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The Present Direction of Research in Forensic Odontology

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ABSTRACT: Forensic odontology is receiving increased attention in the literature and has become a widely recognized field of expertise with broad ramifications. With this growth, research is needed to solve the most pressing problems of the discipline. The purpose of this paper is to identify current trends in research in forensic odontology. The review consisted of studies using the scientific method and reports of new techniques being tested. Also, abstracts from the annual meeting of the Odontology Section of the American Academy of Forensic Sciences from 1980 to 1987 have been reviewed to determine the current areas of emphasis in forensic dentistry.

KEYWORDS: odontology, research, human identification, bite marks

Forensic odontology is receiving increased attention in the literature and has become a widely recognized field of expertise with broad ramifications. With this growth, research is needed to solve the most pressing problems of the discipline. Whittaker [*1*] reported that although numerous case reports had been published, there were "fewer than 80 research reports readily identifiable as projects set up specifically to investigate dental forensic problems." Furthermore, Whittaker stated that his article on research in forensic odontology was the first review of its kind, and no other formal review of research in this area has been undertaken since. The purpose of this paper is to fill this void and to identify current trends in research in forensic odontology.

Methods

The review consisted of studies using the scientific method and reports of new techniques being tested. The major topics addressed include dental age estimation and identification, mass disaster identification, computerization, craniofacial superimposition, and bite mark analysis. Abstracts from the annual meeting of the Odontology Section of the American Academy of Forensic Sciences from 1980 to 1987 have been reviewed to determine the current areas of emphasis in forensic dentistry. Abstracts were categorized according to the type of paper (research, technique improvement, case report, literature review, or education-re-

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lated) (Table 1) and the topic of the paper (identification, bite marks, mass disaster, photography, computerization, law, child abuse, and miscellaneous topics) (Table 2).

Results

From 1980 to 1987, there was a 359% increase in the number of abstracts (17 to 61). In general, the largest number of abstracts per year were case reports followed by technique improvements and research studies. The highest percentage of all abstracts per year were case reports in 1980 through 1986 and research studies in 1987. The number of research studies increased 633%, from 3 in 1980 to 19 in 1987. The percentage of research studies of the total abstracts has varied from 10 (1983) to 31% (1987).

The two most frequently reported topics during this period were bite marks (1980 and 1982 to 1986) and identification (1981, 1987) (Table 2). The percentage of abstracts per year which dealt with bite marks varied from 30 (1981) to 55% (1982), while those which dealt with identification varied from 18 (1980, 1984) to 55% (1981). There has been an increase in the number of abstracts on mass disasters, photography, computerization, and legal aspects

TABLE 1—*Types of abstracts, 1980-1987.*

	1980	1981	1982	1983	1984	1985	1986	1987
Research	3 (18%)	5 (25%)	4 (20%)	3 (10%)	6 (14%)	11 (24%)	10 (21%)	19 (31%)
Technique improvement	3 (18%)	5 (25%)	5 (25%)	7 (23%)	7 (16%)	13 (28%)	8 (17%)	15 (25%)
Case report	6 (35%)	8 (40%)	7 (35%)	17 (55%)	24 (55%)	15 (33%)	26 (54%)	16 (26%)
Review	4 (24%)	2 (10%)	4 (20%)	3 (10%)	6 (14%)	7 (15%)	3 (6%)	11 (18%)
Education	1 (6%)	0	0	1 (3%)	1 (2%)	0	1 (2%)	0
Total abstracts	17	20	20	31	44	46	48	61

TABLE 2—*Topics of abstracts, 1980-1987.*

	1980	1981	1982	1983	1984	1985	1986	1987
Identification	3 (18%)	11 (55%)	7 (35%)	12 (39%)	8 (18%)	12 (26%)	12 (25%)	23 (38%)
Bite mark	6 (35%)	6 (30%)	11 (55%)	16 (52%)	21 (48%)	16 (35%)	20 (42%)	18 (29%)
Mass disaster	0	2 (10%)	1 (5%)	1 (3%)	2 (5%)	2 (4%)	6 (12%)	8 (13%)
Photography	0	2 (10%)	3 (15%)	2 (6%)	2 (5%)	3 (7%)	7 (15%)	5 (8%)
Computerization	3 (18%)	1 (5%)	2 (10%)	1 (3%)	0	1 (2%)	4 (8%)	3 (5%)
Law	2 (12%)	1 (5%)	0	0	12 (27%)	9 (20%)	6 (12%)	4 (7%)
Child abuse	3 (18%)	0	0	0	0	2 (4%)	0	0
Miscellaneous	2 (12%)	1 (5%)	0	1 (3%)	2 (5%)	1 (2%)	1 (2%)	5 (8%)
Total abstracts	17	20	20	31	44	46	48	61

