J Forensic Sci, January 2009, Vol. 54, No. 1
doi: 10.1111/j.1556-4029.2008.00921.x
Available online at: www.blackwell-synergy.com

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Computer-aided Dental Identification: An Objective Method for Assessment of Radiographic Image Similarity*

ABSTRACT: A pilot study evaluated a computer-based method for comparing digital dental images, utilizing a registration algorithm to correct for variations in projection geometry between images prior to a subtraction analysis. A numerical assessment of similarity was generated for pairs of images. Using well-controlled laboratory settings, the method was evaluated as to its ability to identify the correct specimen with positive results. A subsequent clinical study examined longitudinal radiographic examinations of selected anatomical areas on 47 patients, analyzing the computer-based method in making the correct identification based upon a threshold level of similarity. The results showed that at a threshold of 0.855, there were two false negative and two false positive identifications out of 957 analyses. Based on these initial findings, 25 dental records having two sets of full mouth series of radiographs were selected. The radiographs were digitized and grouped into six anatomical regions. The more recent set of films served as postmortem images. Each postmortem image was analyzed against all other images within the region. Images were registered to correct for differences in projection geometry prior to analysis. An area of interest was selected to assess image similarity. Analysis of variance was used to determine that there was a significant difference between images from the same individual and those from different individuals. Results showed that the threshold level of concordance will vary with the anatomical region of the mouth examined. This method may provide the most objective and reliable method for postmortem dental identification using intra-oral images.

KEYWORDS: forensic science, forensic dentistry, forensic odontology, human identification, dental radiography

Dental forensic identifications can be based upon visual comparison of the postmortem specimen with antemortem records or by comparison of postmortem dental radiographs of the specimen with antemortem radiographs (1). An individual's dentition can provide for a unique combination of decayed, missing, and filled teeth. Furthermore, the mineral composition of teeth is such that a tooth is resistant to fire, extreme temperatures, and decomposition. Dental structures represent the hardest and most resilient tissues of the body. Bernstein (2) noted that nearly 70% of identifications in airline mass disasters are based upon dental comparisons. Paramount in the identification process is the ability to secure antemortem records and the accuracy of such documentation (3–8).

A confounding issue of postfluoridation efforts is the increasing numbers of individuals who are caries-free and without dental restorations (9). In one study of fire victims, it was noted that the lower percentage of established dental identifications for victims younger than 20 years of age was a result of fewer dental restorations being present to provide discriminating potential (10). Other articles affirm the difficulty in identity determination for those without dental restorations (11,12).

Dental radiographic comparisons in forensic cases often require meticulous attention to minute details of bony trabecular patterns, anatomical landmarks, and pathological conditions (13,14). Dental comparisons, in contrast with fingerprint analysis, do not have a standard number of concordant points of similarity between records in order for a positive identification to be rendered (15,16). The expert dental examiner must be prepared to justify his assessment of identity in a court of law (17). One unique dental characteristic, as with a peg lateral or multi-rooted mandibular premolar, could serve to establish positive identification. However, the literature is lacking in estimations of probabilistic aspects of dental identification (18).

Sholl (19) conducted an experimental forensic dental identification with 198 periapical and bitewing radiographs of 22 skulls. The examiners were asked to match the randomly mixed radiographs into sets. The success rate at matching radiographs was 100% if the examiner had either formal training and experience, or extensive experience without formal training. Those with formal training but little practical forensic experience demonstrated lower success rates, with the conclusion that formal training is highly desirable but no substitute for practical experience. Depth of knowledge of the forensic odontologist correlated poorly with the number of correct identifications made. Examiners believed that root morphology and alignment, not crown morphology, had been the greatest aid to subjectively matching radiographs.

One of the challenges to matching radiographs is the disparate projection geometry between the images. Hubar (20), noting that deviations in conventional bitewing radiographs by as little as five degrees horizontally made identification difficult, utilized computed dental radiography in a simulated forensic case to replicate the antemortem film angulation. Wenzel (21) evaluated a subtraction program based on positioning of reference points in two dental images with that of manual superimposition of the images during video capture. The reference point method required the use of computer algorithms for translation, rotation, and perspective distortion to achieve the best overlap of images. The reference point method

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*Portions of the results were given in oral presentations at the 53rd and 54th Annual Meetings of the American Academy of Forensic Sciences, Seattle, WA (February 2001) and Atlanta, GA (February 2002).

