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A Specimen Positioning Device for Dental Radiographic Identification—Image Geometry Considerations

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ABSTRACT: Preventative dental treatment has reduced caries incidence and thereby rendered dental identification, in caries-free individuals, more difficult. An alternate method comparing spatial relationships of dental structures in digitized superimposed antemortem and postmortem radiographs has been previously developed. This paper examined the limitations of this technique and demonstrates a positioning device suitable for reproducing antemortem radiographic image geometry. The paper also examined three specific aspects of image geometry namely horizontal angulation, vertical angulation and focal film distance. Deviations in horizontal angulations between antemortem and postmortem radiographs by as little as 5 degrees makes identification difficult. Changes in vertical angulation or focal-film distance had no affect. This procedure, and the positioning device used to accurately replicate antemortem image geometry is an economical, easy to use adjunct to current methods of dental identification.

KEYWORDS: forensic science, forensic dentistry, radiology, digital radiology

Identification of the deceased is essential for humanitarian reasons and for the investigation of homicides and missing persons. Routine methods of identification include visual and clothing recognition, personal artifacts, fingerprints, DNA matching and medical, skeletal, serological, hair, and dental comparisons (1–4). Other methods of identification include lip prints and specific morphological tooth traits (5–7). Despite the abundance of possible techniques, in cases where bodies are decomposed, fragmented, burned, or otherwise mutilated, the human dentition is likely to be the most valuable in yielding identifying information.

Radiology serves as one of the most objective types of information for evaluation of clinical treatment data and is considered definitive evidence in both litigation and cases of identification (8,9). The application of radiology in forensic sciences was introduced in an 1896 homicide case to demonstrate the presence of bullets inside a victims head (10). The use of radiographs for identification purposes was first proposed by Schuller in 1921 (11). Subsequent early studies have made comparisons of the cranium, skeletal structures, and paranasal sinuses for comparison is impossible if an individual has had none. Since the caries rate has decreased it may be reasonable to assume that there are many persons in the general population who have never had restorative dental treatment. Fortunately most persons have sufficient evidence of antemortem dental treatment which permits conventional dental identification in most cases.

Bernstein (1985) reported a case where conclusive results in a postmortem dental identification could not be obtained even with the aid of posterior bitewing radiographs exposed in a manner duplicating the antemortem films (16). Borrman (1990) encountered similar difficulty in laboratory investigations using patients categorized with and without restorations, finding a greater propensity for error when attempting to correctly match "antemortem" and "postmortem" radiographs of the non-restored group (17).

Traditional methods of antemortem and postmortem dental radiographic examinations centered around visual comparison, presence, absence, shape, and size of dental restorations with less emphasis placed on natural anatomic features such as root shape and bone patterns (18,19). Changing trends in dentistry, however, have necessitated the utilization of alternate methods of examination involving spatial relationships (8,12,13).

The comparison between antemortem and postmortem dental radiographs constitutes an important basis for victim identification. In cases where bodies need to be identified using scientific comparative methods, dental radiographs constitute the most readily available records. Dental records and radiographs are invaluable in body identification in mass disasters, their use highlighted in the investigation of the Noronic disaster (14). Dental X-rays are of high value in forensic identification since they are an accurate reflection of the condition and anatomy of the teeth and jaws at one point in time. Although they can be of poor quality, it is possible to duplicate their exposure parameters at the postmortem radiographic examination.

The advent of modern dentistry has resulted in a decline in dental restorations. In those individuals who have not had restorative dental treatment dental identification may be difficult. Graves (1985) showed that the decayed missing filled surfaces score (DMFS), an indicator of the uniqueness of the dentition, had dropped from 7.06 to 4.77 between 1974 and 1980 (15). In addition, composite and glass ionomer dental materials are being used which cast little or no radiographic shadow further hindering identification. Obtaining a physical match using dental restorations as a means of comparison is impossible if an individual has had none.

