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TECHNICAL NOTE

ODONTOLOGY

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Testing a Novel 3D Printed Radiographic Imaging Device for Use in Forensic Odontology*

ABSTRACT: There are specific challenges related to forensic dental radiology and difficulties in aligning X-ray equipment to teeth of interest. Researchers used 3D printing to create a new device, the combined holding and aiming device (CHAD), to address the positioning limitations of current dental X-ray devices. Participants ($N = 24$) used the CHAD, soft dental wax, and a modified external aiming device (MEAD) to determine device preference, radiographer's efficiency, and technique errors. Each participant exposed six X-rays per device for a total of 432 X-rays scored. A significant difference was found at the 0.05 level between the three devices ($p = 0.0015$), with the MEAD having the least amount of total errors and soft dental wax taking the least amount of time. Total errors were highest when participants used soft dental wax—both the MEAD and the CHAD performed best overall. Further research in forensic dental radiology and use of holding devices is needed.

KEYWORDS: forensic science, forensic dentistry, forensic odontology, forensic dental identification, intraoral forensic radiography, dental radiology technique, radiation safety, postmortem, antemortem, 3D printing

Dental identification methods are often used when visual recognition of victims of homicides, accidents, or mass fatalities incidents (MFI) is not possible (1). Distinct dental features remain one of the most efficient postmortem (PM) identifiers (1); teeth have the ability to survive decomposition and extreme temperatures when the deceased are found decomposed, burned, dismembered, or skeletonized. Dental identifications have been made on a single tooth alone (2). An important part of the dental identification process is accomplished by comparing antemortem (AM) radiographic images and dental records, to PM images. In order for victims to be correctly identified, the PM dental radiographs must accurately capture similar angulations, anatomical structures, dental restorations, and dental appliances for comparisons. (1) Limitations of radiographic identifications based on AM and PM image comparisons are well described in the forensic literature as "labor-intensive, subjective, of poor image quality, and containing insufficient dental anatomy for differentiation among teeth and other dental anatomy"(1,3). Specifically, common technical errors related to dental radiographic exposure include film packet and/or sensor placement and angulation discrepancies (2). Bruhn, Newcomb and Giles presented a comprehensive protocol for PM radiographic techniques with the dental hygienist as part of the forensic radiology team and determined error rates for the exposure of 380 PM intraoral dental forensic radiographs (4). The paralleling technique was found to produce less technique errors when compared to the bisecting technique, with errors in horizontal and vertical angulation as specific error types that were found as causing retake exposures (4). Substantial differences in angulation between comparable radiographs can cause distortion and false variations of dental anatomy shapes and patterns (2). Other technical errors in dental radiology (not necessarily exclusive to forensic odontology) are exposure and processing mistakes (2). All dental radiographs, including AM and PM, need to be properly angulated, well exposed, and well processed when used for comparisons and identifying missing, or unidentified individuals and victims of mass fatality incidents (MFI) (2).

Specific forensic odontology challenges related to radiology include lack of occlusion and difficulties in aligning X-ray equipment to teeth of interest (2). As deceased victims cannot hold their jaws in place to position radiology props or equipment, aiming device and film and/or X-ray sensors, dental radiographers may make several attempts at choosing which radiographic technique (paralleling or bisecting) and type of holding device (i.e. commercial film holders, soft dental wax) to use. The effectiveness of dental radiology techniques (paralleling and bisecting-the-angle) and use of holding devices or props vary within forensic odontology literature and have not been proven as more advantageous over another. The Manual of Forensic Odontology (Fifth edition) describes general techniques

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used to hold film and/or digital sensors "in place" when exposing dental remains (2). For dental remains described as "accessible," commercial film or X-ray holders can be used; soft dental rope wax or clay can also be used to secure film and/or sensors to teeth for fragmented dental or skeletonized remains. Other techniques included a radiographer or assistant using lead gloves or other available props to keep film and/or sensors in place (2).