Received 18 Mar. 2007; and in revised form 16 Mar. 2008; accepted 15 June 2008.

was found to be superior to manual superimposition for all angulations evaluated.

In a paper by Bowers (22), a computer-based program was used to rotate and resize digitized images in an attempt to create identical horizontal orientations of the cemento-enamel junctions (CEJs) of the teeth for the ante- and postmortem evidence. The postmortem image selected for analysis was chosen as that most closely approximating the tooth angulation seen in the antemortem image. After orientation of CEJs, the postmortem image was then moved onto the antemortem image for a shape comparison evaluation. They concluded that the ability to digitally resize radiographs would allow the investigator to measure and superimpose physical dental features seen in the ante- and postmortem radiographs, thus facilitating in cases with few dental restorations.

Other computer-based techniques utilize different mathematical transformations to produce a corrected image. This corrected image is an approximation of the image that would be acquired if the same projection geometry as the baseline image was used. Dunn (23) described the use of invariant geometric structures to determine the projection geometry used to acquire an image. He demonstrated that the relationship of these two-dimensional points recorded on the image was independent of the projection geometry from which they were acquired. Further, he postulated that these same invariant structures could be used to register images taken from disparate projection geometries. Even when imaging geometry is nearly constant, radiographs must be registered after digitization due to system "noise" or geometric variation caused by the digitization process itself (24,25).

The basis of subtraction imaging is to detect changes in internal structures over time for dental images of an identical maxillofacial region of a patient. Lehmann (24) studied the use of similarity measures for dental subtraction imaging. Most subtraction analyses involve sequentially acquired radiographs utilizing fixed mechanical aids for identical projection geometry of the area of interest. In assessing digital free-hand subtraction radiographs, the radiographs must be adjusted for all possible differences in projection angulations. Lehmann evaluated eight mathematical measurements of image similarity that could be used for the quality assessment of different registration methods for digitized images, including the cross covariance coefficient (CCC). In digital image processing, the CCC is well known as a bias-independent measure for two-dimensional discrete data (26). All eight measures had been used in medical or dental fields, either for assessing pairs of radiographs or to compute an automated image alignment. The measurements obtained were normalized to a range of zero to one, with one indicating a perfect image similarity. Lehmann tested 172 radiographs taken with varying projection angles of a human mandible. Following registration, two images would be considered identical if they contained the same gray level values at all points within the registered image. Two completely different radiographs with no overlapping regions should be zero. Lehmann noted that as a result of system noise, two images will never be identical even with constant projection geometry and exposure factors. In this study he found image similarity and registration are inversely related, with the degree of image similarity increasing with decreasing registration error between two images. Of the eight measurements he concluded that in digital free-hand subtraction radiography the CCC is an appropriate computer algorithm to qualitatively compare different means of automatic alignment of x-ray images.

The aforementioned study involved the assessment of subtracted radiographs from a single individual taken at different times. Recognizing the uniqueness of human dentition, root form and trabecular pattern, it was hypothesized that images from the same anatomical region from two individuals would have a lower similarity index than comparing two radiographs taken of the same person. This difference could be exploited for making postmortem identifications.

To test this hypothesis, a simulated forensic investigation utilizing direct digital imaging and CCC analysis for postmortem identification was performed. Ten anatomically similar human jaw specimens were imaged using a direct digital radiographic detector system at 15 different projection geometries per specimen. The image identified as the postmortem image was registered with the chosen antemortem image by selecting specific invariant dental structures (root apices and interproximal CEJs) found in agreement on both images. UTHSCSA ImageTool version 3.0, a general purpose image processing and analysis application developed at the University of Texas Health Science Center at San Antonio, was the application software. Registration was performed to correct for differences in projection geometries between the two images. Following the registration process, a region of interest was selected. Images were analyzed for similarity by computing the CCC within the region of interest. The pilot study showed perfect discrimination between similar and nonsimilar samples when trabecular bone pattern and root shape were analyzed using a CCC threshold value of 0.840 as identity (27,28).

