ten most frequently observed dental patterns are presented in Tables 4 and 5 along with their frequency of occurrence. Results are provided for only the TSCOHS dataset, although the NHANES III data produced very similar results (see Ref 22 for a complete list). Both the detailed and generic formats of the data are presented.

As the tables show, with the exception of individuals possessing all virgin teeth, most dental patterns are very infrequently observed or are unique. Tables 4 and 5 clearly show that there are not common dental patterns observed in the population and that most individuals will possess a combination of dental characteristics that is relatively individualistic when at least one dental characteristic is present. Furthermore, the tables reveal that this trend is present in both the detailed and generic formats of the data. The observed frequency rapidly drops below 1% in both data formats, indicating

TABLE 4—*The ten most frequent dental patterns from the Detailed TSCOHS data.*

Detailed TSCOHS 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	LEFT		
	V	V	V	V	V	V	V	V	V	V	V	V	V	V		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
Unique Dental Patterns																13,631	70.18

TABLE 5—*The ten most frequent dental patterns from the generic TSCOHS data.*

Generic TSCOHS 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	LEFT		
	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
Unique Dental Patterns																7,471	38.47

that in most cases at least 99% of the individuals express a different pattern. This trend shows that for complete sets of teeth there is little improvement gained in the assessment of dental patterns using detailed documentation of restoration locations on teeth.

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 TSCOHS dataset was again 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 ten most frequently observed dental patterns created by consideration of only the molars and premolars from both the detailed and generic formats of the TSCOHS data are presented in Tables 6 and 7. Very similar results were derived from the NHANES III data, but are not presented here (see Ref 22 for a complete list).

The results presented in Tables 6 and 7 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. Furthermore, the generic format of the data provides pattern frequencies that are nearly identical to the detailed format. These results show that even in cases involving significant postmortem loss, a distinctive dental pattern may be present for comparison.

Case Examples

In order to provide an indication of the utility of empirical comparison in forensic identification cases, two examples are presented. Case Example 1 represents a dental pattern from a forensic identification case where there is complete congruence between all 28 teeth in the treatment records of a missing individual and the charting of an unidentified set of remains (antemortem radiographs were not present for comparison). Case Example 2 provides an example of a situation in which there is extensive postmortem loss of teeth. In both types of situations it is useful to determine if the congruent dental patterns are rare or very common in the overall population. Specifically, how likely is it that an individual drawn at random from the relevant population without replacement would also show this pattern?

For both case examples 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 dataset. Based on the arbitrary points of concordance outlined by Sognnaes and Keiser-Nielsen, the observed match can be classified in one of three categories: possible identification, probable identification, or certain identification. With the empirical comparison technique, 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: $\left(\frac{X+1}{N+1}\right) \cdot 100$, 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, the number of matches should be considered to be $1/(N+1)$.

Case Example 1

A dental record was randomly selected from an actual forensic identification case that involved only routine dental treatment. The antemortem dental record consists of the most recent dental chart from the individual's medical file. For this example, all 28 teeth (excluding third molars) were found to show exact congruence between the antemortem and postmortem record (Table 8). It is important to keep in mind that there is an exact correspondence be-

TABLE 6—*The ten most frequent dental patterns from the Detailed TSCOHS data with only molars and premolars.*

Detailed TSCOHS 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
Unique Dental Patterns										12,928	66.56

TABLE 7—*The ten most frequent dental patterns from the Generic TSCOHS data with only molars and premolars.*

Generic TSCOHS 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
Unique Dental Patterns			4,806	24.75

tween the postmortem chart and the antemortem records of a missing individual, and it is the strength of this match that needs to be quantified. In other words, the technique does not select a specific individual for consideration from the dataset, but rather it quantifies the strength of a match that has already been discovered to exist with a missing individual. While additional circumstantial evidence may be present in this type of situation (e.g., personal effects or archaeological provenience), only the strength of the dental evidence is considered here.

Case Example 1 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 8). 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 their location within the dental arch, and they would be considered to be "ordinary." Based on the points of concordance standards recommended by Sognnaes and Keiser-Nielsen, 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. When the overall pattern is compared with the combined TSCOHS and NHANES III datasets ($N = 29\ 152$), it was found to be unique in the detailed format (1/29, 153 or 0.003%) and to only occur four times (5/29, 153 or 0.017%) in the generic format. Due to the large sample size, these values can be considered to be an accurate indication of the expected frequency in the population. In this case, the dental pattern in the detailed format would be expected to occur in only 0.003% of the population, meaning that 99.997% of the population can be excluded as being a source for the evidence. Even in the generic format, where the dental codes are greatly simplified, the interpretations are nearly identical. Overall, the 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.