of forensic odontology. A small number of papers have been reported on child abuse. The most frequent topics of research papers have been identification and bite marks, respectively. There was an increase in the number of research abstracts dealing with computerization, mass disaster, and legal aspects.

Discussion of Forensic Odontology Research

Dental Age Estimation and Identification

Estimation of age at death by examination of teeth has received considerable attention. Such a determination can be made in young individuals by comparison of radiographs to charts of tooth development [*2*]. In older individuals, however, the process is more difficult. Gustafson is credited with reporting the first method of calculating age from teeth, using six age-associated parameters determined from sections of ground teeth [*3*]. The translucence of dentin, one of two factors which correlate highly with age [*2*], is evaluated from a 1.0-mm-thick section, while the others are evaluated from 0.25-mm-thick portions.

Metzger et al. [*2*] suggested that the evaluation of thin sections results in potential problems, including inaccurately high values for dentin translucence. They advocated the use of a thick (1.0-mm) section in the use of teeth for age estimation. In a related article [*4*], the "half-tooth technique" was compared with thin sections for accuracy in age estimation. Although Solheim [*4*] reported that this technique has a tendency for higher values, the results showed no significant differences between the two techniques. This appears to be a superior technique in some regards, including faster preparation of teeth.

The use of cemental annulations as a method of age determination in humans has been evaluated [*5–7*]. Stott and Levy [*5*] reported that countable cemental annulations are present in human teeth. In evaluating teeth from three dissection cadavers, the authors concluded that with proper staining and by utilizing light microscopy and photography, cemental annulations can be counted and used to provide a close estimate of age. Miller et al. [*7*] analyzed cemental annulations from 79 extracted human teeth. Contrary to the previous study, results showed that determining chronological age from cemental annulations was not possible. Additional large-scale human studies would be useful in further evaluating this technique.

Whittaker and Kneale [*8*], using scanning electron microscopy (SEM), evaluated the mineralizing front in human dentin as an aid in age determination. Results showed a relationship between the number of tubules seen at the dentin/predentin junction and the age of the tooth. The relationship was not significant, however, and did not seem reliable enough for use in forensic odontology. Studies evaluating mineral content and transparency of root dentin [*9*] and racemization of aspartic acid in dentin [*10*] as determinants of age have also been reported.

As an alternative to using skull characteristics and morphology of teeth in sex determination of humans, experimentation using pulp tissue has been conducted. Whittaker [*11*] stained the pulpal tissue from 200 extracted teeth and examined cells for the presence of a fluorescent Y chromosome. Correct assessments of sex determination were common (usually better than 70%) in pulpal tissues up to 5 weeks after removal of the blood supply. Although this may represent a viable alternative to evaluating skull and tooth characteristics, refinement of the technique is still needed.

The determination of species of origin of a tooth has been previously attempted by examination of tooth morphology and of enamel and dentin variations. Whittaker et al. [*12*], using electrophoresis, demonstrated that such a determination could be made by serologic means, using extracted antigens from the crushed dentin powder of five species, including humans. Results indicated that no cross-reaction occurred between species, and no false positives were observed. The technique was deemed reliable in determining species up to ten weeks after removal of the tooth [*12*].

In recent years, several polymorphic enzyme systems in the human body have been used as aids to the forensic science identification of blood samples and stains [*13*]. Turowska and Trela [*14*] demonstrated through electrophoresis that phosphoglucomutase (PGM), adenosine deaminase (ADA), and adenylate kinase (AK) phenotypes were found in dental pulp, but not in dentin. Whittaker et al. [*13*], using starch gel electrophoresis, demonstrated the presence of PGM in about half of the fresh teeth tested. The authors pointed out that fluoride is an inhibitor of the PGM enzyme, and this may prove to be a limitation of this technique and other systems used to type blood [*13*].