To evaluate the promise of this new methodology, a postmortem identification plug-in titled "UT-ID" was developed for UTHSCSA ImageTool version 3.0. This new plug-in provided an index of image similarity called the "UT-ID" index based on the CCC analysis and a proprietary registration algorithm. A second study was performed to evaluate the usefulness of the UT-ID index for postmortem identification on a more clinically relevant sample. The clinical study utilized 47 dental records from the University of Texas Dental School at San Antonio outpatient clinic. Inclusion criteria consisted of a minimum of two 20-exposure full mouth series taken over at least a 3-year period. Posterior and anterior periapical films from each full mouth series were digitized using a flatbed scanner with transparency adapter. All x-ray films were digitized at 400 dpi (63.5 micron pixels) and 8 bit (256) gray levels. Patient information was redacted for patient confidentiality and a random patient number assigned to each set of digital images. Four anatomical areas were selected for analysis: right maxillary premolar, right mandibular premolar, left mandibular molar and right maxillary central/lateral incisor. A single image was selected randomly from each anatomical area to serve as a postmortem image, with all other images in the group serving as potential matching antemortem images. The image taken of the same individual from the earlier series was the matching antemortem image in each group. The study found a 0.42% error rate at a threshold level of 0.855 for identity. The sensitivity and specificity at this threshold were calculated to be 0.92 and 0.99, respectively. These initial pilot studies point to the potential of the UT-ID method of image analysis as an objective, scientific method on which to base a forensic dental identification (27,29).

The difficulties with the subjective analysis of radiographic images in the absence of any restorative or unique developmental findings are apparent. A problematic issue is that not all remains recovered will result in an intact dentition for examination. Additionally, variations in projection geometry between ante- and postmortem images have been shown to complicate radiographic comparison. In recent years there has been a shift within the courts of law from analysis of evidence based upon the skill and judgment of the expert witness to one based upon independent judicial assessment of the reliability of a particular methodology (30). Clearly, a more objective approach to image analysis is needed.

The present study was undertaken to further test the UT-ID method of image analysis, expand the number of anatomical regions evaluated, and to determine the error rate of the method for different anatomical areas when used for objective dental forensic identification. Establishing and testing a method for objective analysis of dental images, a proven scientific approach to dental identification would be validated.

Materials and Methods

The study involved the digitization of two sets of full mouth intraoral radiographic films from 25 patient records. Patient information was redacted from the selected radiographs for patient confidentiality and random patient numbers assigned to each image. This information protection and confidentiality follows the legislation of the Health Insurance Portability and Accountability Act of 1996 (HIPAA). The protocol was approved and accepted as exempt research by the Institutional Review Board of the University of Texas Health Science Center at San Antonio (IRB Protocol E-012-144).

Images were digitized using an Epson Expression 16 Professional flatbed scanner with transparency adapter. All films were digitized at 400 DPI and 8 bit (256) gray levels. Contrast and brightness were automatically optimized using Photoshop© software prior to scanning. Posterior images were cropped to a standard 620×460 pixel matrix size. Anterior images were cropped to 360×610 pixel matrix size. The presence of the alveolar bone was maximized during the cropping process, as well as preserving the region of the mouth selected for analysis. The scanned images were then saved as TIF image files and randomly assigned a three-digit number. Images from the same anatomical area were grouped for analysis. The anatomical areas selected were maxillary right premolar, maxillary left molar, mandibular right molar, mandibular left premolar, maxillary right lateral and central incisor, and mandibular central incisors.

For the six anatomical regions examined, the images from the more recent intraoral series were assigned a random number that was coded back to the original demographics to denote it as the simulated postmortem image. The 25 coded postmortem images were then registered with all 50 images for that region. Each coded image generated up to 50 values: one between identical images, one between radiographs of the same individual but at different dates, and 48 between radiographs from a different individual. This resulted in a sample size of 1250 comparisons for each of the six anatomical regions. Additionally, three investigators analyzed subsets of the films to assess the intra-investigator and inter-investigator reliability of the test method.

All image registration and analysis was performed on an Intel Pentium II personal computer using UTHSCSA ImageTool version 3.0 and the UT-ID plug-in module. UTHSCSA ImageTool is a general purpose image processing and analysis application developed at the University of Texas Health Science Center at San Antonio, in the Department of Dental Diagnostic Science and is accessible through the Internet at http://ddsdx.uthscsa.edu/dig/itdesc.html (31). The software is extensible through the use of a plug-in interface similar to Adobe Photoshop. UT-ID streamlines the registration and UT-ID analysis, based upon the CCC, of the two images being compared.

Using the UT-ID plug-in, the postmortem image was selected first. The software then prompted for the selection of the antemortem image. Image registration involved the selection of four anatomical points in the coded postmortem image (Fig. 1) and four corresponding points in the coded antemortem image (Fig. 2) to be registered. The anatomical points were two interproximal cemento-enamel junctions (CEJs) and two root apices found in both radiographic images. These points were selected so as to be co-planar within the dental arch but not co-linear. In an attempt to register as wide of an area within the images as possible, the most distant anatomical points were chosen whenever possible.