Radiology equipment can also exacerbate alignment issues. Portable equipment such as the Nomad Pro™ (Aribex, Inc. Charlotte, NC, USA) is commonly used for dental radiation exposure during MFI's, mobile dentistry, and in mortuary settings. In such cases, the "arm" of external aiming devices can block part of the portable X-ray equipment from coming into proper alignment for imaging—causing misalignment between the two pieces of equipment. This misalignment increases the odds of failing to correctly image the teeth of interest. It is never recommended that the portable X-ray equipment backscatter rings be removed or adjusted in a way that would void manufacture safety guidelines (5). In this study, researchers took a commercially used aiming device and modified the "arm" by decreasing the length. It was hypothesized that a shorter arm length would allow radiographers to align the aiming device flush to the portable X-ray equipment and backscatter ring; this modified external aiming device (MEAD) was one device researchers used in this study. However, more research is needed to determine exact modifications needed to make holding devices more applicable for forensic dental radiology.

3D printing technologies have been deemed "the next industrial revolution" and are estimated to change healthcare delivery models in both medicine and dentistry (6). More specifically, 3D printing has gained popularity in dentistry because parts, equipment, and products can be customized—for example, crowns, bridges, models, and a range of orthodontic appliances (6). The use of 3D printing allows for rapid production of the device, which can be important in MFI situations when resources can be quickly depleted (6). 3D printing is also being used in forensic imaging; 3D printers are being used to create models of anatomical structures representing bone fractures, vessels, cardiac infarctions, ruptured organs, and bitemark wounds. These anatomical replicas are then used for displaying forensic findings for victim identification study and presentations in courtrooms (7). In this study, researchers from the School of Dental Hygiene and Virginia Modeling Analysis and Simulation Center used 3D printing technology to create a novel alignment device, the combined holding and aiming device (CHAD), to address the positioning limitations of current aiming devices and radiographic equipment. This device was designed to help hold (through a new securing mechanism) X-ray aiming equipment onto teeth of interest for the purpose of allowing dental professionals to more accurately obtain precise X-ray images on victim remains. The CHAD has a sliding lock mechanism that securely adheres to the tooth; the sliding lock mechanism can also adjust to the size of each tooth type (incisors, canines, molars, premolars) including those that may be broken or chipped (Fig. 1). Overall, the CHAD has the following capabilities: (i) allows portable X-ray equipment to align with the CHAD, (ii) keeps the X-ray sensor or film in place and in alignment with the jaw while PM X-rays are taken, and (iii) facilitates infection control and is environmentally friendly as it is made out of disposable biodegradable polymer PLA plastic.

The purpose of this research study was to determine the rate of error when completing radiographic exposures of PM intraoral periapical images. Three different holding devices: (i) Device A—soft dental wax only, (ii) Device B—the modified external aiming device (MEAD) used with soft dental wax, and (iii) Device C—the combined holding and aiming device (CHAD) were compared by device preference, radiographer's efficiency, and technique errors.

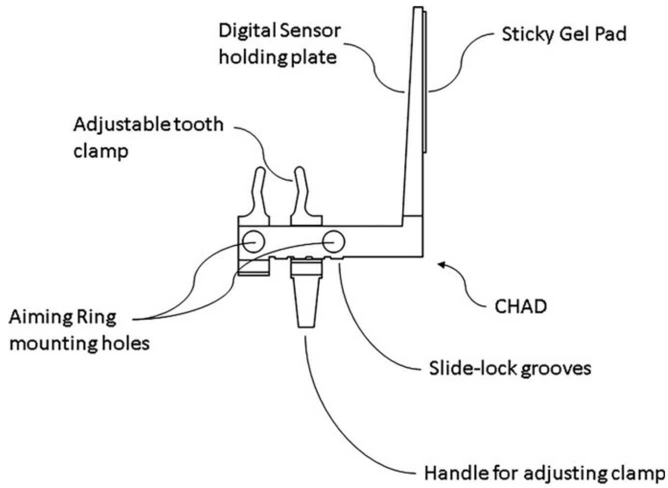

FIG. 1—*CHAD schematic rendering.*

Materials and Methods

A total of 24 dental hygienists were recruited and enrolled in the study. Dental hygienists were chosen for the study as they expose radiographs in practice (including during victim identification) and are well educated in dental radiology techniques (4,8–14). Participants were recruited through personal phone calls, emails, and announcements at professional meetings and various professional social media websites. Prior to the study, a brief phone questionnaire was completed by each participant. This questionnaire gathered information regarding the participant's work setting, education, years of dental hygiene experience and preference, and proficiency in taking dental X-rays. Current dental hygiene licensure in the state of the research study (Virginia) and at least 10-years of clinical experience was required to participate. Inclusion criteria also involved participants' willingness to review instructions on radiation safety when using the portable X-ray device, willingness to participate in scenarios using simulated victim remains, and the ability to use the Nomad Pro™ portable X-ray device. Individuals who reported being pregnant or suspected pregnancy were excluded from the study for radiation safety purposes. The University Institutional Review Board approved the study, and informed consent was obtained from all study participants.

