Robert E. Wood,[1] D.D.S., Ph.D.; Nigel J. Kirk,[1] B.D.S.; and David J. Sweet,[2] D.M.D., Ph.D.

Digital Dental Radiographic Identification in the Pediatric, Mixed and Permanent Dentitions

REFERENCE: Wood RE, Kirk NJ, Sweet DJ. Digital dental radiographic identification in the pediatric, mixed and permanent dentitions. J Forensic Sci 1999;44(5):901–916.

ABSTRACT: The purpose of this paper is to investigate the utility of digital dental radiographic superimposition in the various stages of development of the human dentition. Digital, computer assisted dental identification is a means of identification which allows the spatial relationships of the root and support structures of the teeth to be compared one to the other. The technique has not been tested in patients with developing dentitions. Dental radiographs from patients in the pediatric, mixed and permanent dentition stages of development, simulating "antemortem" and "postmortem" radiographs, were digitized using a flat field radiograph scanner. Anatomic features were used as points of comparison utilizing image editing software whereby anatomic sections were digitally cut from the antemortem image and compared to the same anatomic locations on the postmortem image to assess for points of concordance. The technique was applied to 25 cases within the primary dentition, 25 cases within the mixed dentition and 25 cases within the permanent dentition. Results showed that this was a viable technique within both the pediatric and permanent dentition although it was of little value within the mixed dentition.

KEYWORDS: forensic science, forensic dentistry, digital radiology

Nortje (1986) stated that "the radiographic appearance of the teeth and of the bone of the face is a permanent record of these tissues, even when the teeth and sections of bone are removed for histopathologic examination" (1). Radiology can serve as an objective source of information and is considered definitive evidence in cases of identification (1,2). Postmortem dental radiographic evidence may also be more readily obtained since even minute fragments may be present from burned, macerated or decomposed victims which can be radiologically examined (3). In the authors experience, very small fragments may be forensically useless although a portion of jaw which can be anatomically identified and oriented with respect to right and left and maxilla or mandible may provide enough material to undertake an identification.

Numerous features evident on intraoral radiographs should be assessed in the process of radiographic comparison. These include bone marrow spaces, nutrient canals, incisive canals, median sutures, retained roots, impacted teeth, bony sclerosis, anatomic and non-anatomic radiolucencies and alveolar bone resorption (4). The variability of this evidence over time must be considered and the appropriate weight for each identification must take into account the amount of evidence available, the quality of the evidence, and the experience of the forensic scientist (5). In addition, postmortem dental radiographs should be exposed in a manner which mimics positioning and angulation of the antemortem ones as closely as possible (3). Goldstein et al. (6) designed a specimen positioning device for this purpose, and it has been shown to replicate accurately antemortem image geometry over a range of variables (6).

Common methods of antemortem and postmortem dental comparison concentrate on visible similarities and differences between the two, including presence, absence, shape and size of dental restorations, as opposed to the naturally occurring anatomic features such as bony trabeculation, root morphology and the spatial orientation of teeth (6–8). Direct, radiographically-visible restorative materials are particularly useful in that they have "accidental characteristics" which are unique. A problem in identification arises in persons who have few restorations available for antemortem/postmortem comparison.

In today's population, there are less dental restorations due to the success of preventative interventions (9). Alexander (1991) examined dental charting practices in the American Navy and found that the majority of military personnel "had no or very few restorations upon entry into active duty" (10). This reduction in caries was significant even when compared to similar studies of the same population in the time period 1969–1970 (10). Alexander (1991) suggested that this lack of restorations might simplify charting and reduce charting errors but would also render dental identification more difficult (10).

The problem may be larger than that indicated by Alexander (1991) in that children in Western countries have experienced a dramatic reduction in caries levels (and therefore numbers of restorations) over the past 20 years (11). In a study by Graves (1985), the diseased missing filled surfaces score (DMFS), an indicator of the uniqueness of the dentition dropped from 7.06 to 4.77 between 1974 and 1980 (12). The problem is further compounded by dental materials which cast little or no radiographic shadow, such as glass ionomer cements or resin-composites which are now being used more frequently (6,13).