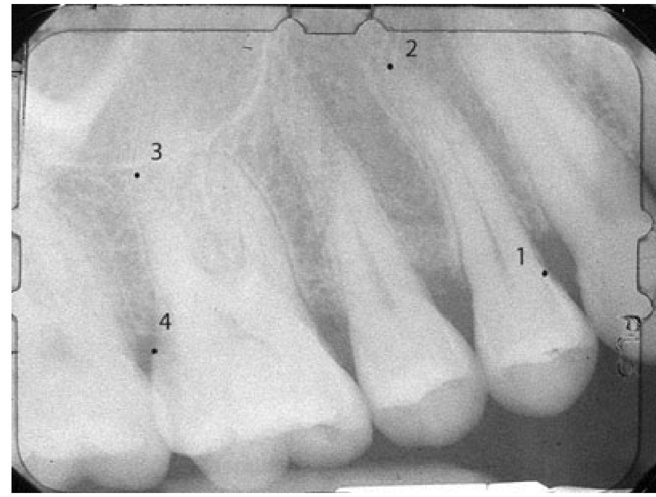

FIG. 1—*Digital postmortem radiograph with four registration points.*

FIG. 2—*Digital antemortem radiograph with four registration points.*

Once the four anatomical points were chosen in the postmortem and antemortem image, the UT-ID algorithm for scaling, translation, rotation and perspective distortion of identical structures was applied to the antemortem image. A subtracted image of the registered antemortem image and the postmortem image was then displayed to assess the quality of registration (Fig. 3). Following registration, the investigator designated an area of interest for image analysis within the four anatomical registration points (Fig. 4). The area of interest from the antemortem and postmortem images contained *c.* 35,000–50,000 pixels each. These pixel values were used in the calculation of the UT-ID index.

The potential range of UT-ID values is between zero and one, with perfect image similarity between two images generating a value of 1.00. The degree of similarity was determined by assessing the differences in density and contrast on a pixel-by-pixel basis between the postmortem and registered antemortem images through computer algorithm software.

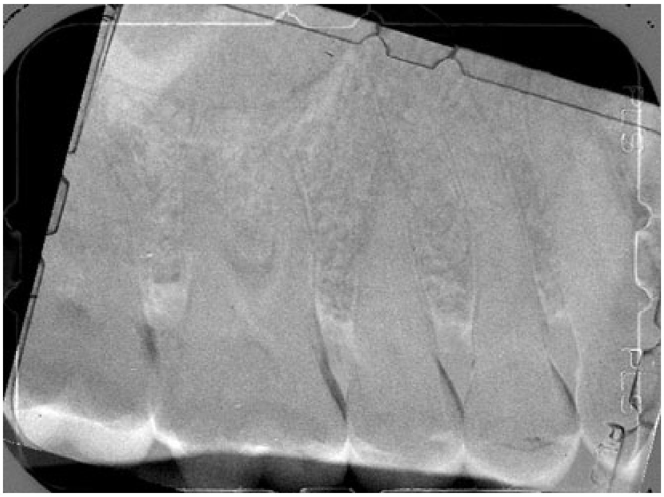

FIG. 3—*Digital subtraction image for evaluating image registration.*

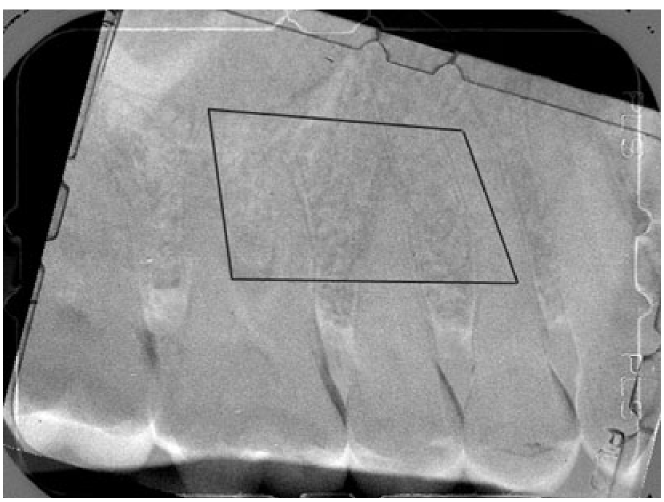

FIG. 4—*Digital subtraction image with area of interest used in calculating the UT-ID index.*

The resulting means of the UT-ID values for similar versus nonsimilar images were compared using a Student's *t*-test ($p \leq 0.05$). Sensitivity, specificity, false acceptance rates, and false rejection rates were calculated for each region examined and for all regions combined. Analysis of variance was used in order to assess independent variables such as anatomic region, investigator and identity. ANOVA and *post hoc* testing were performed using the StatView® for Windows software, Version 5 (SAS Institute, Inc., Cary, NC).