Consenting participants were individually briefed regarding the radiology laboratory and MFI simulation requiring them to take PM X-rays on victim remains, and the three devices were also introduced. Each device was demonstrated one time to each participant due to participants' lack of familiarity with the research procedures. All research procedures were conducted at a Dental Hygiene Research Center (DHRC).

Radiology Laboratory and MFI Simulation

Fragmented real human skulls were used to create the radiology laboratory simulating a forensic training scenario (11,13). The skulls used included bisected mandibles and maxillas with broken, missing, and loose teeth (3). The condition of the skulls included stained and brittle areas— researchers wanted to present a variety of challenges to provide participants with a more realistic forensic dental radiology experience. Dry dental remains were

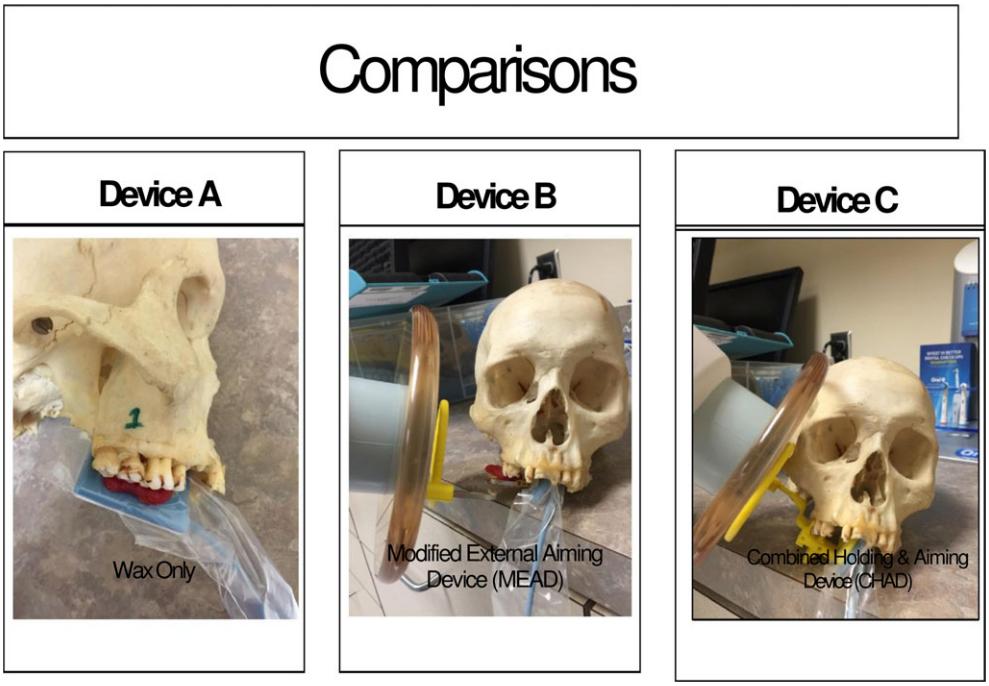

FIG. 2—*Devices A, B and C. [Color figure can be viewed at wileyonlinelibrary.com]*

readily available to researchers at the University study site because the skulls and fragments are used within the dental hygiene programs as an existing resource; additionally real human skulls and fragments are recommended for general and MFI training purposes (3,9,15). Simulations included six diverse intraoral dental images taken on various anatomical sites as follows: (1) posterior periapical (PA) maxillary arch, (2) posterior PA mandibular arch-bisected mandible, (3) posterior PA-premolar maxillary arch-intact skull, (4) posterior PA-premolar mandibular arch-intact skull, (5) anterior PA mandibular arch, and (6) anterior PA maxillary arch. To assure the order in which participants' used each device, the sequence in which the devices were tested was randomly assigned to each participant. In total, there were six anatomical sites that each device was tested on—yielding 18 images per device (three devices x six anatomical locations each).

