MATCHING SIMULATED ANTEMORTEM AND POSTMORTEM DENTAL RADIOGRAPHS FROM HUMAN SKULLS BY DENTAL STUDENTS AND EXPERTS: TESTING SKILLS FOR PATTERN RECOGNITION

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ABSTRACT

The aim of this study was to evaluate the ability of undergraduate dental students to match simulated ante- and post-mortem radiographs in human skulls with "experts" as controls for the 1)number of post-mortem images needed for a match, 2)accuracy of the matches, and 3)time spent for a match. A film bitewing was recorded in each side of 51 dentate dry human skulls (a.m.-images) and digital images of the teeth were recorded using a sensor (p.m.-images). 102 correctly matching and 102 non-matching image pairs were constructed. Ten students and three experts scored the image pairs as: "certain match", "certain non-match", or "uncertain". None of the experts but half of the students made false positive scores. Half of the students performed just as accurately as the experts. All students (except one who made 8 false positive results) asked for more p.m.-images than did the experts before deciding on a match, however, all students, but one, also spent less time per image pair than did the experts before deciding on a match (P<0.001).
This simulated test sample may identify dental students and dentists with abilities for pattern recognition and thus help in the decision on who might be included as part of a forensic dental team when extra help is needed.

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INTRODUCTION

Dental records, and in particular radiographs, are one of the most reliable methods of victim identification after disasters. After the Asian tsunami (2004), the identification of missing persons with dental records was significantly higher than among those without.[1-3] Teeth and dental restorations are to some extent resistant to fire,[4] and identity was established through dental evidence in 92% of burn victims (292 cases)[5] and in 39%[6] and 88% respectively, of flight crash victims.[7] Radiographs were available in 71% of fire victims in Scandinavia sampled over a 10-year period;[5] these were mostly bitewings, which are the most frequent radiographs taken in general dental practice.[8]

Radiographic identification is based on the recognition of characteristic patterns when comparing the antemortem (AM) and postmortem (PM) images, and dental work facilitates the matching.[9] Improvements in dental health status leading to more individuals without dental restorations may interfere with the discrimination potential[5] when merely anatomic features such as the shape of crowns, pulp chambers and roots, the pattern of alveolar bone trabeculae and crest of the alveolar bone can be used.

Matching of the AM and PM radiographs is undertaken by forensic odontologists following a disaster, and a fundamental requirement is that they make few matching errors. A false positive match may be crucial whilst a false negative match may be less critical since alternative methods may subsequently contribute to the correct match. Specialist training may secure a low number of matching errors. Previous studies have shown that a forensic specialist made fewer false positive matches than a general dentist and a dental student.[10,11] One report states that forensic odontology cannot be carried out by dentists without the proper training, but in disasters of a large scale where there are thousands of fatalities, non-specialists also participated in the identification process.[12] The ability for pattern recognition in volunteers participating in victim identification may be tested in a simulated situation before they take part in true forensic work.

AIM

The aim of this study was to evaluate the ability of dental students to match simulated antemortem and postmortem dental radiographs from human skulls with “experts” as controls, to assess whether inexperienced volunteers possess the same ability for pattern recognition as experts.
Factors for consideration:
1) Number of post-mortem images needed for a match
2) Accuracy of the matches
3) Time spent for a match

MATERIALS AND METHODS

Fifty-one consecutively numbered, dentate dry human skulls were selected for the study. Twenty-five percent of the skulls were from young individuals judged from the minimal tooth wear and developing third molars, and 75% were from older individuals with moderate to extensive tooth wear. None of the teeth had restorations.

Recording of conventional film (antemortem images)

Four bitewings (BW) (an anterior and a posterior exposure in both the left and the right side) were exposed using Kodak Insight (Eastman Kodak Company, Rochester, N.Y., USA) dental film size 2 (31x41 mm) with one film in each paper pack and placed in a film holder (Kwik Bite, Hawe Neos Dental, Bioggio, Schweiz). After insertion of the film holder, the mandible was fixed in occlusion on the holder (Fig. 1). Exposure settings were standardized (Gendex 1000 dental unit, 15 mA, 65 kV, 32 cm f-f distance, rectangular tube collimation, 12 mm acrylic soft tissue simulation). Exposure time varied between 0.26 and 0.34 seconds to obtain a subjectively judged adequate density and contrast in the image. Film processing was semi-automated in a Periomat Plus (Zenith Dental, Agerskov, DK) processing machine. If approximal surfaces overlapped into the dentine, the image was retaken.