Results

The registration of the postmortem image paired with itself was used as an internal control but not included in the statistical analysis of identity, since exact images would never be paired in a forensic radiographic comparison. UT-ID values for such identical pairings approached 1.00, denoting perfect similarity, and would have biased the identity results with inflated UT-ID values. Thus each postmortem radiograph had only one self-match with its corresponding antemortem image.

For the combined regions, pairings of antemortem and postmortem images from the same individual (identity) had a mean UT-ID value of 0.764 (SD = 0.109), whereas nonidentity images (images from two different individuals) had a mean UT-ID of 0.429 (SD = 0.201). ANOVA testing indicated that similarity by anatomical region has a significant effect on UT-ID values. Thus, a UT-ID threshold was not determined for the combined anatomical areas due to the wide standard deviation.

The effect of the variability by anatomic region (Table 1) showed the mandibular molar area with the highest mean UT-ID for both identity at 0.814 (SD = 0.105) and for nonidentity at 0.571 (SD = 0.179). The mandibular premolar produced the lowest mean UT-ID for identity at 0.702 (SD = 0.112) and the lowest mean for nonidentity at 0.299 (SD = 0.160) of any of the six anatomic regions. Within each region, the ANOVA indicated that there was a significant difference in UT-ID values between identity and nonidentity groups at the 0.05 significance level. Fisher's Protected-Least-Significant-Difference (PLSD) test demonstrated that each region also was found to be significantly different for identity/nonidentity groups when compared to other regions at the 0.05 significance level. The results suggest that the UT-ID index can be used for identity determination when analyzing antemortem and postmortem radiographs by anatomical region. To assist in a determination, thresholds were calculated for each anatomical region.

Varied threshold values for UT-ID for identity with calculated sensitivity, specificity, false acceptance rates, and false rejection rates are presented by region in Tables 2–7. In this study sensitivity is defined as the proportion of times a pair of radiographs

TABLE 1—*UT-ID index for regional identity and nonidentity.*

Similarity	Number	Mean UT-ID	SD
Identity, maxillary premolar	22	0.787	0.091
Identity, maxillary molar	24	0.778	0.112
Identity, mandibular molar	25	0.814	0.105
Identity, mandibular premolar	22	0.702	0.112
Identity, maxillary incisor	25	0.749	0.102
Identity, mandibular incisor	25	0.746	0.104
Nonidentity, maxillary premolar	945	0.506	0.171
Nonidentity, maxillary molar	1101	0.430	0.191
Nonidentity, mandibular molar	1200	0.571	0.179
Nonidentity, mandibular premolar	922	0.299	0.160
Nonidentity, maxillary incisor	1164	0.357	0.174
Nonidentity, mandibular incisor	1200	0.393	0.198

TABLE 2—*Threshold effects for maxillary premolar area.*

UT-ID Index Threshold	Sensitivity	False Negative Rate/100	Specificity	False Positive Rate /100
0.975	0.00	100	1.00	0
0.950	0.00	100	1.00	0
0.925	0.05	95	1.00	0
0.900	0.05	95	1.00	0
0.875	0.14	86	1.00	0
0.850	0.22	78	0.99	1
0.825	0.41	59	0.99	1
0.800	0.50	50	0.99	1
0.775	0.68	32	0.98	2
0.750	0.68	32	0.97	3
0.725	0.82	18	0.93	7
0.700	0.82	18	0.90	10
0.675	0.95	5	0.84	16
0.650	0.95	5	0.82	18

