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Dentists' Qualifications Affect the Accuracy of Radiographic Identification*

ABSTRACT: This study assessed the effects of forensic odontologists' training and experience upon the accuracy of their dental radiographic identifications. Forty participating odontologists with various levels of training and experience completed a Web-based survey of their qualifications and then completed nine Web-based radiographic identification cases. They made their identifications using the American Board of Forensic Odontology Categories and Terminology for Body Identification. The results indicate that odontologists with high levels of training and experience performed significantly more accurately than those with lower levels. We conclude that high levels of training and experience in forensic odontology should be developed, maintained, and required of dentists who participate in a forensic team dealing with challenging identification cases.

KEYWORDS: forensic science, forensic dentistry, forensic odontology, human identification, dental radiography, telemedicine, observer variation, training standards

Identification of a deceased through his or her teeth is a well-accepted forensic method. Dental identification is based on comparison of the postmortem dental data with the antemortem dental records. These dental records typically include textual treatment notes, odontograms, and X-rays. Dental X-rays are considered the most important data because they are widely available, objective, and reveal details not visible to the naked eye, such as hidden fillings, root shape, endodontic treatments, and alveolar bone morphology. Their utility in identification has been well established (1–5). In general, the greater the number of unique restorations and abnormalities displayed in a dental X-ray, the greater are the points of potential comparison that may lead to a positive identification. However, even if the victim's teeth are free of restorations, digital superimposition and comparison of bony and dental features can provide evidence of identity (6–8).

While these studies demonstrated identification by dental X-ray, they did not validate the reproducibility or accuracy of the identification judgments. Therefore, other studies have attempted to validate radiographic dental identifications (9–12). However, these studies have a critical limitation: they have not examined whether dentists' experience and training levels affect their diagnostic accuracy. Instead, the studies have mostly focused on the effects of various case attributes, such as an extended time elapsed between ante- and postmortem radiographs or the presence of subsequent restorations not present on antemortem films. While this focus is also important, the variability in human judgments is a critical factor that has not been adequately studied. One other limitation to many of these studies is that they have used simulated identification cases, for instance, using ante- and "postmortem" X-rays obtained from living patients enrolled in a dental practice. These studies did not provide any evidence to validate their simulations. Previous analyses of medical problem solving have demonstrated that case simulations must be both carefully constructed and validated in order to be accurate measures of medical expertise (13).

Some examples of the previous research include MacLean (9) and subsequently Kogon (10), who both studied the effect of variable elapsed time between ante- and postmortem radiographs upon identification accuracy. Each study included only three participants, ranging in expertise from a dental student to a trained forensic dentist. Because there was only one participant at each experience level, these studies were unable to statistically assess the effects of differential training and experience upon the identification results. Borrman (11) tested the accuracy of seven participants (six oral radiologists and one forensic dentist) upon both simple and more complex dental identifications. She found that some participants performed more poorly on the complicated cases, but she did not identify or analyze her data upon participants' experience levels. She suggested repeating her study with forensic odontologists and subsequently did this in collaboration with Ekstrom (12). This study had 17 forensic odontologists who analyzed 31 simulated forensic cases. However, the authors did not analyze the performance of the poor and good performing odontologists in relation to measures of their experience or training. Furthermore, these 31 cases were not the same as the 20 cases used in the previous study, so no comparisons could be drawn between the average results of the odontologists and the average results of the oral radiologists.

Finally, Sholl (14) has attempted to relate the training and experience of odontologists to their accuracy in forensic identification.

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He examined the relative identification performance of nine dental hygienists, nine dental students, and nine forensic odontologists. He stated that the odontologists' group performed best and that the subgroup of odontologists with the most forensic experience performed even better. However, he did not support this conclusion with any numerical analysis, stating: "The results can only provide a general indication of trends rather than be subject to any statistically significant analyses."

Therefore, the question of whether differences in odontologists' training or experience (e.g., forensic fellowship, number of actual cases, years of practice) affect their subsequent accuracy on dental identifications remains largely unanswered. The present study is designed to test the hypothesis that different levels of training, experience, and practice affiliation among forensic odontologists correlate significantly with their identification accuracy. The authors believe that answering these questions will have important implications on the future training and certification of forensic odontologists.