Blood group determination may also be accomplished using pulpal tissue from human teeth. Higginson and Hill [*15*], using the microelution technique, reported that 17 of 18 ABO determinations were accurate, as were 15 RhD determinations. Korszun et al. [*16*] raised the question of whether thermally changed tissues retain blood group activity or not. Results of their study showed that antigenic activity was not detectable in pulps of ABO blood groups at temperatures between 200 and 300°C.

Mass Disaster Identification

Various identification systems using microdisks or other markers placed on teeth have been introduced and evaluated for individual and mass disaster identification. In the Swiss Identification System [*17*], an information-encoded microchip (gold disk, 2.0 mm in diameter and 0.25 mm thick) is placed in a small cavity preparation on the lingual surface of a molar tooth. The preparation is cut within the enamel, and filled with a fire-resistant, leakage-proof, colored, composite material. In the event of a fatality, in theory, the colored restoration could be easily located, the information chip retrieved, and from the code, a positive identification made. A similar system, the American Dental Identification Registry, was proposed in 1985, but ultimately has not been available because of patent problems.

Another system, The Dentify System, advocates placing small data-encoded chips under amalgam restorations, which include a radiographically identifiable notched pin to alert the postmortem examiner to the tooth [*18*]. In a study by Wilson and Kolbinson [*18*], 20 teeth containing such identification chips with notched pins were heated to a temperature of 1000°C for 1 h and then examined by SEM and optical microscopy. Of the 18 chips that were recovered, 16 were considered readable. The identifier pins, however, were partially or completely damaged at this high temperature and served little value as a marker device.

It has been estimated that 25% of the victims in a mass disaster could be complete or partial denture wearers [*19*]. For purposes of identification, it has been recommended that all removable prostheses be permanently marked [*19,20*]. MacEntee and Campbell [*20*], in testing various materials for denture inclusion under high temperatures, found that stainless steel labels would endure fire exposure most successfully in terms of accurate identification.

Computerization

Advances have been made in computerization as it relates to forensic odontology. Siegel et al. [*21*] suggested the need for a central computerization system for dental records, not only for mass disaster purposes, but also for identifying individual missing persons. The authors described a new charting system in which the dental data can be processed in a computer system. By incorporating dental profiles of both missing persons and unidentified corpses, the computer system correctly matched 85 of 100 cases, demonstrating the practicality of this system. The NOVA*STATUS system, a text-retrieval program used by Norwegian police, enables the user to locate all documents containing a certain word or combination of words in 1 sentence [*22*]. Another system, using a 6-digit code, uses 2 digits for tooth designation, 2 for tooth surface involved and 2 for treatment type and material [*23*].

Other computerized systems presently in use in the United States include CAPMI and

NCIC. The U.S. Army developed the CAPMI (Computer-Assisted Postmortem Identification) system, a computer-based identification system which stores information concerning the type and location of restorations and the presence or absence of teeth. The CAPMI system has been effectively utilized in both experimental trials [*24*] and real-life situations [*25*]. Present studies are evaluating the incorporation of radiographic information into the CAPMI system. The FBI National Crime Information Center (NCIC) [*26,27*], another computer-based identification registry, is used nationwide by local, state, and federal agencies. The NCIC includes a missing person file and an unidentified person file, both of which may be cross-checked. Dental charting is an integral part of the personal descriptors form and indicates presence or absence of teeth, restorations or caries present by tooth surface, removable appliances, and other characteristics. The NCIC system is in operation 24 h a day, seven days a week. More work is needed to evaluate the use and efficiency of these types of systems.

Besides the identification of mass disaster and other victims, computers are being used for bite mark evaluation. Duguid and McKay [*28*] evaluated bite marks by examining bite length measurements and tooth-to-arch relationships. These are compared to a previously selected ideal arch form using an *X, Y* digitizer and computer. Computer analysis of bite marks has also been investigated by Rawson et al. [*29*], who demonstrated the individuality of bite marks from the human dentition. Sognnaes et al. [*30*] used computer analysis to show differences in the bite mark patterns of five pairs of identical twins. This application of computers may be helpful in eliminating subjective correlations made in bite mark analysis.