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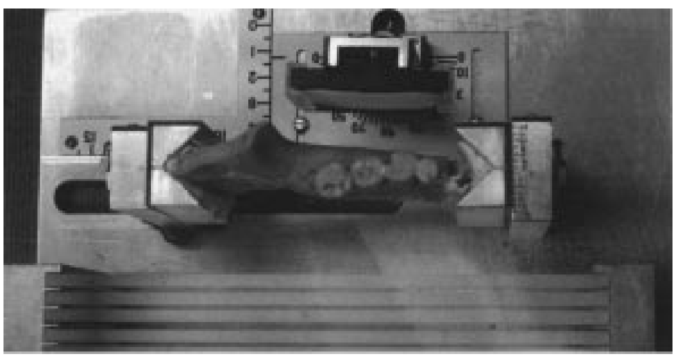
The superimposition of antemortem and postmortem records in forensic sciences has been used in sophisticated computer analysis of facial and cranial features (20). The authors propose a technique and apparatus that enables dental identification of the deceased by comparing spatial orientation of teeth on superimposed digitized antemortem and postmortem dental radiographs. The technique and apparatus are economical and advantageous to use when the identification of a dentition exhibiting minimal dental intervention is necessary.

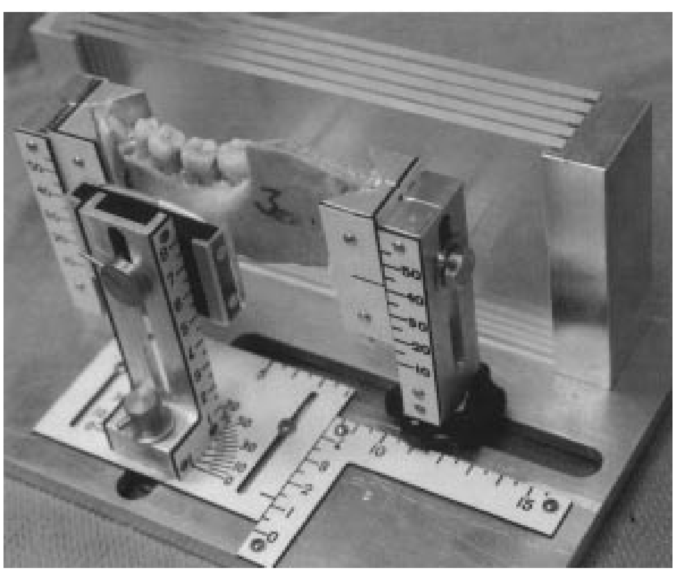
The purpose of this study is to describe a positioning device designed for altering image geometry variables in mandibular anatomic specimens. A secondary purpose is to explore the limits of the use of the spatial orientation of dental structures with respect to image geometry considerations.

Materials and Methods

Technique

The technique involved the construction of a radiographic positioning device on a metal base which housed a film holder ("a") and a specimen holder ("b") (Figs. 1 and 2). Both assemblies are situated behind five removable 0.5-cm thick Lucite sheets used to duplicate X-ray scatter resulting from soft-tissue. The specimen-holding apparatus was constructed to allow vertical movement and horizontal angulation of the mandible section. The film holder allowed vertical movement and vertical angulation of the X-ray film (Fig. 2). Together, the assemblies provide the operator with the ability to manipulate the orientation of the specimen image on the film. Gradations are placed to enable the quantification of movements and angulations (Fig. 2).





FIGS. 1 and 2—*Photographs showing top (Fig. 1) and side views (Fig. 2) of the radiographic positioning device. Commercially-available dental film is placed into the film holder (a) which allows for vertical angulation of the image. The mandible holder (b) allows for horizontal angulation. Lateral displacement of one pole accomodates mandibular sections of varying lengths. Gradations are placed to enable the quantification of movements and angulations. (Schematic of apparatus is available upon request)*

Following postmortem removal, the jaw can be sectioned and a portion placed into the specimen holder. The holder is composed of a fixed pole and a mobile pole which provides for lateral displacement according to the length of the sectioned mandible.