Materials and Methods

In order to engage a substantial number of participants, a study Web site was established at http://umed.med.utah.edu/dentalstudy (15). Potential participants were recruited via the American Academy of Forensic Sciences (AAFS) members' roster, the *International Organization of Forensic Odonto-Stomatology (IOFOS) Newsletter*, a list of Worldwide forensic odontologist contacts (16), and via personal contacts. Altogether over 200 forensic odontologists were contacted via e-mail and asked to participate. The survey was hosted on a Microsoft Access 2000 database and served to the participants using Allair Cold Fusion server pages (17) designed and programmed by the principal author. In order to collect details of the participants' qualifications, the survey contained very granular questions on each participant's background, including education (schools attended, year finished, degrees and fellowships earned), membership in professional organizations, years of forensic dental practice, work sector (academia, government, or private), and number of dental identification cases previously encountered.

Based on their survey answers, the participants were grouped into high, medium, or low levels of forensic training. The criteria for classifying the levels of the independent variable we call participant Training were:

1. At least one fellowship in forensic odontology.
2. At least one advanced degree in forensics.
3. Active membership in a forensic professional organization, such as the AAFS or the American Board of Forensic Odontology (ABFO).
4. Recent participation in a forensic odontology training course on identification.

Participants were rated as having a high level of the Training independent variable if they met three or more survey training criteria, medium if they met only two criteria, and low if they met one or fewer criteria (fewer than one, e.g., if they had attended one forensic lecture, presentation, or short symposium).

Likewise, participants were grouped into high, medium, or low levels of forensic experience. Participant experience was classified based upon:

1. Five or more years of forensic odontology experience.
2. Participation in at least 30 single identification cases per year.
3. Participation in mass disaster victim identifications.
4. Current and active affiliation with a forensic institution or team.

Participants were rated as having a high level of the Experience independent variable if they met three or more survey experience criteria, medium if they met only two criteria, and low if they met one or fewer criteria (fewer than one, e.g., if they had only assisted an experienced forensic odontologist in an identification case).

A third independent variable was based upon the survey of employment sector. The Sector independent variable was classified according to three levels based upon each odontologist's primary affiliation: academic practice, government service, and private practice. In summary then, there are three independent variables: training, experience, and sector, each with three levels.

Following the survey, participants were asked to perform nine identification cases consisting of antemortem small X-rays (bitewings and apical radiographs) and nine corresponding postmortem panoramic radiographs. Each postmortem X-ray was accompanied by a brief forensic case history, and the antemortem X-rays were each accompanied by a brief clinical history taken from the dental records. All cases were positive identifications taken from real forensic cases. Radiographs and case histories were de-identified in order to preserve patient privacy. The nine cases were each presented to the participants on separate Web pages. After reviewing each case, the participants were asked to assess the identification using the ABFO Categories and Terminology for Body Identification (18):

1. Positive identification.
2. Possible identification.
3. Insufficient evidence.
4. Exclusion.

This rating allowed us to create the main dependent variable, called participant Accuracy. Accuracy is the mean of the ABFO ratings provided on nine cases by each participant. Because all of the cases were true identifications, a perfect accuracy score is 1.

An overview of the characteristics of the nine cases is shown in Table 1. Column four in the table refers to the number of matching "points" (19) in the ante- and postmortem comparisons, such as uniquely shaped fillings, extractions, root treatments, and any congenital or acquired abnormalities visible both in ante- and postmortem X-rays. In column five, an "explainable inconsistency" (19) is a postmortem finding consistent with an evolution of the antemortem condition (e.g., crown replaces previous filling). The sixth column shows the elapsed time between the ante- and postmortem radiographs. These three columns show variables that have been previously related to the difficulty of identifications (9–12). As the data in these columns suggest, the nine cases varied in relative difficulty. Table 2 shows the cases rank-ordered by overall participant accuracy, allowing us to create a covariate called Difficulty with two levels, easy and hard.

Results

In total, 40 forensic odontologists from 19 different countries completed the survey and the nine identification cases. Training levels among the participants were distributed as follows: 22 highly trained, 12 medium trained, and 6 with low training. Experience levels were thus: 17 highly experienced, 10 with medium experience, and 13 with low experience. Employment or work sector was also assessed: 17 participants were academicians, 14 worked in government service, and 9 were in private practice. The mean results achieved by the 40 participants on the nine cases are shown in Table 2.