Fig. 1. *Antemortem film exposure in a skull.*

Recording of digital images (postmortem images)

Four of the 51 skulls had loose teeth (premolars or molars), and these teeth were removed (simulated tooth extraction) to give variation to the sample. Four BWs were recorded as for the ante-mortem images using a Schick CMOS sensor size 2 (Schick Technologies Inc., N.Y., USA) and a sensor holder (CDR Universal holder, Schick Technologies Inc., N.Y., USA). Further, periapical images were recorded in the premolar and molar regions in both jaws. During these recordings the sensor was supported by wax when positioned behind the teeth and jaw bone. Exposure settings were standardized as for film, and exposure time was 0.18 to 0.22 seconds. The digital images were saved in their original software (Schick CDR, DICOM for Windows, version 3.5.0.145) and thereafter exported to .tiff (tagged image file format).

Scoring antemortem and postmortem image pairs

For the AM image, the BW film that displayed the highest number of teeth (either the anterior or the posterior image from each side of the jaw) was chosen. This film was mounted in a frame and numbered with the skull number. The corresponding post-mortem digital BW from the same side of the same skull was selected. These two images were defined as a match. In this way 102 (51 skulls x 2 sides) correctly matching image pairs were produced. Thereafter, 102 non-matching image pairs were produced by pairing a film and a digital image from the same side of a jaw haphazardly, though not mixing a “young” and an “older” skull. In total, the study sample thus consisted of 204 image pairs, 50% matching and 50% non-matching.

Thirteen participants took part in the study: ten fourth-year pregraduate dental students (Stud01 - Stud 10) who after an invitation to the whole group volunteered to participate, and three “experts” served as controls: one radiologist (Exp02) and two forensic specialists (Exp01 and Exp03) who had worked for more than a decade with forensic sciences (among other tasks, both participated in the victim identification after the tsunami in Thailand 2004-2005).[13] A dedicated program (UniScore, Erik Gotfredsen, School of Dentistry, Aarhus University, Aarhus, Denmark) was developed to display the digital images and score the image pairs. The digital images were blinded with regard to skull number and displayed on a laptop computer (Fujitsu Siemens, 17” monitor, resolution 1024x768 pixels, 32 bit color depth) in 1:1. When displaying a digital image the program stated which film BW was to be paired with the digital image. The film was viewed with a viewer (magnification 1.5) on a light box. The observer scored the image pair as being a: “certain match,” “certain non-match,” or “uncertain” (i.e. cannot decide whether or not this is a match).

It was decided by each individual participant when and for how long they would work at any given time. Each participant logged in using an individual code, and the program kept track of the image pairs that had been scored by that participant. The remaining images were mixed and shown in a random sequence for every log in. When all participants had decided on the 204 image pairs (1st session), those image pairs that had been scored as “uncertain” were re-evaluated in a 2nd session. In this 2nd session, the same digital post-mortem BW plus the other digital BW that had been taken from the same side of the jaw (if the BW shown in the first session was the anterior, then also the posterior was shown and *vice versa*) were displayed and used for the comparison with the film BW. Again, “uncertain” scores were re-evaluated in a 3rd session, in which all post-mortem images, including periapicals and BWs, were displayed and used in the scoring.

Time taken for scoring an image pair was recorded without the participants’ knowledge.

Data treatment

The number of image pairs scored as a “certain match,” “certain non-match” and “uncertain” were counted for each participant in the three scoring sessions, and the following statistics were calculated: True positive (TP) = score “certain match”, which was correct; False positive (FP) = score “certain match,” which was not correct (it was not a match); True negative (TN) = score “certain non-match,” which was correct; False negative (FN) = score “certain non-match,” which was not correct (it was a match).

Differences between the experts and students in the number of images scored as “uncertain” *vs.* “certain” (“certain match” + “certain non-match”) were analyzed by chi-squared tests, along with the differences between the participants in the number of correct (TP+TN) *vs.* incorrect (FP+FN) scores.

Time consumption for matching an image pair ranged from 11 seconds to five minutes; 99% of the scores had taken between 11 and 195 seconds. Since the participants did not know that time was recorded, they may have left the program or have been disturbed without logging out, and the histogram distribution of seconds showed interval breaks after 99%. Therefore, the time for the last 1%, equaling 48 scores in total, was set to 195 seconds, which was thus defined as the longest time used for scoring an image pair.