Graves (1985) stated that this would lead to "a much simpler restorative pattern than at present" (12). This is the exact opposite of what the forensic dentist requires in order to facilitate dental identification. Wenzel (1994) specifically noted that this lack of dental intervention would impede successful identification of victims in the future (14). In a population with an almost non-existent caries rate, conventional dental identification may be of limited value (15).

[1] Office of the Chief Coroner of Ontario.
[2] Bureau of Legal Dentistry, Vancouver, British Columbia.
Received 13 Nov. 1998; and in revised form 12 Jan. 1999; accepted 15 Jan. 1999.

This impedance of identification has been reported in attempted postmortem identification. Even with the aid of posterior bitewing radiographs purposefully exposed in a manner so as to duplicate the antemortem ones, it was impossible to state with certainty that a match had been made (16). In this case, similarities could be seen with respect to the anatomic features but a conclusive match was not possible (16). In laboratory investigations using groups of patients with and without restorations; difficulties in correct identification occurred with greater frequency in the non-restored group (13). Borrman (1990) did not use anatomical features but did suggest that comparison of structures such as pulp, root, and spacing between teeth and bone marrow cavities might have reduced the number of errors (13).

The concept of superimposing antemortem and postmortem records in forensic dentistry is not new. Sophisticated techniques such as computational superimposition of two-dimensional digital facial photographs with three-dimensional cranial surfaces of an unknown skull have been developed (17,18). A technique has also been developed which involves digital photographic superimposition of antemortem and postmortem radiographs comparing spatial orientation of teeth (9,19), this is the technique used in this study.

While this case has been used in clinical coroners cases (Wood, Tai et al.) (9) in the adult dentition, there has been little proof that it is a valid, reproducible, and sensitive method of performing identifications in the pediatric, mixed, and even permanent dentition.

The purpose of the study is to determine whether identification is possible in the pediatric dentition when there is temporal space between antemortem and postmortem examinations, whether identification is possible within the mixed dentition when comparing the spatial relationships between antemortem and postmortem pairs of radiographs and also whether identification is possible in the permanent dentition when the spacing between antemortem and postmortem examinations is chronologically protracted.

Materials and Methods

Technique

Radiographs were digitized on a Macintosh® IIci computer[3] with a flat field X-ray scanner. Adobe Photoshop™ image editing software was used to manipulate the digitized radiographic images. This program is a commercially available program operated on a personal computer. The brightness and contrast of each image was adjusted by the authors using the “output levels” and “brightness/contrast” command of the image editing software until the images were clinically acceptable. The “output levels” command allows the examiner to select the window of radiographic density he/she wishes to see on the computer screen. This is accomplished by selecting the maximum density, minimum density, and mean density using sliding “switches” which appear on the screen. An operator can choose to view only the lightest areas of the film, the darkest, the mid-tones.

A horizontal section of the roots was then randomly selected by one of the authors from the postmortem radiograph and superimposed on the antemortem radiograph using the “cut” and “paste” commands.[4] The horizontal cut consisted of a viewable section across the roots of a group of teeth from anterior to posterior in a mesio-distal direction. The height of the cut was restricted to between $^1/_5$ to $^1/_3$ of the estimated root height. The matching process involved isolating the best matching root (based on gross morphology) of the horizontal section and fitting it to the corresponding tooth on the antemortem radiograph. One of the authors and a research assistant then looked for points of concordance along this horizontal section in an antero-posterior direction. A grade of match, no match, or not visible on film was assigned to the mesial lamina dura, mesial periodontal ligament space, pulp chamber, distal periodontal ligament space, and distal lamina dura in each of the encountered roots or the mesial lamina dura and distal lamina dura of a tooth socket where a tooth was lost postmortem. A structural feature was graded as a match if the antemortem and postmortem images lined up within a width of 0.1 mm (approximately $^1/_2$ a normal radiographic periodontal ligament width space). With their scales equalized, a horizontal section across the tooth roots was excised from either the “antemortem” image and “floated” over its corresponding “postmortem” image in such a manner as to compare the dental landmarks of each root complex structure one to the other. In evaluation of these cases, the following was determined:

- How many anatomic landmarks aligned when comparing radiographs taken at two different times?
- How many anatomic landmarks were available for potential evaluation?
- How many anatomic landmarks did not align?
- What was the degree of concordance (C) of points of identification?