TABLE 3—*Threshold effects for maxillary molar area.*

UT-ID Index Threshold	Sensitivity	False Negative Rate/100	Specificity	False Positive Rate/100
0.975	0.00	100	1.00	0
0.950	0.00	100	1.00	0
0.925	0.04	96	1.00	0
0.900	0.04	96	1.00	0
0.875	0.21	79	1.00	0
0.850	0.38	62	1.00	0
0.825	0.38	62	1.00	0
0.800	0.50	50	0.99	1
0.775	0.58	42	0.99	1
0.750	0.63	37	0.97	3
0.725	0.71	29	0.95	5
0.700	0.75	25	0.94	6
0.675	0.83	17	0.92	8
0.650	0.92	8	0.89	11
0.625	0.92	8	0.85	15
0.6000	0.96	4	0.80	20

TABLE 4—*Threshold effects for mandibular molar area.*

UT-ID Index Threshold	Sensitivity	False Negative Rate/100	Specificity	False Positive Rate/100
0.975	0.00	100	1.00	0
0.950	0.04	96	1.00	0
0.925	0.04	96	1.00	0
0.900	0.08	92	1.00	0
0.875	0.24	76	1.00	0
0.850	0.48	52	1.00	0
0.825	0.64	36	0.99	1
0.800	0.72	28	0.97	3
0.775	0.80	20	0.92	8
0.750	0.84	16	0.89	11
0.725	0.88	12	0.82	18
0.700	0.88	12	0.75	25

TABLE 5—*Threshold effects for mandibular premolar area.*

UT-ID Index Threshold	Sensitivity	False Negative Rate/100	Specificity	False Positive Rate/100
0.975	0.00	100	1.00	0
0.950	0.00	100	1.00	0
0.925	0.00	100	1.00	0
0.900	0.00	100	1.00	0
0.875	0.00	100	1.00	0
0.850	0.00	100	1.00	0
0.825	0.05	95	1.00	0
0.800	0.09	91	1.00	0
0.775	0.14	86	1.00	0
0.750	0.36	64	1.00	0
0.725	0.64	36	1.00	0
0.700	0.68	32	0.99	1
0.675	0.73	27	0.99	1
0.650	0.82	18	0.99	1
0.625	0.82	18	0.98	2
0.600	0.86	14	0.97	3

was correctly called a match (identity) based on UT-ID values. Specificity is noted as the proportion of times a pair of radiographs was correctly determined a mismatch (nonidentity) based on UT-ID values. False negative rates are representative of the number of times out of 100 that the correct identity match was not made between antemortem and postmortem radiographs based on UT-ID values. In other words, the UT-ID threshold would be higher than the true identity match UT-ID number generated. False positive rates represent the number of times out of 100 that radiographs from two individuals are incorrectly called an identity match. At a 0.80 threshold, sensitivity ranged from a low of 0.09 for the mandibular premolars to a high of 0.72 for mandibular molars. Specificity at the 0.80 threshold was at 0.97 to 1.00 for any region. At a 0.70 threshold, sensitivity ranged from a low of 0.68 (mandibular premolars) to a high of 0.88 (mandibular molars). Specificity at the 0.70 threshold was between 0.90 and 0.99 for any region. The false positive rate ranged between 1/100 and 3/100 for all regions at the 0.80 threshold, with the mandibular molar region having 25/100 false positives at a threshold of 0.70.

TABLE 6—*Threshold effects for maxillary incisor area.*

UT-ID Index Threshold	Sensitivity	False Negative Rate/100	Specificity	False Positive Rate/100
0.975	0.00	100	1.00	0
0.950	0.00	100	1.00	0
0.925	0.00	100	1.00	0
0.900	0.00	100	1.00	0
0.875	0.12	88	1.00	0
0.850	0.20	80	1.00	0
0.825	0.36	64	1.00	0
0.800	0.36	64	1.00	0
0.775	0.40	60	0.99	1
0.750	0.52	48	0.99	1
0.725	0.60	40	0.99	1
0.700	0.72	28	0.99	1
0.675	0.72	28	0.98	2
0.650	0.80	20	0.97	3
0.625	0.84	16	0.95	5
0.600	0.92	8	0.92	8

TABLE 7—*Threshold effects for mandibular incisor area.*

UT-ID Index Threshold	Sensitivity	False Negative Rate/100	Specificity	False Positive Rate/100
0.975	0.00	100	1.00	0
0.950	0.00	100	1.00	0
0.925	0.00	100	1.00	0
0.900	0.04	96	1.00	0
0.875	0.04	96	1.00	0
0.850	0.12	88	1.00	0
0.825	0.20	80	1.00	0
0.800	0.40	60	0.99	1
0.775	0.48	52	0.99	1
0.750	0.56	44	0.99	1
0.725	0.68	32	0.98	2
0.700	0.72	28	0.96	4
0.675	0.80	20	0.94	6
0.650	0.80	20	0.91	9
0.625	0.80	20	0.88	12
0.600	0.88	12	0.83	17

The effect of various investigators on UT-ID values was also analyzed, as shown in Table 8. The ANOVA test for identity showed no significant difference among the investigators. There was a significant difference demonstrated by ANOVA testing for the repeated registration of nonidentity images between Investigator 1 and the other investigators.