TABLE 8—*Case Example 3 with antemortem-postmortem match for all 28 tooth locations (Universal Charting).*

	Tooth No.	Unidentified Individual	Antemortem Records of John Doe
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	-	-

Case Example 2

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 have only partial dental remains available for comparison with the antemortem records. While it has been demonstrated in the previous example 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. Case Example 2 represents a forensic case in which only a limited number of teeth were recovered. The antemortem and postmortem charts presented with the following example correspond exactly (Table 9). In this example eight teeth were recovered, all from the mandible. 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 under their criteria.

Empirical comparison of the same eight teeth with the reference populations from the NHANES III and TSCOHS datasets produced quite different conclusions from the arbitrary guidelines. As it is very common for the mandibular molars to be filled, it would be of considerable interest to a 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 TSCOHS and the NHANES III datasets ($N = 29\ 152$) indicates that this pattern created by only eight teeth is unique to the detailed dataset (indicating an expected frequency of 1/29 153 or 0.003% of the population). This provides a very strong association to a specific individual.

If the detailed surface information is removed concerning the four restorations and is replaced with the generic format, drastically different results are attained. Comparison to the generic TSCOHS and NHANES III showed that this pattern now matches 5523 cases (5524/29 153 or 18.95%). Using the generic format of the data, approximately one in five randomly selected individuals could be expected to have this dental pattern. In this example, comparison with the generic format of the data does not provide strong evidence to associate the eight teeth with a specific individual. It is clear 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 discrimi-

TABLE 9—*Case Example 2 with antemortem-postmortem match for only eight tooth locations. Postmortem loss designated by shaded cells (Universal Charting).*

	Tooth No.	Unidentified Individual	Antemortem Records of Bob Smith
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		-

nating and provide frequencies that are nearly equal to the detailed format in their overall rarity.

OdontoSearch Computer Program

In order to overcome the inherent obstacles present in identification cases involving only charts and treatment records (i.e., antemortem radiographs are lacking), a new computer program has been developed that applies the principle of empirical comparison to a large reference population. Through this program, referred to as OdontoSearch, it is possible to compare a specific dental pattern to a large reference sample that is demographically and temporally diverse. In addition to the NHANES III and TSCOHS datasets described in this paper, other datasets have been incorporated in the program that were derived from military personnel that served in WWII, the Korean War, or the Vietnam War. In total, the dental information for approximately 40 000 adults is available for comparison. Through OdontoSearch comparisons can be performed according to the desired criteria (e.g., a pattern is only compared to a modern civilian population). Furthermore, this program allows for any number of teeth from one to 28 (excluding third molars) to be entered, which allows for consideration of cases involving postmortem loss. By tabulating the number of matches between an observed pattern and those in the database, it is possible to provide objective statistics regarding the strength of a dental pattern match. In many instances the results may be counterintuitive since the presence of only a few common restorations may create a very rare dental pattern when all of the teeth are considered. To the extent that the sample of records used represents the relevant population, it is then a reasonable assumption that the true population frequency of an observed dental pattern can be estimated from the OdontoSearch program. 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 intelligible and defensible in a court of law.

Two important points need to be understood as part of this technique. First, the OdontoSearch program does not provide a database that is intended to be used to match a dental pattern to a specific individual (WinID and CAPMI are designed for this purpose). Instead, once an association to an individual has been made, the technique simply allows for the significance of the dental pattern match to be quantified. Second, many forensic odontologists are reluctant to establish a positive identification using dental treatment records and charts alone. It is anticipated that this type of evidence, often in conjunction with other circumstantial evidence, can now be used to form an objective and quantifiable association between a missing individual and an unidentified set of remains.

In order to utilize this database, OdontoSearch can be accessed via the Internet at (www.cilhi.army.mil). Instructions for the use of this program are available through the website, along with information concerning the various population subsets that comprise the data.

Results and Conclusions

Prior to this research, forensic odontologists did not have a reliable technique for assessing the strength of an antemortem-postmortem match between nonradiographic dental evidence. In general, forensic comparisons have been based on the subjective judgment of the dentist that cannot be statistically quantified. Through empirical comparison with a large, representative dataset, these dental patterns can now be objectively assessed. Patterns that may be initially hypothesized to be common in the general population may actually be shown to be extremely rare and individualistic based on empirical comparison to a reference dataset. Even postmortem loss does not necessarily have a prohibitive effect on the identification process, a fact that is obviously beneficial to forensic investigations.