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

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

Concordance of 80% was considered to be a match during this experiment. The computer software allows extreme magnification of the image on screen to assess these minor differences. During this experiment the magnification on screen was 1:1 with the images being viewed on a high resolution computer monitor with low ambient room lighting. The concordance for each of the antemortem and postmortem radiographs was equivalent to the total number of matched points divided by the (total number of points examined minus the total number of points “not visible”).

A point of match was present when the antemortem anatomic structure directly overlaid the image of the same structure on the postmortem radiograph. “Not visible” points were points that were not present or visible on one or the other of the “antemortem” or “postmortem” films. Two operators examined the radiographs to assess whether a point was indeed missing from the film. If 80% or more of the radiographic features examined in this portion of the experiment were in concordance, then the two images were considered to be from the same person, otherwise the images would be considered as a nonmatch.

The radiographs used in the study were not actual antemortem and postmortem radiographs but radiographs of the same patients separated by time, thereby simulating the equivalent conditions.

Stability Study Within the Pediatric Dentition

This study was done using sequential dental radiographs from a single operator at another institution. These were provided, along with an answer key, by one of the authors who did not take part in the observational part of the study. With regards to the stability of the spatial relationships of teeth as viewed on dental radiographs, there were three distinct groups of patients evaluated. These are

[3] Apple Computer Corporation Cupertino California.
[4] Adobe System Inc. Mountain View California.

those in the pediatric dentition, the mixed dentition, and the adult population.

The pediatric radiographs examined in this study contained both matches and non-matches (false matches). The radiographs consisted of paired posterior bitewing radiographs in which both the maxillary and mandibular posterior teeth distal to the cuspid were visible. The radiographs were personally exposed by a single dentist in private practice in a single geographic site over a period of many years. He used archival processing and high quality films. The radiographs were coded prior to their receipt. The radiographs were mounted as pairs and the observers were not aware as to whether the pair was a match or a non-match until the conclusion of the experiment. Some of the radiographs were matches and some were non-matches (i.e., from different patients but having highly similar features). The radiographs were digitized and managed as described above. Following their digitization the "contrast," "density" and "output levels" of the radiographs were manipulated to yield optimum image quality when viewed on the computer monitor. A horizontal section through the roots of deciduous teeth, as previously described, was cut from the "antemortem" and superimposed over the "postmortem" (Fig. 1). The number of aligned points, concordance, and whether the author believed the case to be a match or non-match was recorded. The authors decision of whether the case constituted a match or not was then compared to the key provided at the end of the experiments. The sensitivity, specificity, and predictive value of the test were deduced and expressed.