Statistical analyses of the participants' results were done against the training level (high, medium, low), experience level (high, medium, low), and sector independent variables and the dependent variable, participant accuracy, using an analysis of variance (ANOVA) technique and unpaired t-tests. A multivariate analysis of covariance (MANCOVA) was done on training, experience, and sector utilizing the within subjects repeated measure of case difficulty (easy versus hard). Statistical analyses were performed using StatView version 5.0 (20) and SPSS version 11.0 (21).

Training Effects—The level of training (high, medium, low) was significant by ANOVA ($F = 6.063$, $p = 0.0053$). Power was adequate at $P = 0.869$. The means for the three training levels, shown in Table 3, are in the hypothesized direction, namely, high training predicts greater accuracy. Unpaired t-tests were done to assess the significance of these means. This analysis was significant for high versus low training levels ($t = -2.853$, $p = 0.0084$) and high versus medium comparisons ($t = -3.149$, $p = 0.0035$), but not for medium versus low ($p =$ ns).

Experience Effects—The level of experience (high, medium, low) was borderline significant by ANOVA ($F = 3.068$, $p = 0.0585$). Power in the AVOVA for a sample size of 40 participants, given the mean differences observed, was slightly low at $P = 0.549$. However, the results of the unpaired t-tests comparing experience levels were definitely significant for high versus low ($t = -2.162$, $p = 0.0393$) and high versus medium ($t = -2.247$, $p = 0.0337$) comparisons, but not for medium versus low ($p =$ ns). The means for the three experience levels, shown in Table 3, are also in the hypothesized direction.

Sector Effects—An ANOVA analysis done upon the sector of employment (academic, government, or private) was also highly significant ($F = 7.594$, $p = 0.0017$, power $= 0.939$). The means

TABLE 1—*Description of the nine identification cases provided to the participating forensic odontologists.*

Case Number	Victim's Age at Death	Sex	Number of Matching Points Between AM & PM X-Rays	Number of Explainable Inconsistencies Between AM & PM X-Rays	Interval Between AM & PM X-Rays, Years
1	51	M	16	0	11
2	40	F	13	2	4
3	71	M	10	4	7
4	46	M	11	2	4
5	49	F	15	1	2
6	55	M	20	0	3
7	76	M	9	2	5
8	53	F	6	2	1
9	73	M	12	3	3

TABLE 2—*Nine cases ordered by participant identification accuracy.*

Case Number	Victim's Age	Sex	Number of Matching Points	Number of Explainable Inconsistencies	Time Elapse in Years	Mean Participant Accuracy*
6 (easy)	55	M	20	0	3	1.225
1 (easy)	51	M	16	0	11	1.27
5 (easy)	49	F	15	1	2	1.275
2 (easy)	40	F	13	2	4	1.3
4 (hard)	46	M	11	2	4	1.55
3 (hard)	71	M	10	4	7	1.6
9 (hard)	73	M	12	3	3	1.625
7 (hard)	76	M	9	2	5	1.8
8 (hard)	53	F	6	2	1	1.925

* The closer the score is to 1 (i.e., positive identification) the higher the participant's accuracy.

TABLE 3—*Mean participant accuracy ratings and standard deviations (SD) for experience and training levels and for work sector.*

	Experience		Training			Work Sector	
	Mean Accuracy	SD	Mean Accuracy	SD		Mean Accuracy	SD
High	1.294	0.366	1.288	0.342	Academy	1.235	0.307
Medium	1.700	0.576	1.759	0.531	Government	1.579	0.536
Low	1.641	0.514	1.815	0.587	Private	1.914	0.451

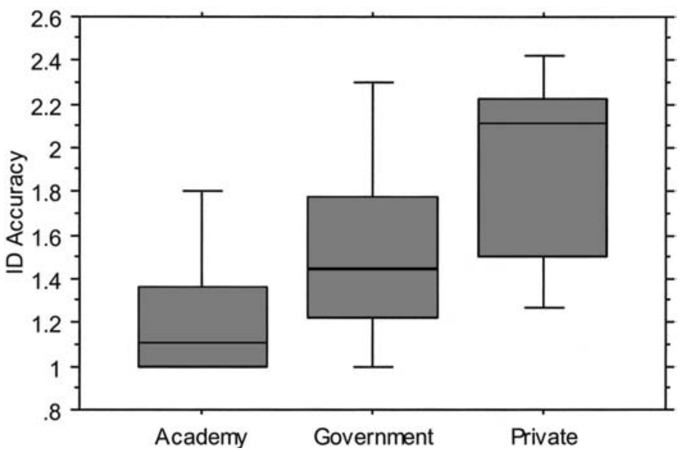

FIG. 1—*Box plot illustrating differences in identification accuracy between participants in different work sectors.*