A dental film is placed into the X-ray holder. The angles of the mandible section and the film are manipulated to match the orientation of the antemortem film. Successive films are exposed until the operator achieves a similar orientation between antemortem and postmortem radiographs.

The antemortem and postmortem radiographs are then scanned with a flat-field X-ray scanner (XRS, model 3CX, Torrance, CA, U.S.A.) and digitized on a Macintosh Ilci computer (Apple Computer, Cupertino, CA, U.S.A.). Using Adobe Photoshop image-editing software (Adobe Systems, Mountain View, CA, U.S.A.), the digitized radiographic images are adjusted with the brightness/contrast and levels commands to clinically-acceptable standards. The size and shape of the images are not altered.

Using a closely matching root as a reference point, a horizontal section of the roots from the postmortem film is superimposed on the antemortem radiograph with the cut command. The dental landmarks of each root structure are examined under high magnification on the high resolution monitor. Points of concordance are established along the horizontal section while examining the mesial lamina dura, mesial periodontal ligament space, pulp chamber, distal periodontal ligament space in each of the encountered roots or the mesial and distal lamina dura of a tooth socket where a tooth was lost postmortem. A point is "matched" if the antemortem and postmortem images line up within a width of 0.1 mm (corresponding to half the normal radiographic periodontal ligament width space, Fig. 3).

The degree of concordance (C) for a pair of antemortem and postmortem radiographs is equivalent to the total number of matched points divided by the difference between the total number of points examined and the number of points that were not visible. Congruency is established if the degree of concordance for the antemortem and postmortem radiographs is equal/greater than 90%.

Experimental Procedure

Following the procedure outlined above, a laboratory mandible specimen was sectioned and placed into the apparatus. The horizontal angulation control was incrementally altered, the specimen was radiographed, and the resultant images compared to a control image in order to quantify the limits of angulation. This procedure was repeated for the vertical angulation control.

The technique protocol was followed in a subsequent attempt quantify the effects of changes in focal film distance. The focal spot to film distance was incrementally altered, the specimen was radiographed, and the resultant images were then compared to a control image.

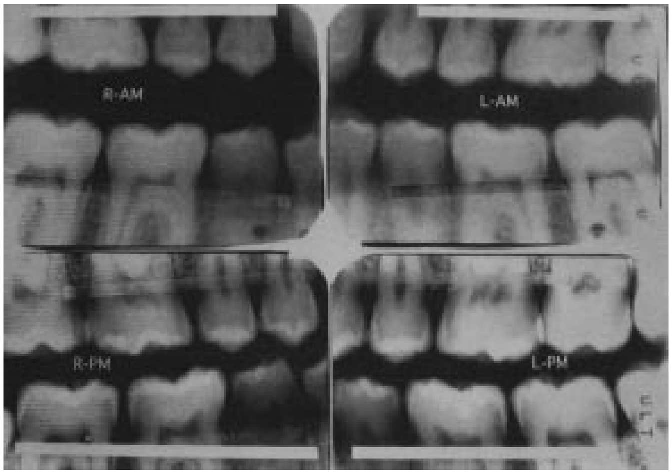


FIG. 3—*Digitized image showing a match between antemortem and postmortem radiographs. A horizontal section from the postmortem film (PM) was digitally "cut" and superimposed along the corresponding section on the antemortem film (AM). The placement of the cut image on the antemortem film was approximated using gross root morphology. A match was determined if the anatomic feature was within 0.1 mm. In this figure all vertical anatomic landmarks were perfectly aligned. This can be clearly seen when examining vertical radiolucent and radiopaque lines extending from the top of the cut section, through the cut section and again below it.*

Results

Examination of the influence of horizontal angulation on the ability to match the spatial relationships of the teeth reveals that angulation differences in excess of 10 degrees from the norm results in a rapid deterioration of the ability to use this technique (Table 1). The percentage of matched points was 100 when a difference of 5 degrees from "antemortem" to "postmortem" was maintained. At an angulation of 20 degrees in either direction, this dropped precipitously to less than 40% of points being matched. Additionally, the number of comparable points available to match decreased as images of objects were projected off the film plane.