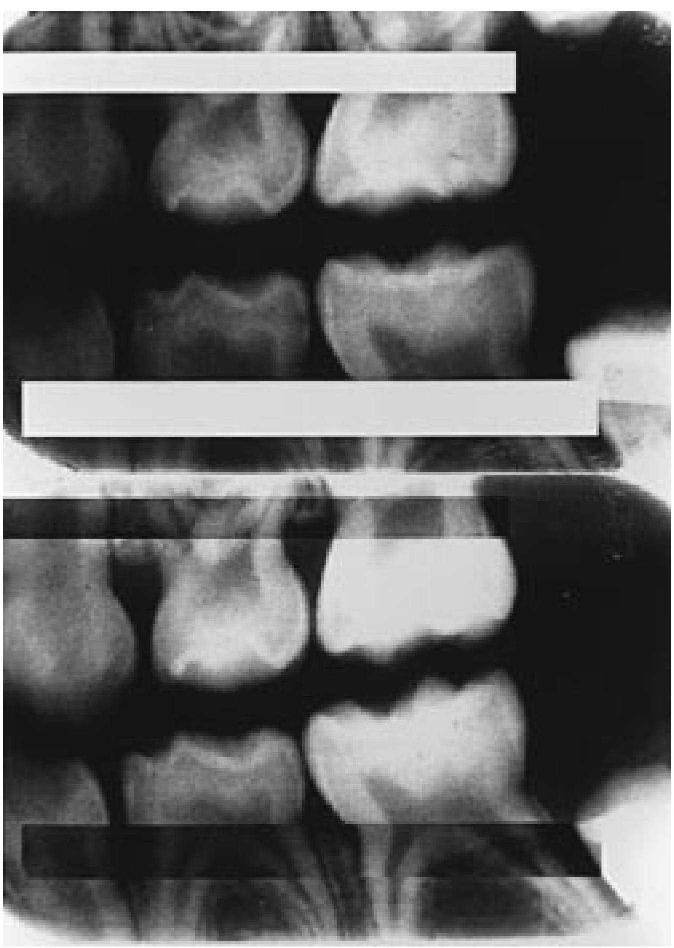

FIG. 1—*Pediatric digitized images showing a high degree of concordance between "antemortem" and "postmortem" dentitions.*

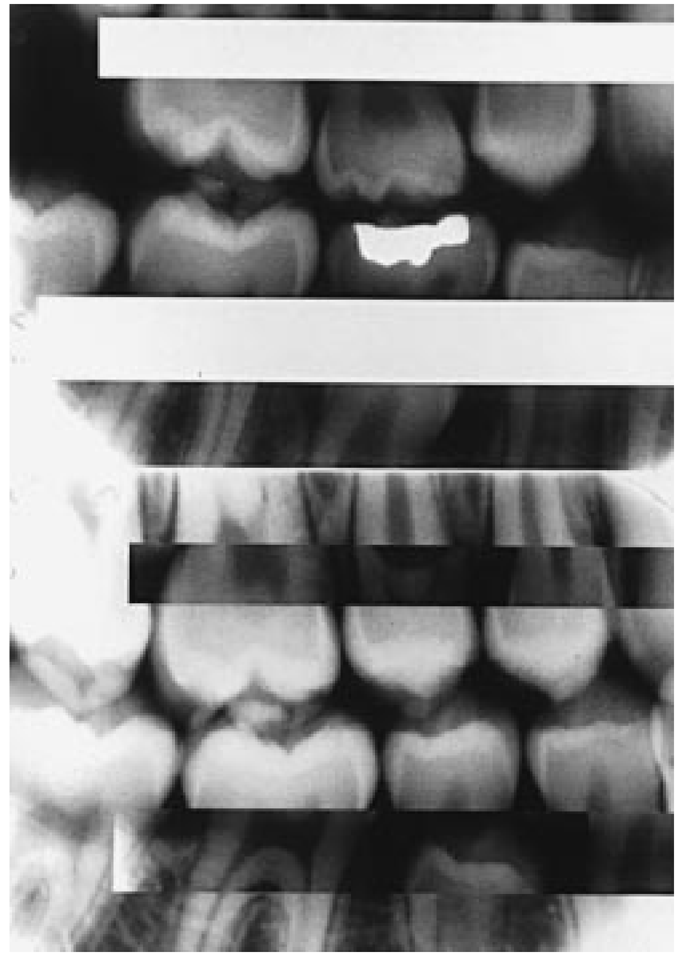

FIG. 2—*Mixed dentition images showing a very low degree of concordance between "antemortem" and "postmortem" dentitions.*

Stability Study of Subjects in the Mixed Dentition Stage of Dental Development

The analysis of the spatial relationship of the roots of the teeth within the mixed dentition, for forensic purposes, is least reliable. At the time of the change in the buccal dental segments from primary to permanent dentition there is significant change in the mesio-distal widths of the buccal segments. In this section of the experiment, the authors define mixed dentition as subjects in whom the permanent buccal teeth are erupting. Since there is no collection in which the exact chronological spacing in terms of months between "antemortem" and "postmortem" radiographs were taken a second series of 25 pairs of posterior bitewings were also exposed in the office of a single practitioner. The radiographs consisted of matches and non-matches with both "antemortem" and "postmortem" radiographs temporally spaced but within the mixed dentition. The images were digitized as before. Measurements were made of the number of possible points in the cut section taken from the "antemortem" film, the number of sections for comparison to the "postmortem" film (Fig. 2). The concordance was also calculated. From the concordance data the case was described as a match or non-match and compared to a master list which contained the information as to whether the pair of radiographs were indeed taken from the same patient. The mean number of aligned points for the true matched group was compared to the true non-matched group using a Student's t-test. The sensitivity, specificity and predictive value of the test were deduced and expressed as a percentage.