In many instances the detailed surface codes for restorations were found to be irrelevant for comparative purposes. An important exception to this trend occurs in the case of extensive postmortem loss. 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 does not necessarily imply that surface codes should never be utilized, but use of a generic system is likely to reduce subjectivity and decrease error rates.

The quantitative information derived from empirical comparison can be used to attach a degree of certainty to a match between dental patterns (the likelihood that two individuals would share the same dental pattern). 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 interpretable. The OdontoSearch program allows for this technique to be applied by forensic experts via the Internet.

Acknowledgments

This research could not have been completed without guidance from Gary Bell, Tom Holland, John Byrd, and Mark Leney. In addition, I am indebted to my Ph.D. committee including Richard Jantz, Murray Marks, David Gerard, and especially Lyle Konigsberg. Programming for OdontoSearch was completed by Cheryl Shigeta, Amanda Drogosch, and Richard Schumann. The TSCOHS data were graciously provided by Bruce Brehm. I would also like to acknowledge the individuals who read early drafts of this paper and provided comments, including John Lewis and Paul Emanovsky.

References

1. Sopher IM. Forensic dentistry. Springfield: Charles C Thomas, 1976.
2. Bass WM. Outdoor decomposition rates in Tennessee. In: Haglund WD, Sorg MH, editors. Forensic taphonomy: the postmortem fate of human remains. New York: CRC Press, 1997;181–6.
3. Adams BJ. The diversity of adult dental patterns in the United States and the implications for personal identification. J Forensic Sci 2003;48(3).
4. U.S. Department of Health and Human Services/National Center for Health Statistics. Third national health and nutrition examination survey, 1988–1994, NHANES III examination data file (CD-ROM). Public Use Data File Documentation Number 76200. In: Hyattsville, MD: Centers for Disease Control and Prevention, 1996.
5. Friedman RB, Cornwell KA, Lorton L. Dental characteristics of a large military population useful for identification. J Forensic Sci 1989;34(6): 1357–64.
6. Stimson PG. Radiology in forensic odontology. Dent Radiogr Photogr 1975;48(3):51–5.
7. Mertz CA. Dental identification. Dent Clin North Am 1977;21(1):47–67.
8. Sognnaes RF. Oral biology and forensic science. Annu Meet Am Inst Oral Biol 1975:126–39.
9. Sognnaes RF. Dental science as evidence in court. Int J Forensic Dent 1976;3(9):14–6.
10. Sognnaes RF. Talking teeth. Am Sci 1976;64(4):369–73.
11. Keiser-Nielsen S. Person identification by means of the teeth: a practical guide. Bristol: John Wright and Sons Ltd, 1980.
12. Anonymous. Body identification guidelines. American Board of Forensic Odontology, Inc. J Am Dent Assoc 1994;125(9):1244–6,1248,1250 passim.
13. Luntz LL, Luntz P. Handbook for dental identification. Philadelphia: J. B. Lippincott Company, 1973.
14. Gustafson G. Forensic odontology. London: Staples Press, 1966.
15. Sognnaes RD. Forensic stomatology (third of three parts). N Engl J Med 1977;296(4):197–203.
16. Sognnaes RF. Dental evidence in the postmortem identification of Adolf Hitler, Eva Braun, and Martin Bormann. Leg Med Annu 1977:173–235.
17. Sognnaes RF. Hitler and Bormann identifications compared by postmortem craniofacial and dental characteristics. Am J Forensic Med Pathol 1980;1(2):105–15.
18. Sognnaes RF, Strom F. The odontological identification of Adolf Hilter. Definitive documentation by x-rays, interrogations and autopsy findings. Acta Odontol Scand 1973;31(1):43–69.
19. Keiser-Nielsen S. Dental identification: certainty V probability. Forensic Sci 1977;9(2):87–97.
20. Holland MM, Parsons TJ. Mitochondrial DNA sequence analysis—validation and use for forensic casework. Forensic Sci Rev 1999;11:21–50.
21. Lorton L, Langley WH. Design and use of a computer-assisted postmortem identification system. J Forensic Sci 1986;31(3):972–81.
22. Adams BJ. Personal identification based on patterns of missing, filled, and unrestored teeth [Ph.D. dissertation]. Knoxville: University of Tennessee, 2002.

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