RESULTS

Number of postmortem images needed to decide on a match

No participant was able to decide if all image pairs were a “certain match” or a “certain non-match” in the 1st session, and a large number of image pairs were scored as “uncertain” (Table 1). Two of the experts scored the lowest number of “uncertain” matches (11%). One student (Stud07) scored fewer “uncertain” cases than did the third expert, but this student made 16 false scores. The remaining nine students scored significantly more “uncertain” cases than the experts ($P<0.05$). In the 2nd session all students still scored a number of cases “uncertain” (range 2-15 cases) while only one of the experts scored “uncertain” (in four cases). In the 3rd session, where periapical images were also available, all observers had decided on either a “certain match” or a “certain non-match.”

Accuracy of matches

In Table 1 the number of correct matches, TP and TN, and the number of incorrect matches, FP and FN, can be seen for the three sessions. None of the experts scored FP while one student made one FP, three students made two FP and one student made 13 FP scores. All observers (except Stud09) made FN scores. Since the total number of incorrect scores was rather small (Table 1), only the difference between the experts and Stud07 was statistically significant ($P<0.02$).

Time consumption

In Table 2 the mean time use per image pair and the total time consumption for each participant can be seen. All students except Stud02 spent less time per image pair than did the three experts ($P<0.001$) (Fig. 2). Stud02, Stud03 and Stud10 spent significantly more time than the remaining students ($P<0.001$), and Stud02 more time than the two others. The remaining students did not differ significantly.

DISCUSSION

Victim identification is frequently based on radiography of the teeth when ante-mortem radiographs are available. The post-mortem exposures may be obtained either by film or by digital receptors. The conventional film demands special facilities, such as developing machines with chemicals that are dependent on clean water, constant temperature, electricity etc. Waiting for the film to be developed may also be an inconvenience, particularly if many retakes are needed. The problems with film development have been described after the air flight crash in 1980, where film development was performed in hotel rooms.[6] Digital dental radiography demands electricity, a digital receptor and a pc, and since image capture takes but a few seconds, the number of images and retakes are not important delaying factors. In the identification of victims after the tsunami in Thailand in 2004, Thai forensic odontologists used a digital sensor to record the post-mortem images (Alan Richards, personal communication). Some ante-mortem radiographs of the missing persons were transmitted in digital form to Thailand using secure wireless transmission protocols,[14] but most ante-mortem images were film-based. The present experiment imitated the situation where ante-mortem images are film-based and post-mortem images are recorded digitally. The Schick CMOS sensor is one of the most commonly sold dental sensors, and was therefore used in the present study for the post-mortem images. In the future most intraoral radiographs will be digital as dentists worldwide are changing to digital receptors.[15,16] It may be that the larger digital image as displayed on a monitor even facilitates the pattern recognition in ante- and post-mortem radiographs compared to a 3x4 cm dental film. This was not part of the present study, but may be interesting for a future investigation.

In our study there were no anatomical differences between the AM and PM images except in cases, where a tooth had been “extracted”. It may therefore be anticipated that it would be an easy task to match the pairs of radiographs correctly. However, there were no dental restorations in the skulls, and tooth wear was quite alike in many of them. While we appreciate that this simulated situation does not resemble true forensic victim identification, this test sample seemed to be useful to distinguish between participants with strong and weaker abilities for pattern recognition.

The number of images needed before an observer could decide on a match or non-match was larger for the students (except for one) than for the experts in our study. Using film, this would result in a slower identification process and additional costs while using a digital receptor, capturing additional images is extremely fast[15,17] and with little extra costs. The difficulties in positioning the sensor for a bitewing examination in a patient[18] may be less severe in the deceased (or when fragmentation occurs) where the jaws can be fixed in occlusion by various methods.

The majority of the students spent less time for scoring an image pair since they apparently sooner scored “uncertain” when in doubt. This may strategically be an efficient approach, particularly when working with a digital receptor where many exposures can be performed in a short period of time, and radiation dose need not be considered.