Stability Study of Subjects in the Permanent Dentition Stage of Dental Development

Permanent dentition is defined as those patients in whom all of the clinically present teeth are permanent ones. The permanent dentition has been used for identification using this technique in excess of 30 cases by one of the authors with a time span between antemortem and postmortem radiographs as great as 11 years. For this reason the time between "antemortem" and "postmortem" in the study group of radiographs must be extended. Twenty-five patients were used with time differentials between sets of radiographs as long as possible. The minimum cut-off time difference between "antemortem" and "postmortem" images was 60 months (5 years). The images were digitized as outlined above and comparisons were made as previously described. The number of aligned points, concordance, and whether the author believed the case to be a match or non-match was recorded (Fig. 3). The authors' decision of whether the case constituted a match or not was then compared to the answer key held by one of us. Once again the material was supplied from a single dentist from whose practice these radiographs were obtained. The mean number of aligned points for the true matched group was compared to the true non-matched group using a Student's t-test. In addition the sensitivity, specificity and predictive value of the test were deduced and expressed as a percent. In addition the number of months (maximum, minimum, mean, and mode) were calculated.

TABLE 1—*Comparison of the points of concordance within the primary dentition for a group of 25 sets of bitewing radiographs.*

Patient Number	Points Aligned	Concordance (%)	Match (Y/N)	Correct (Y/N)
126	6	27	N	Y
125	27	87	Y	Y
124	23	85	Y	Y
123	3	16	N	Y
122	8	38	N	Y
121	5	23	N	Y
120	19	95	Y	Y
119	6	24	N	Y
117	4	27	N	N
116	3	19	N	Y
115	29	100	Y	Y
114	3	13	N	Y
113	5	21	N	Y
112	19	90	Y	Y
111	6	29	N	Y
110	8	31	N	Y
109	21	91	Y	Y
108	5	23	N	Y
107	24	100	Y	Y
106	4	18	N	Y
105	22	94	Y	Y
104	7	32	N	Y
103	6	22	N	Y
102	23	100	Y	Y
101	22	92	Y	Y

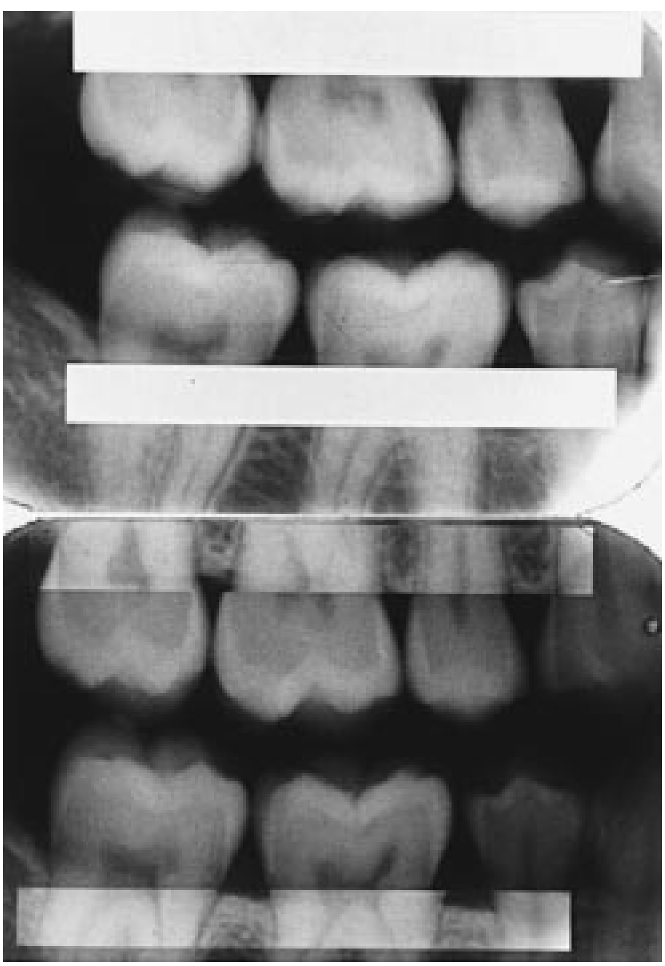

FIG. 3—*Permanent dentition images showing a high degree of concordance between "antemortem" and "postmortem" dentitions.*