Vertical angulation differences did not affect the ability to match cut sections for identification purposes even when vertical angulation varied as much as 30 degrees (Table 2). Over the range of focal-spot to film distances used there was no effect on the ability of the operator to discern the matching points (Table 3).

Discussion

The use of this technique for the analysis of forensically important dental radiologic landmarks relies on their accurate depiction on radiographs. The alignment of numerous anatomic landmarks between antemortem and postmortem radiographs is highly dependent on image geometry. Changes in horizontal and vertical angulation between an "antemortem" and "postmortem" radiograph can affect the ability of an operator to align the radiographic landmarks for identification purposes.

Because horizontal sections are used in this technique, it would be apparent that changes in horizontal angulation between antemortem and postmortem radiographs would have a great influence on the ability of the operator to align the radiographic landmarks for identification purposes.

Horizontal angulation appears to be a critical factor in the application of this technique. In bitewing and most other intraoral dental radiographic studies the horizontal angulation is intended to pass directly through the contact points of the teeth. Examination of Table 1 reveals that an angle change of 10 degrees or more in horizontal angulation makes the comparison of the antemortem and postmortem radiographs impossible with respect to spatial relationships of the tooth-root complexes. Following an angulation of 10 degrees, matching is no longer possible. The potential matches drop from a ratio of 17:17 (matches to possible matches) to a ratio of 5:17. The diminution progresses with each 5 degree angle change (Table 1). Excessive horizontal angulations (45 to 50 degrees from normal) can still yield a single point match because it is always possible to demonstrate at least one periodontal ligament shadow regardless of the horizontal angulation change between antemortem and postmortem radiographs. Matching of this single reference point however is clinically useless.

Errors in vertical angulation are common in the clinical practice of intraoral radiology. To test the influence of these factors on the ability to match horizontal anatomic points of identification,

TABLE 1—*Showing concordance changes as horizontal angle is altered between antemortem and postmortem radiographs. Table 1 shows that angle changes in excess of 5 degrees yield a concordance value (<0.9) which can not be used to wazzu confirm a match.*

Antemortem-postmortem Horizontal Angle Difference	Visible Antemortem Points	Visible Postmortem Points	Matched Points	Concordance*|†
5‡	17	17	17	1.00
10‡	17	17	12	0.71
15‡	17	16	10	0.67
20‡	17	15	6	0.46
25‡	17	13	5	0.56
30‡	17	11	3	0.60
35‡	17	11	2	0.40
5§	17	17	17	1.00
10§	17	17	5	0.29
15§	17	16	4	0.27
20§	17	15	3	0.23
25§	17	14	3	0.27
30§	17	13	3	0.33
35§	17	12	2	0.29

*Concordance = matching points/(total points − points not visible on film).
†Figures have been rounded off.
‡Central ray directed antero-posteriorly.
§Central ray directed postero-anteriorly.

TABLE 2—*Showing concordance for vertical angle changes between "antemortem" and "postmortem" radiographs. Table 2 illustrates that vertical angulation differences do not appear to affect concordance values.*

Antemortem-postmortem Vertical Angle Difference	Visible Antemortem Points	Visible Postmortem Points	Matched Points	Concordance*
Elongation:				
5	17	17	17	1.00
10	17	17	17	1.00
15	17	17	17	1.00
20	17	17	17	1.00
25	17	17	17	1.00
30	17	17	17	1.00
Foreshortening:				
5	17	17	17	1.00
10	17	17	17	1.00
15	17	17	17	1.00
20	17	17	17	1.00
25	17	17	17	1.00
30	17	17	17	1.00

*Concordance = matching points/(total points − points not visible on film).