When visually matching dental radiographs of teeth with no restorations or other dental work, a correct match depends on the observer’s ability for pattern recognition, that is, to analyze and compare the anatomical pattern of crowns, roots, pulp chambers, interproximal marginal bone, etc. Knowledge of distortion in the image due to differences in projection geometry between the ante- and post-mortem images also plays a role. It has been stated that forensic odontology should not be carried out by general dentists without specialist training.[19] Inexperience of the operator is suggested to have lead to errors in the comparative dental analyses that followed the Asian tsunami of 2004.[20] The pregraduate dental students in our study had all passed the same exams including a course in radiology. However, there were large differences between them with respect to the number of false scores made during matching. A false positive match may be unfortunate since in the real situation this means that the deceased is identified and returned to the bereaved family, while a false negative match means that the body is still under investigation, and other methods may aid this. The experts made no FP scores. Half of the students made FP scores, and in particular one student made a large number. The other half of the students made no FP, and made no more FN than the experts. These students seemingly were stronger in pattern recognition than the other students. It may seem odd that the periapical images helped the observers to decide on a match when they were not able to do so when the two postmortem bitewings were compared with the antemortem bitewing. It may be that the projection geometry in the periapicals in some instances was more equal to that of the ante-mortem BW, and the radiographic patterns were therefore more alike. The fraction of incorrect matches was in accordance with previous studies on simulated antemortem and postmortem matching of bitewing radiographs. In another study a forensic specialist, a dentist, and a student matched film bitewings taken several years apart in patients (adults and children) with and without fillings. Also in that study the forensic specialist performed more accurately (2 FP matches) than the other observers (8 FP matches).[11] The number of FN recordings in that study depended on the time interval between the BW to be matched, the longer time between them, the more FN scores.[10] In children it should be more difficult to recognize the radiographic pattern, which changes with growth, the longer the time period between the radiographs, and therefore more FN would be expected.

CONCLUSIONS

In this study of matching simulated antemortem and postmortem radiographs, dental students needed more post-mortem images before deciding on a match than did experts. However, the students spent less time in scoring an image pair than did the experts. Half of the students were less accurate than the experts; in particular they scored false positives, which the experts did not. Half of the students performed just as accurately as the experts. This limited simulated test sample may identify dental students and dentists with abilities for pattern recognition and thus help in the decision as for who might be included as part of a forensic dental team when extra help is needed.

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***Table 1:** Outcome for the 13 participants matching 204 image pairs during the three sessions*

1st session	**True positive**	**False positive**	**True negative**	**False negative**	**"Uncertain"**	**Total**
Exp01	64	0	92	4	44	204
Exp02	86	0	93	2	23	204
Exp03	89	0	89	3	23	204
Stud01	80	0	74	3	47	204
Stud02	49	0	89	1	65	204
Stud03	47	0	86	0	71	204
Stud04	58	0	74	2	70	204
Stud05	71	*1*	66	2	64	204
Stud06	67	0	76	5	56	204
Stud07	87	*8*	72	3	34	204
Stud08	54	0	62	2	86	204
Stud09	69	0	71	0	64	204
Stud10	52	*1*	69	1	81	204
2nd session						
Exp01	29	0	10	1	4	44
Exp02	13	0	10	0	0	23
Exp03	8	0	14	1	0	23
Stud01	13	0	24	0	10	47
Stud02	38	0	11	2	14	65
Stud03	49	0	16	3	3	71
Stud04	36	0	29	0	5	70
Stud05	19	*1*	31	2	11	64
Stud06	26	0	24	0	6	56
Stud07	11	*5*	16	0	2	34
Stud08	42	*2*	38	1	3	86
Stud09	30	0	26	0	8	64
Stud10	42	0	24	0	15	81
3rd session						
Exp01	3	0	1	0	0	4
Stud01	5	0	5	0	0	10
Stud02	10	0	3	1	0	14
Stud03	2	0	1	0	0	3
Stud04	5	0	0	0	0	5
Stud05	6	0	4	1	0	11
Stud06	3	0	3	0	0	6
Stud07	0	0	2	0	0	2
Stud08	2	0	1	0	0	3
Stud09	2	*2*	4	0	0	8
Stud10	6	0	9	0	0	15

Table 2: *Mean, minimum and maximum time (seconds) to assess one image pair by each participant and total time spent for matching all 204 image pairs (minutes)*

	Mean sec.	Min. sec.	Max. sec.	Total min.
Exp01	79	24	195	331
Exp02	62	18	195	235
Exp03	66	17	195	248
Stud01	41	14	195	176
Stud02	67	16	195	315
Stud03	52	15	195	240
Stud04	40	12	195	185
Stud05	35	11	195	163
Stud06	38	11	195	170
Stud07	31	11	176	125
Stud08	38	13	133	185
Stud09	41	16	195	188
Stud10	47	14	195	233