Results

Pediatric Dentition

Examination of the radiographs with respect to the relationships of the teeth for identification purposes reveal that in most cases the technique may be used in routine bitewing radiographs in the pediatric dentition (Table 1 and Fig. 1). In one case (case #117) there was a gross difference in the horizontal angulation between the "antemortem" and "postmortem" radiographic examinations. Despite the observers' intuition that these radiographs would match, using the strict criteria of the experimental design they did not, having a concordance of only 27%. This error is not critical in that it would not result in a mis-identification, (false positive) only an inability to make the identification (false negative). This could conceivably be altered by controlling the horizontal angulation in the process of doing the postmortem examination. This was not possible in the current series since the "postmortem" series of radiographs were culled from live patients. These radiographs are archival and the patients have since aged, negating the possibility of doing a second corrected set of radiographs. Even if the patients were available it would not be ethically responsible to expose an extra or additional set of radiographs for the purposes of this study.

Examination of the results of this group of patients reveals that in all cases identifications were positive in those cases where the "antemortem" and "postmortem" radiographic examinations were from the same patient. In those cases where the "antemortem" and "postmortem" radiographic examinations were similar but from different patients, the technique correctly predicted that they were a non-match even though some cases were highly similar clinically. The largest percentage of matching points in a case where radiographs were taken from different patients was 32%. The smallest percentage of matching points in a case where it was deemed there was a match (negating the false negative described above) was 85% (Table 1).

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

Mixed Dentition

The test method proved to be useless in the mixed dentition cases (Table 2 and Fig. 2). A comparison of the predicted matches to the known matches revealed that there was not a single case in which the technique allowed for the successful matching of the "antemortem" to the "postmortem" radiographs. Of equal importance is the observation that the technique did not result in false identification of any individual. In summary the technique was extremely insensitive, not terribly specific but did not result in any critical errors, a critical error being a mis-identification. Surprisingly a comparison of the number of aligned points using Student's t-testing revealed significant differences between matched cases and unmatched cases ($p < 0.007$). A similar comparison of the mean concordance using a t-test reveals the results as significant at $p < 0.05$. This may indicate that there is still value in undertaking the test in cases where there is a moderate to large closed population of subjects. Such examination may lead to information as to which bodies may need further study using alternate identification methods such as DNA analysis. Examination of the sensitivity reveals the test to be 0% sensitive but 100% specific. The predictive value of the test in the mixed dentition is 0% making the test impractical for single cases in open populations.

Examination of the radiographs reveals an average increase in the number of erupted teeth as 3.8 (range 1 to 7 teeth per case) which may partially explain the dramatic decrease in the efficacy of the technique in the mixed dentition subject. If a new tooth arrives on the scene it automatically translates into 5 new points which will not align with "antemortem" points of identification (Table 3).

TABLE 2—*Comparison of the points of concordance within the mixed dentition for a group of 25 sets of bitewing radiographs.*

Patient Number	Points Aligned	Concordance (%)	Match (Y/N)	Correct (Y/N)
1	5	20	N	Y
2	6	27	N	Y
3	6	24	N	Y
4	10	35	N	N
5	6	27	N	N
6	4	14	N	Y
7	8	26	N	N
8	8	34	N	N
9	6	23	N	N
11	6	26	N	N
12	6	23	N	N
13	4	15	N	Y
14	4	25	N	Y
15	12	44	N	N
16	7	24	N	Y
17	10	38	N	N
18	6	25	N	N
19	8	32	N	Y
20	14	52	N	N
21	8	31	N	N
22	8	28	N	N
23	6	25	N	Y
24	2	7	N	Y
25	4	16	N	N
61	8	32	N	N

TABLE 3—*Number of new teeth reaching occlusal plane, concordance and presence of "true match."*