TABLE 3—*Showing concordance for changes in focal-film distance (object-to-film distance held constant). Table 3 shows that focal-film distance differences do not appear to affect concordance values.*

Focal-Film Distance Increase (cm)	Visible Antemortem Points	Visible Postmortem Points	Matched Points	Concordance*
6	17	17	17	1.00
11	17	17	17	1.00
16	17	17	17	1.00
21	17	17	17	1.00
26	17	17	17	1.00
31	17	17	17	1.00
36	17	17	17	1.00

*Concordance = matching points/(total points − points not visible on film).

elongation and foreshortened images were created from a normal pose where the film plane is perpendicular to the central ray in the vertical plane.

Vertical angulation had no effect on the utility of the technique (Table 2). Even deliberately fore-shortened and elongated images (up to 30 degrees from the norm) had no effect on the ability to use the spatial relationships of the teeth for identification (Table 2). If, however, vertical angulation was so grossly off in a manner which would cast the shadows of the crowns of the teeth over the mid-root region the technique could not be used. The use of the mid-root region rather than the apex of the teeth or the coronal aspect was selected for use arbitrarily. This selection was chosen in that the mid-root region is probably the most stable and reproducible portion of the image of the tooth-root complex owing to both its anatomic position and that it lies in the center of the axis of vertical rotation.

One area which was not addressed specifically in this study was the possibility of having both horizontal and vertical angulation changes in tandem (and perhaps in different directions) as a means of confounding the system. While this is not only possible but probable in clinical dental practice the design of the positioning jig allows for independent correction of both vertical and horizontal errors in antemortem film production when preparing the postmortem radiograph.

The relative focal spot/object/film positions also govern radiographic image formation. In dental radiography, the focal spot is the tungsten target in the anode of the X-ray generator, the object is the teeth, and the film position is the plane of the dental X-ray film. Their relative positions influence the magnification of the image size relative to the object size. When the object to film distance is large, the image appears magnified. Although it is clinically difficult to place the film at a great distance from the teeth, it is not difficult to alter the focal-spot to film distance.

Focal-spot to film distance did not influence this technique. This is not surprising since the object film distance was so small. The image produced by a dental X-ray can be likened to a shadow. If the tooth is close to the film then the shadow of the tooth will be an accurate depiction of the object. If the focal spot is exceedingly close to the object and the film is further away from the object, then the shadow (or image) of the tooth on the film will be much larger than the tooth itself. Although it would be expected that gross differences in the focal-spot to film to object would make relating vertically-oriented landmarks difficult, this did not occur.

The software utilized in this study was used because of its wide availability. It may be run on numerous computer operating systems and is relatively inexpensive. Although other imaging programs are available on the market, they were not used in the present study since the authors were familiar with this program and its many applications. Adobe Photoshop can be used to degrade images by manipulating matrix sizes and shades of gray. Such manipulations could potentially be used to assess the quality of dental radiographic images for forensic purposes and could be a potential avenue of further research. It is likely that using 256 shades of gray and 300 dots-per-inch resolution is in excess of what is needed for the balance between adequate image detail and file storage size.

Another consideration when using this technique would be to determine the minimum and maximum useful height (and length) of digitally cut sections which can be matched from antemortem to postmortem. Throughout the experiment the height of the cut was restricted to between one-third to one-fifth of the total root length. This proved to be adequate and could probably be used as a good general guide.

Despite the development of the concept of concordance and acceptance of a match, the judgment of whether a point matches or not is still a judgment. The technique, in the authors' opinion, should never be used without the careful supervision of a forensic dentist. This is not a weakness since even sophisticated dental matching programs require the forensic dentist to make the final "call" (21–23). As with other forensic techniques, the presence or absence of a match must therefore rest with the responsible individual.

There is little doubt of the remarkable ability of dental spatial analysis to accurately discriminate cases within the permanent dentition even in instances where the antemortem and postmortem radiographic time interval is extensive (24). Similar achievements have also been obtainable without using spatial analysis as described here by MacLean and co-workers (25). In that investigation visual comparison of dental bitewing radiographs showed an accuracy of 93% although the cases used were not "forensic" cases and radiographs were all performed by the same radiographer over a time span of up to 15 years.