The intra-investigator variability on identity and nonidentity analyses is shown in Table 9. More variability was shown in UT-ID values among the three investigators for repeated registrations of the five nonidentity pairs of images as opposed to the five identity pairs.

TABLE 8—*Inter-investigator effects on repetition.*

Image pairs	Investigator	Mean UT-ID	SD	Coefficient of Variance
Identity	1	0.863	0.060	0.070
	2	0.869	0.051	0.059
	3	0.859	0.061	0.071
Nonidentity	1*	0.390	0.110	0.281
	2	0.480	0.084	0.175
	3	0.501	0.062	0.124

*Significant difference demonstrated between Investigator 1 and other investigators.

TABLE 9—*Intra-investigator effects on repetition.*

Image pairs	Investigator	Mean UT-ID	SD	Standard Error	Variance	Coefficient Variance
Identity	1	0.863	0.060	0.012	0.004	0.070
	2	0.869	0.051	0.010	0.003	0.059
	3	0.859	0.061	0.012	0.004	0.071
Nonidentity	1	0.390	0.110	0.022	0.012	0.281
	2	0.480	0.084	0.017	0.007	0.175
	3	0.501	0.062	0.012	0.004	0.124

Discussion

The traditional method of measuring image similarity is subjective in nature. It is determined by visual interpretation based on points of concordance between the antemortem and postmortem dental radiographs or digital images. The challenges to this method of identification are numerous—among them, lack of distinctive dental morphology, changes to the radiographic appearance with replacement of restorations, differences in projection geometry between ante- and postmortem images, and the experience of the forensic odontologist. Numerous studies have shown that odontologists with forensic experience will perform at a higher level of accuracy in radiographic identification tests than those with limited experience. However, each study was based on subjective comparison of the films or images (4,19,32–34).

Articles that describe computer programs to correct for differences in projection geometry between dental images have been descriptive in nature, with proposed benefits to forensic applications not based on any controlled testing (20–22). The need for further studies of an objective dental radiographic analysis, accounting for differences in projection geometry as in a true forensic investigation, was evident. Also important would be a system that could be accurate for cases where the decedent had no restorations or unique crown morphology. This study was designed to address these concerns.

Results indicate that there is a significant difference in the UT-ID index between images of the same individual (identity) and images from dissimilar individuals (nonidentity). Following data collection and identity determination, it was apparent that there was a wide variation in the mean UT-ID indices among the six anatomical regions for both identity and nonidentity. The characteristics of teeth and anatomical features of the mouth present numerous differences when comparing maxillary and mandibular teeth, as well as anterior to premolar or molar regions. Though one universal UT-ID threshold could be considered, it would result in a significantly large error rate depending upon anatomical site or arch. Widespread errors in postmortem identification would have significant impact on criminal cases and legal ramifications of death declaration. It was demonstrated in this study that anatomic region had a profound effect on the UT-ID index. Based on the ANOVA, if the UT-ID index was to be used, it would only be used on a region-to-region basis with different thresholds established for each region. Because teeth and regional features are unique, the UT-ID thresholds were calculated based on anatomical area to eliminate the variability found between regions of the mouth. In so doing, a more objective and representative determination of identity threshold could be evaluated for each of the six anatomical sites. Sensitivity, specificity, false negative and false positive rates were computed based on anatomic site and thresholds.

Factors affecting the registration of images and UT-ID values from any region related to exposure or processing variables, wide differences in horizontal or vertical angulation between two images, artifacts or emulsion tears. Variations in location and extent of restorations on the teeth limited the selection of registration points in some instances, resulting in a less than ideal point determination. On a few radiographic pairings, it was difficult to determine the location of the apex of the tooth, either due to the tip of the apex not being viewed on the radiograph or being obscured by some other feature or artifact. Additionally, the presence of endodontically-treated teeth on one image and not the other could impact the resulting UT-ID value as the entire canal space would be opaque on one film compared to a darkened canal space on the other. The logical result would be a lower similarity score for the two images, even if from the same individual, due to wide variations of pixel intensities for the canal spaces between the images.