Patient Number	Concordance (%)	No. of Newly Erupted Teeth	True Match (Y/N)
1	20	2	N
2	27	2	N
3	24	4	N
4	35	4	Y
5	27	4	Y
6	14	1	N
7	26	4	Y
8	34	7	Y
9	23	6	Y
11	26	2	N
12	23	2	Y
13	15	2	N
14	25	3	N
15	44	5	Y
16	24	3	N
17	38	5	Y
18	25	4	Y
19	32	7	N
20	52	1	Y
21	31	3	Y
22	28	4	Y
23	25	2	N
24	7	6	N
25	16	6	Y
61	32	6	Y

Permanent Dentition

A single case JC-R was not identified using this technique. The remainder of the tests revealed that the test was employed successfully in predicting a match when a cut off of 80% concordance was used as the lower limit as a match (Fig. 3). The mean number of months separating the "antemortem" and "postmortem" images was 188 months with a lower limit of 60 months and an upper limit of 355 months. The median value number of months separating the "antemortem" and "postmortem" images was 176 months (Table 4). The greatest number of months at which a match could be made was 352 months which translates into more than 29 years. Comparison of the mean number of aligned points using the Student t-test reveals there is a highly significant difference between the true matched and true non-matched groups ($p < 0.0001$). This also holds true when concordance is similarly compared ($p < 0.0001$).

TABLE 4—*Long term stability of 24 patients in the permanent dentition.*

Patient Number	Time Difference (Months)	Points Aligned	Concordance (%)	Match (Y/N)	Correct (Y/N)
TM-R	108	26 of 31	83	Y	Y
TM-L	60	24 of 26	92	Y	Y
PC-L	297	24 of 30	80	Y	Y
JC-R	132	17 of 28	61	N	N
PB-R	352	16 of 30	53	N	Y
AL-R	225	20 of 25	80	Y	Y
PC-R	355	9 of 30	30	N	Y
PB-L	352	11 of 29	38	N	Y
PC-L	355	25 of 30	83	Y	Y
DD-L	62	11 of 28	39	N	Y
RA-L	174	12 of 34	35	N	Y
PS-L	63	15 of 26	58	N	Y
MB-L	176	9 of 27	33	N	Y
JC-L	134	15 of 29	52	N	Y
RA-R	174	10 of 30	33	N	Y
GM-R	190	27 of 31	87	Y	Y
PO-L	173	6 of 28	21	N	Y
LM-L	60	6 of 31	19	N	Y
RC-L	132	8 of 34	24	N	Y
JC-R	305	21 of 26	81	Y	Y
DB-R	234	24 of 30	80	Y	Y
CO-L	67	23 of 26	88	Y	Y
RB-L	132	7 of 30	23	N	Y
GM-L	178	29 of 31	94	Y	Y
DP-L	220	10 of 30	33	N	Y

The sensitivity of the test is 91% and the specificity and predictive value are both 100%.

Discussion

The results of the utilization of this technique in the pediatric dentition are convincing (Table 1). Despite this, one case could not be identified using this technique. It is important to note that once again the problem was not one of mis-identification but inability to identify in case #117 due to the gross geometric differences between the "antemortem" and "postmortem" images. In a mortuary situation this could be accounted for by purposefully altering the image geometry so that the antemortem image geometry could be reproduced in the postmortem image.

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

The utility of the test in the mixed dentition is exceedingly poor. The use of spatial relationships of the teeth is not useful in the mixed dentition. This limitation is not unexpected since by definition the mixed dentition is one of the most dynamic stages of human dental development. This is due in part to the exfoliation of primary teeth and the eruption of permanent teeth (Table 3). It may also be at least in part due to the highly individualistic manner in which the buccal segments of teeth re-arrange themselves during closure of the buccal segments. It is therefore reasonable to expect that this technique will not work during the mixed dentition. Of interest is the 100% specificity the test exhibited. This figure may be spurious since the predictive value and sensitivity was 0% although it does indicate once again the ability of the test to not include false positives. It should also be noted that the test may be useful in individual cases where there has not been a great deal of change in the buccal segments and tooth eruption. The use of spatial relationships of the teeth in the mixed dentition should be undertaken with extreme caution. Furthermore if orthodontic treatment is undertaken within any of the age groups the ability to rely on the unique spatial relations of the teeth and their supporting complexes is not possible.