Although the application of spatial analysis in the paediatric dentition has been successful, eruption of new teeth as the paediatric dentition develops would confound the utilization of spatial relationships as an evaluative tool in the both the primary and mixed dentitions (24). The utilization of this technique in those instances is the subject of further investigation.

Application of this technique is limited only by logistics. Although not tested in a mass disaster, this system has been successfully integrated into a Coroner's office. An operator familiar with the technique would require at least one hour to supplement a dental identification. This is not a problem in cases in which there is a single or a few decedents but it may pose an impediment to cases of mass disaster. Its widespread use in mass disasters must be questioned due to the amount of time it would add to identification. As an adjunctive means, however, it may prove useful in subjects with minimal dental intervention.

References

1. Buchner A. The identification of human remains. Int Dent J 1985; 35:307–11.
2. Evans K, Knight B. Forensic radiology. Br J Hosp Med 1986;36: 14–20.
3. Dorion R. Disasters big and small. Can Dent Assoc J 1990;56: 593–8.
4. Risch N, Devlin B. On the probability of matching DNA fingerprints. Science 1992;255:717–20.
5. Tsuchihashi Y. Studies on personal identification by means of lip prints. Forensic Sci 1974;3:233–48.
6. Dahlberg A. Ontogeny and dental genetics in forensic problems. Forensic Sci Int 1986;30:163–76.
7. Fischman S. The use of medical and dental radiographs in identification. Int Dent J 1985;35:301–6.
8. Nortje C, Harris A. Maxillo-facial radiology in forensic dentistry: a review. J Forensic Odonto-Stomatol 1986;4:29–38.
9. Sopher I. The dentist, the forensic pathologist and the identification of human remains. J Amer Dent Assoc 1972;85:1324–9.
10. Eckert W. The history of the forensic applications in radiology. Am J Forensic Med Path 1984;5:53–6.
11. Schuller A. Das roentgenogramm der Stirnhohle-eid Hifsmittel fur die identitatsbestimmung von schadeln. Monatsschrift fur Ohren Heikunde 1921;55:1617–20.
12. Knight B. How radiology aids forensic medicine. Radiography 1984;50:5–10.
13. Harris A, Wood R, Nortje C, Thomas C. The frontal sinus: forensic fingerprint?—a pilot study. J Forensic Odonto-Stomatol 1987;5: 9–15.
14. Grant E, Prendergast W, White E. Dental identification in the Noronic Disaster. Can Dent Assoc J 1952;18:3–18.
15. Graves R, Stamm J. Oral health in the United States: prevalence of dental caries. J Dent Educ 1985;49:341–5.
16. Bernstein M. The identification of a John Doe. J Amer Dent Assoc 1985;110:918–21.
17. Borrman H, Grondahl H. Accuracy in establishing identity by means of intraoral radiographs. J Forensic Odonto-Stomatol 1990; 8:31–6.
18. Mertz C. Dental identification. Dent Clin N Amer 1977;21:47–67.
19. Devore D. Radiology and photography in forensic dentistry. Dent Clin N Amer 1977;21:69–83.
20. Brocklebank LM, Holmgren CJ. Development of equipment for the standardization of skull radiographs in personal identifications by photographic superimposition. J Forensic Sci 1989:34: 1214–21.
21. Lorton L, Rethman M, Friedman R. The computer assisted postmortem identification (CAPMI) system: a computer based identification program. J Forensic Sci 1988;33:977–84.
22. Lorton L, Rethman M, Friedman R. The computer assisted postmortem identification (CAPMI) system: sorting algorithm improvements. J Forensic Sci 1989;34:996–1002.
23. Wenzel A. A quantitative analysis of subtraction image based on bite-wing radiographs for simulated victim identification in forensic dentistry. J Forensic Odonto-Stomatol 1994;12:1–5.
24. Wood R. Forensic radiographic identification using manipulated digital dental images (Ph.D. thesis). University of Stellenbosch, 1996.
25. MacLean DF, Kogon SL, Stitt LW. Validation of dental radiographs for human identification. J Forensic Sci 1994;39:1195–200.

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