In utilizing an objective method for identity, the resulting error rate of the test must be critically examined. The implications of falsely identifying an individual based upon a threshold determination would be more troublesome as opposed to a failure to correctly match antemortem and postmortem records. The false negative and false positive rates at each threshold should be carefully examined to optimize the potential of a correct identity match of antemortem and postmortem images.

For each region, there was a threshold value where the false positive rate increased dramatically with incremental lowering of the threshold. The ideal properties of a testing device would be to have high sensitivity and high specificity. In terms of forensic identifications, one would seek to have a low false positive rate (when mismatched images are labeled as identity) and a low false negative rate (images from the same individual being called a mismatch). Proposed working threshold levels for identification, optimizing for low false identity rates, are 0.750 for maxillary molar, 0.775 for maxillary premolar, 0.700 maxillary central/lateral, 0.800 for mandibular molar, 0.650 for mandibular premolar and 0.725 for mandibular anterior. Each of these specific regional thresholds has a false positive rate of 3/100 or less and false negative rate of 37/100 or less. These thresholds were proposed to maximize specificity, and then maintain sensitivity as high as possible.

This study also demonstrated the inter-investigator and intra-investigator reliability of this method of image analysis. The ANOVA test for identity showed no significant difference between the investigators. There was a significant difference demonstrated by ANOVA testing for the registrations of nonidentity images between Investigator 1 and the other investigators. Attempting to match nonidentity pairs demonstrated more variability and a wider range in the mean standard deviations among the three operators. That images from two individuals will introduce more variability in reference point selection due to inherent differences in image data is more likely to be the reason for this finding than to attribute the significant difference to technique or operator, as a significant difference was not found with identity registrations between investigators.

More variability was shown in UT-ID values among the three investigators for repeated registrations of the five nonidentity pairs of images as opposed to the five identity pairs. As with inter-investigator registrations, this is due to the inherent nature of registering radiographs from two individuals with disparate image data. The matching of same region images from two different individuals will be more dissimilar than matching two images of one anatomical area from one individual. Thus there is inherently more variability in the registration of nonidentity pairs of images.

The factors contributing to the significance between the anatomical areas and their unique UT-ID thresholds are not identified by this study. There was no attempt to eliminate anatomical areas based on UT-ID values or rank order the regions as to preferred registration regions. The latter might be an issue for only those cases where an intact postmortem specimen was recovered and with limited time for analysis. In cases of fragmentation of mandible or maxilla, registration would likely occur for any or all segments obtained.

All three examiners in this research were dentists with advanced educational training in dentistry. Previous studies have shown that past experience in forensic identifications can be significant in the subjective matching of dental radiographs in simulated forensic identifications. The effect of disparate dental experience or participation in forensic identifications among examiners should be further evaluated to establish the true objectivity of the UT-ID index.

The purpose of the study was to determine if computer image analysis through the use of the UT-ID index as a measure of image similarity could provide a means of establishing identification when evaluating dental radiographs. Two pilot studies were used to address the basic question of whether CCC and the UT-ID index can be used to assess similarity of dental radiographs with disparate projection geometries when using a computer program to first register the images. The promising results from those pilot studies led to the development of the present project, which included testing of the effect of regions on the UT-ID index and the reliability of the method through repeated registrations or various operators. Most importantly, the regional effect of UT-ID on selected thresholds was examined to ascertain error rates on identity determination.

The results of this study found a significant difference in the UT-ID index between images of the true identity population versus images from the population of nonidentity or mismatched individuals. There are threshold levels that can be established by regions for determination of identity, with calculable error rates at the established thresholds for false acceptance and false rejection rates. Examiner variability in UT-ID values was low when pairs of images were registered and analyzed by three operators. Because the UT-ID index has shown to have high inter-operator reliability, the potential for this method to have high reproducibility and acceptance by individual forensic odontologists should not be discounted.

Four critical factors in the science of admissible evidence in federal courts are (1) the testability of the methods used, (2) the error rate of these methods, (3) the acceptance of the testing methods by the scientific community, and (4) the published method having undergone peer review (30,35,36). This study fulfills the requirements for the first two objectives and seeks to fulfill the third. The UT-ID index of image similarity will need to be used in actual forensic applications to gain general acceptance and to meet the last Daubert guideline.

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