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

One may pose the question as to why the technique remained valid over such a length of time. Certainly part of this is due to the skill and uniformity of technique used by the dentist from whom these files were culled. It is reasonable to assume that his technique would remain similar throughout his practicing years. It follows then that radiographs such as those received from Coroner's offices (and therefore from different dentists) would not share this uniformity of technique. Fortunately, the postmortem radiographs can be exposed without concern to the radiation dose received so that the postmortem radiographs of deceased persons can be matched to the antemortem ones (6,19). The sensitivity is less than perfect at 91% but the specificity of 100% more than makes up for this small reduction in sensitivity. It seems that dental spatial relationship analysis is a valid tool when applied to a clinical situation in cases with good image quality and standardized technique. Further, the technique can be used in cases with extensive time intervals between antemortem and postmortem radiographic examinations.

Conclusion

Using this technique identification is possible in the pediatric dentition when there is temporal space between antemortem and postmortem radiographs. Reliable identification is not likely in the mixed dentition when comparing spatial relationships between antemortem and postmortem pairs of radiographs. Identification is possible in the permanent dentition when the spacing between antemortem and postmortem examinations is chronologically protracted.

References

1. Nortje CJ, Harris AMP. Maxillo-facial radiology in forensic dentistry: a review. J For Odonto-Stomatol 1986;4:29–38.
2. Sopher IM. The dentist, the forensic pathologist and the identification of human remains. J Am Dent Assoc 1972;85:1324–9.
3. Sognnaes R. Forensic stomatology. N Engl J Med 1977;296:79–85, 149–53, 197–203.

4. Borrman H, Grondahl HG. Accuracy in establishing identity in edentulous individuals by means of intraoral radiographs. J For Odonto-Stomatol 1992;10:1–6.
5. Dailey JC. The identification of fragmented Vietnam war remains utilizing a healing extraction site. J Forensic Sci 1991;36:264–71.
6. Goldstein M, Sweet DJ, Wood RE. A specimen positioning device for dental radiographic identification-image geometry considerations. J Forensic Sci 1998;43(1):185–9.
7. Mertz CA. Dental identification. Dent Clin North Am 1977;21:47–67.
8. DeVore DT. Radiology and photography in forensic dentistry. Dent Clin North Am 1977;21:69–83.
9. Wood R. Forensic radiographic identification using manipulated digital dental images (Ph.D. thesis). University of Stellenbosch, 1996.
10. Alexander RE. Charting accuracy in Navy Dental Records. Mil Med 1991;156:8–10.
11. Marthaler TM. Caries status in Europe and predictions of future trends. Caries Res 1990;24:381–96.
12. Graves RC, Stamm JW. Oral health status in the United States: prevalence of dental caries. J Dent Educ 1985;49:341–5.
13. Borrman H, Grondahl HG. Accuracy in establishing identity by means of intraoral radiographs. J For Odonto-Stomatol 1990;8:31–6.
14. Wenzel AA Lis. A quantitative analysis of subtraction image based on bitewing radiographs for simulated victim identification in forensic dentistry. J For Odonto-Stomatol 1994;12:1–5.
15. Clark DH. Dental identification problems in the Abu Dhabi air accident. Amer J Forensic Med Pathol 1986;7:317–21.
16. Bernstein ML. The identification of a John Doe. J Am Dent Assoc 1985; 110:918–21.
17. 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.
18. Nickerson BA, Fitzhorn PA, Koch SK, Charney M. A methodology for near optimal computational superimposition of two-dimensional digital facial photographs and three-dimensional cranial surface meshes. J Forensic Sci 1991;36:480–500.
19. Tai CC, Blenkinsop B, Wood RE. Computerized digital slice interposition in dental radiographic identification. Case Report. J For Odonto-Stomatol 1994;11:22–5.

Additional information and reprint requests:
Dr. R. E. Wood
Department of Dentistry
Princess Margaret Hospital
610 University Avenue
Toronto, Ontario
CANADA M5G-2M9
Phone: (416) 946-2000 ext. 5582 Fax: (416) 946-6576
e-mail: rwood@cgo.wave.ca