for the three sectors, also in the expected direction, are shown in Table 3 and Fig. 1. The unpaired t-test method was again used to compare participant performance. The results were significant for academic versus government ($t = -2.244$, $p = 0.0327$) and academic versus private ($t = -4.558$, $p = 0.0001$). However, the results for government versus private were nonsignificant. To determine whether these results were due to a correlation with the other independent variables, we performed cross tabulations with Pearson chi square statistics. This analysis showed a positive and significant (chi square = 10.775, $p = 0.029$) correlation of sector with training.

Finally, a $3 \times 3 \times 3$ (experience $\times$ training $\times$ sector) MANCOVA was performed using the within subjects repeated measure of case difficulty (i.e., each participant performed both easy and hard cases). The results on difficulty were highly significant ($F = 25.165$, $p < 0.001$). The mean accuracy of the 40 participants on hard cases was 1.751 as compared to 1.298 for easy cases. The main effects on training, experience, and sector were the same as in the previous ANOVA analyses.

Discussion

The present results provide clear evidence that different levels of training, experience, and practice affiliation among forensic odontologists correlate significantly with their identification accuracy. To our knowledge, this is the first study that has collected a participant sample size large enough to rigorously evaluate the statistical significance of the human factors involved in radiographic identifications.

To assess the effects of training, we divided the participants into three training levels as described in the methods. The subsequent results showed that the participants with a high training level were significantly more accurate in their identification diagnoses when compared to participants having medium or low training levels. In order to achieve a high training level, participants must have met at least three of four training criteria. This means that, in addition to a formal fellowship or degree, they had either received recent continuing education, been actively involved in a forensic professional organization, or both. In summary, more training positively correlates with better performance.

To assess the effects of experience, participants were classified in three experience levels. These results suggested that the participants with a high experience level were significantly more accurate in their identification diagnoses when compared with participants having medium or low experience levels. Significant results on this variable were obtained by unpaired t-tests. However, the stricter ANOVA analysis was borderline significant, with a 5.85% probability of a Type I error (i.e., mistakenly identifying an experience effect) compared to the desired standard of 5% or less. The effect size for experience, namely the difference between mean participant accuracy in the high and low experienced groups, was lower than for the training variable. As a result, experimental power to detect a truly existing experience effect was only 54.9% for the current sample size. If we were to recruit an additional 25 participants, estimated power would be more than 95% and we would either find a clearly significant experience effect or not. Participants were classified by work sector according to their survey answers. The ANOVA analysis indicated a significant effect for sector, with academicians performing most highly (see means in Table 3), government employees next best, and private practitioners least well. We considered that these sector results might be due to a significant correlation with another variable, such as training or experience. This was shown to be the case for training. The results of the cross-tabulation of sector with training level showed a significant, positive correlation, indicating that the effect of sector may simply be an epiphenomenon of training. We therefore recommend that forensic practitioners should all strive to achieve and maintain high levels of training regardless of their sector of employment.

Our study, as in previous research (9–12), showed that case difficulty predicts identification accuracy. The MANCOVA showed that overall accuracy was significantly higher among easy cases than hard cases. These results clearly indicate the importance of high levels of training and experience for solving difficult and challenging cases.

Our study used a novel, Web-based approach that allowed us to avoid several limitations of conventional paper-based surveys. Previous studies we reviewed have often proved inadequate for statistical analysis because of low participant numbers. Achieving large participant samples is difficult in part because forensic odontologists are thinly scattered. Consequently, the overhead work to contact them, deliver study materials, keep them in the study, and retrieve their results is considerable. However, use of modern Web technology allowed us to overcome these barriers, thereby obtaining geographically and experientially diverse participants. This approach allowed us to safely and securely recruit participants, deliver their case materials, track progress daily, and retrieve results in real time. Participants also found the process convenient because they could receive, manage, and return study information online according to their own schedules.

Because the study was Web-based, security was of great importance. We utilized secure Web pages to which only invited participants were allowed. The cases displayed on the Web pages were real forensic cases, but all identifying patient data were carefully expunged. Participants' individual results and identifying information are kept in complete confidence. The Web pages were specially protected from being indexed by Web robots and were taken down at the conclusion of the study.