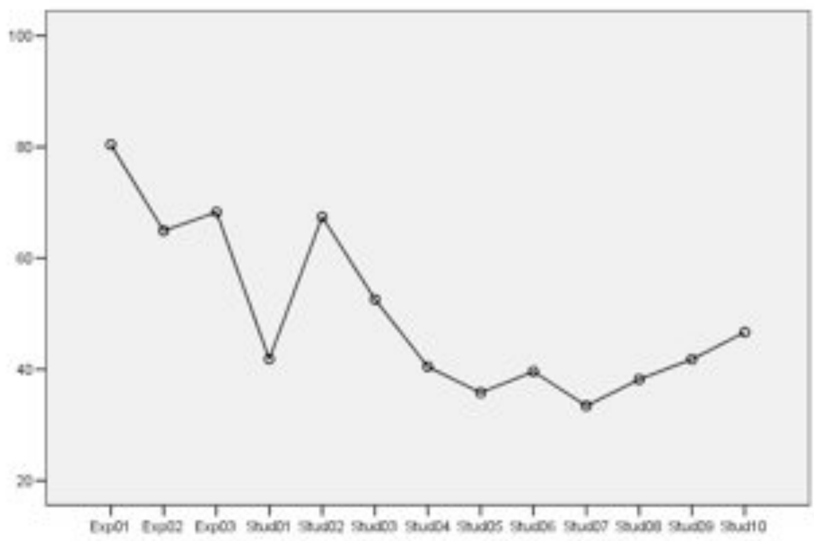

Fig. 2. *Average time spent (seconds) by each participant in scoring an image pair.*

REFERENCES

1. Tan PH. The killing field of Khao Lak: forensic odontology in Thailand tsunami victim identification. *Singapore Dent J* 2005;27:41-50.
2. Petju M, Suteerayongprasert A, Thongpud R, Hassiri K. Importance of dental records for victim identification following the Indian Ocean tsunami disaster in Thailand. *Public Health* 2007;121:251-7.
3. Schuller-Götzburg P, Suchanek J. Forensic odontologists successfully identify tsunami victims in Phuket, Thailand. *Forensic Sci Int* 2007;171:204-7.
4. Sainio P, Syrjänen SM, Komakow S. Positive identification of victims by comparison of ante- and post-mortem dental radiographs. *Forensic Odonto-stomatol* 1990;8:11-6.
5. Andersen L, Juhl M, Solheim T, Borrman H. Odontological identification of fire victims - potentialities and limitations. *Int J Legal Med* 1995;107:229-34.
6. Brannon RB, Morlang WM. The crash of LOT Flight 007: Dental identification. *J Forensic Sci* 2002;6:1323-5.
7. Brannon RB, Morlang WM. Tenerife revisited: The critical role of dentistry. *J Forensic Sci* 2001;46:722-5.
8. Hintze H. Radiographic screening examination: frequency, equipment, and film in general dental practice in Denmark. *Scan J Dent Res* 1993;101:52-6.
9. Andersen L, Wenzel A. Individual identification by means of conventional bitewing film and subtraction radiography. *Forensic Sci Int* 1995;72:55-64.
10. Kogon SL, MacLean DF. Long-term validation study of bitewing dental radiographs for forensic identification. *J Forensic Sci* 1996;41:230-2.
11. MacLean DF, Kogon SL, Stitt LW. Validation of dental radiographs for human identification. *J Forensic Sci* 1994;39:1195-200.
12. Bajaj A. Disaster victim identification: Tsunami. *Br Dent J* 2005;23:504-5.
13. Centers for disease control and prevention (CDC). Rapid health response, assessment, and surveillance after a tsunami-Thailand, 2004-2005. *MMWR Morb Mortal Wkly Rep* 2005;54:61-4.
14. Salo S, Salo H, Liisanantti A, Reponen J. Data transmission in dental identification of mass disaster victims. *J Forensic Odonto-stomatol* 2007:25:17-22.
15. Wenzel A, Møystad A. Experience of Norwegian general dental practitioners with solid state and storage phosphor detectors. *Dentomaxillofac Radiol* 2001;30:203-8.
16. Brady DT. Digital radiography: a survey of dentists in Hawaii. *Hawaii Dent J* 2007;38:12-3.
17. Wenzel A, Kirkevang L-L. Students' attitudes to digital radiography and measurement accuracy of two digital systems in connection with root canal treatment. *Eur J Dent* Educ 2004;8:167-71.
18. Bahrami G, Hagstrøm C, Wenzel A. Bitewing examination with four digital sensors. *Dentomaxillofac Radiol* 2003;32:317-21.
19. Nuzzolese E, Di Vella G. Future project concerning mass disaster management: a forensic odontology prospectus. *Int Dent J* 2007;57:261-6.
20. Kieser JA, Laing W, Herbison P. Lessons learned from a large-scale comparison dental analysis following the South Asian tsunami of 2004. *J Forensic Sci* 2006;51:109-12.

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