Craniofacial Superimposition

Craniofacial superimposition is a complex technique which is being evaluated and utilized by various investigators. Cases using the dentition as part of the technique have been reported [*31,32*]. In one case involving a U.S. serviceman in North Vietnam [*31*], only a portion of the maxilla, less the teeth, was recovered. By magnifying a transparency of an antemortem radiograph of the corresponding section, it was possible to superimpose the radiograph over a photograph of the remains of the maxilla. In another case [*32*], a technique was utilized whereby the distance between two points on the anterior teeth of a skull was used as a reference in determining the necessary magnification of an antemortem photograph of the suspected individual. The validity of the technique is controversial, and more work is needed to document this procedure fully. This technique should not be used as the sole basis of a positive identification, but in conjunction with other more universally accepted modes of identification [*31,33,34*].

Bite Mark Analysis

One of the fastest growing areas of forensic odontology is bite mark analysis as a means of identification. Several unique methods of recording bite marks have been reported. McCullough [*35*] reported a case in which bite mark analysis was carried out with photographic superimposition in conjunction with xerography. Xerographic photocopies of a bite mark in cheese and a subsequent clay bite impression of the suspect were produced on a Savin model 755 photocopier. A mylar transparency copy of the clay bite photo was made, and a strong correlation was found upon superimposing this copy with that of the cheese bite copy.

Rao and Souviron [*36*] suggest dusting and lifting the bite print, as is done with fingerprinting. Standard fingerprint powder is applied to the bite mark with a camel hairbrush, and the print is subsequently lifted with clear fingerprint-lifting tape. The bite print is then placed on a fingerprint card and compared with a similar card produced from the suspect's dentition. This appears to be a useful technique which is underutilized, and further research concerning its application to forensic odontology may be helpful.

Rawson et al. [*37*] evaluated the effectiveness of contrast-enhanced radiography in the

evaluation of bite marks. Bite marks were covered with a thin layer of a radiopaque medium. Xeroradiographs and radiographs using image-intensifying cassettes were taken. Radiographic examination of bite marks was concluded to be a useful adjunct to conventional photography, particularly in demonstrating deep tissue damage.

It has been reported that the quality of the bite mark depends on the substance in which it was left [*38,39*]. Whittaker [*38*], in a laboratory study of bite mark accuracy, compared imprints made in wax versus animal skin, which was used to simulate human skin. Two independent observers correctly matched the wax bite marks to the corresponding stone models of the dentition in 98.8% of the cases, whereas matching the bite marks in the animal skin corresponded in only 76% of the cases. Solheim and Leidal [*40*] assessed the value of scanning electron microscopy (SEM) in the evaluation of bite marks in foodstuffs. Of the various foods which were tested, only a few (butter, chewing gum, and Norwegian brown cheese) showed the necessary detail in the bite mark to warrant use of the scanning electron microscope.

Studies have tested the consistency and reliability among odontologists in analyzing bite marks. The American Academy of Forensic Sciences (AAFS) and the American Board of Forensic Odontology have developed and tested a scoring system for evaluating bite marks to ultimately standardize the procedure [*41*]. The system involves scoring a bite mark for arch size, shape, and tooth positions within the arch. Studies showed a high degree of reliability among raters using this system and an ability to distinguish varying degrees of match [*42*]. An additional study provided recommendations for the analysis of photographically distorted bite marks [*43*].

A description of some of the techniques and trends of research in forensic odontology has been presented. There are other areas addressed in the literature, including photography, child abuse, and legal and educational aspects. Numerous studies on saliva analysis have been reported, including typing of saliva stains [*44-46*], species identification from saliva [*47,48*], and analysis of ABO(H) blood group substances [*49-55*], protein content [*56*], and active microorganisms in saliva [*57-59*]. Research further delineating the characteristics of saliva is needed considering its application in the identification of assailants through saliva samples left on bite marks.

Summary and Conclusions

Current trends in research in forensic odontology appear to be directed toward the continued application of modern technology in areas such as computerization, new and more accurate laboratory tests in areas such as the analysis of bite marks and saliva, mass disaster identification, and age estimation from teeth. From 1980 to 1987, there has been a 359% increase in the number of AAFS Odontology abstracts. The number of research abstracts has increased 633%, while the percentage of research abstracts per year has increased from 10% in 1983 to 31% in 1987. With the ever-increasing interest in the forensic sciences and the increased emphasis in research and application of new and more accurate techniques, research will continue to flourish, helping to complete the transition of forensic odontology from a subjective art to an objective science.

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