An important aim of this study was to advance the level of statistical sophistication applied in this field. That is why we recruited a large participant sample. The use of sophisticated statistical designs allowed us to carefully examine the independent variables and reveal meaningful interactions and associations between them. For example, the significant correlation of training and sector may indicate that academics simply have more time, opportunities, or requirements to achieve high training levels, rather than imply any inherent superiority of academic practitioners.

The present results strongly indicate the importance of training and experience in forensic odontology, especially for hard identification cases. How should odontologists address these findings? Dental schools do not have uniform training requirements in forensic odontology (22). Also, there are only a few formal postgraduate degree programs available. For example, the University of Texas at San Antonio provides two degree programs, a three-year postdoctoral Masters of Science and a 180-hr fellowship in forensic dentistry (personal communication, David R. Senn, D.D.S.). In Vancouver, the Bureau of Legal Dentistry Lab at the University of British Columbia offers Master's and Ph.D. programs in forensic dentistry (22).

However, most busy practitioners cannot spend the time needed to acquire another degree. As a result, continuing education opportunities in dental identification are generally more available and more frequently utilized. Two premier examples include the United States Armed Forces Institute of Pathology annual course in Forensic Dental Identification and Emerging Technologies and the Nordic Organization for Forensic Odonto-Stomatology (NOFOS) International Course in Human Identification. Professional meetings, such as those organized by the AAFS, ABFO, IOFOS and other international groups, are also very important sources of training.

The strong association between training, experience, and performance in the present study indicates that the profession should consider establishing formal criteria for initial forensic training, continuing education, and recurrent experience. The ABFO now leads in setting such standards. Their mission statement reads in part: "The objective of the Board is to establish, enhance, and revise as necessary, standards of qualifications for those who practice forensic odontology…" (23). However, the ABFO requirements for board certification are rigorous and may take many years to achieve. They include requirements to attend annual meetings, present papers, affiliate with a medio-legal agency, and achieve substantial case experience. After meeting these criteria, applicants must still pass a three-day comprehensive exam and then recertify every five years.

All forensic odontologists do not uniformly achieve such high standards. Our study shows that they differ significantly in their levels of training and experience. Only a minority of forensic odontologists are now ABFO certified, and most of those are North Americans. Even in North America, the ABFO has only 83 certified diplomats (24), while the AAFS presently has 424 odontology section members (25). Our study indicates that many practicing forensic odontologists could benefit from clearly defined guidelines for forensic training and experience, short of full ABFO certification. Regional and national forensic organizations could lead in establishing these standards.

Therefore, the authors specifically suggest:

1. Forensic odontology professional organizations should promulgate and harmonize training and experience standards for forensic dentists.
2. Basic certification standards as well as advanced standards are required.
3. Forensic odontologists should demand and patronize forensic training courses.
4. Continuing education materials, delivered over the Web, may prove useful.

We strongly encourage consideration of the fourth suggestion, as the present studies' Web approach was so successful. Today, telemedicine technologies to deliver electronic learning are increasingly robust and ready for adoption. For example, the United States Department of Defense is now training its healthcare providers about weapons of mass destruction using a vendor technology (26) that supports a problem-based learning engine, a didactic presentation engine (including digital images, laboratory result queries, and other realistic data), and a testing and assessment engine. The software includes remotely hosted tools, so that case authors may focus on creating educational content instead of overcoming computer limitations. A professional forensic odontology group could apply such technology to forensic odontology training and assessment.

Our study did suffer from several limitations that future work could address. One limitation was variable computer literacy on the part of some participants. A second limitation was that our study was designed to include only positive identifications. This was because the medical problem-solving literature has indicated that valid simulations are difficult to create (13). As a result we did not assess the effects of training, experience, or sector upon the participants' ability to correctly *exclude* identification. A final limitation was that the independent variables were not completely orthogonal (e.g., training was significantly correlated with sector). In a new study we would attempt to better separate these variables. We might also add additional variables designed to measure the recency of participant training and experience.

Finally, it is important not only to identify potential shortcomings in forensic identifications, but also to generate possible solutions. The present study demonstrates that forensic odontologists must acquire and maintain high-level training and experience in order to achieve their best possible performance. Forensic professional organizations can help them to accomplish this goal by promoting basic and advanced certification standards and by providing effective training courses. In turn, odontologists must actively seek out these training experiences in order to meet the standards.

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26. Medantic Technology Web pages at: http://www.medantic.com/welcome/html/e-learning.html

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