Radiation Safety and Infection Control

The Nomad Pro™ is (16,17) approved for use by regulatory authorities nationwide. While the probability of exposure to ionizing radiation when using the handheld Nomad Pro™ was low (17), extra precautions were taken to ensure as low as reasonably achievable or ALARA safety guidelines were followed during this study. Dental hygiene participants wore a full body cape style lead apron with a thyroid collar, and a thermoluminescent (TLD) dosimeter badge, which was placed at the collar bone on the lead apron while exposing the intraoral images. Radiation warning signs were also placed on the door and inside of the DHRC to indicate caution, along with signage identifying "safe zones." Participants were given instructions on infection control protocol to be followed during the study, including donning and doffing personal protective equipment (PPE) and covering the held-held X-ray system with plastic wrap. Additionally, participants were provided with materials and directions on how to follow laboratory protocol including when to use each device and which fragment or bisect skull to work with.

Researchers insured exposure settings were maintained throughout the study, and preset time (seconds), kilovoltage (kV), and milliamperage (mA) of the Nomad Pro for direct digital sensors were used for each exposure. The three holding devices compared included: (i) Device A—wax only, (ii) Device B—the MEAD with wax, and (iii) Device C—the CHAD (Fig. 2). Radiographic images were scored by two dental hygiene faculty with expertise in oral radiology. A radiographic evaluation form adapted from Kieser et al. (18) was used to score all X-ray images. This type of evaluation allowed scores for total technical errors in four main categories with respective subcategories considered as follows: (i) angulation category; with subcategories incisal edge/apices cutoff, elongation/foreshortening, horizontal overlap, and cone cut, (ii) placement category; with subcategories image too far anterior/posterior, image too far inferior/superior, and incorrect sensor placement, (iii) exposure category; with subcategories of double exposure or under/overexposure, and lastly (iv) a miscellaneous "other" category was used to record nonspecific errors, for example, a tilted image (18) (See Table 1). Errors were scored as 0 = no error, 1 = error not indicating a retake of the image, and

TABLE 1—*Radiographic evaluation technique error categories.*

Technique Errors	
Main Categories	Subcategories
Packet placement	Too far anterior/posterior
	Too far superior/inferior
	Herringbone Error
Angulation	Incisal edges/apices cutoff
	Elongation/foreshortened
	Horizontal overlap
	Cone cut
Exposure	Double exposure
	Under/overexposure
Other	Any miscellaneous error (tilted image)

2 = nondiagnostic error requiring retake of the image. A total of 432 X-ray images were scored (24 participants exposed six X-rays each per device A, B, and C).

Each device was evaluated based on speed (i.e., number of minutes it took each participant to take the six X-rays/per device), quality (number of total errors found on each X-ray), and an evaluation of each device. The device evaluation consisted of participants' response to nine questions scored on a five-point Likert-type scale (1 = *strongly disagree* to 5 = *strongly agree*). The device evaluation addressed ease of use (three questions), observation of errors (three questions), and device preferences (three questions). This device evaluation questionnaire was pretested, via feedback from a panel of faculty dental hygienists at the University who were not participating in the study. The data from each radiographic image were entered into SAS 9.4 for statistical analysis.

Results

At the completion of the study, dosimeter badges for all participants were assessed by Mirion Technologies Inc.; their reports indicated zero exposure to ionizing radiation for each of the participants.

Phone Questionnaire

Results of the questionnaire revealed the majority of participants primarily worked in a clinical setting (92%), with the remaining practicing in educational institutions (8%). When asked the average time needed to image four diagnostically acceptable dental X-rays, more than 60% of the participants reported approximately 1–2 min, while 17% stated approximately 3–4 min, and 13% over 4 min. About 8% of participants stated it took them less than a minute to image four dental X-rays. Participants were also asked what device they use when imaging dental X-rays in practice settings. The majority of participants (79%) reported using the RINN with an external aiming ring. About 46% reported using bite tabs, 25% reported using a RINN without an external aiming ring, and 17% reported using the Snap-a-Ray® image receptor holder.

Time Assessment

A Kruskal–Wallis test was used to compare the number of minutes required to take six X-rays/per device A, B, and C, and a pairwise comparison using Dunn test and Bonferroni's method was used to adjust *p*-values for the pairwise comparison. Kruskal–Wallis chi-squared = 13.1309, df = 2, *p*-value = 0.001408 indicated a significant difference in median times when comparing each device. From the analysis on speed, we can conclude that device A (wax) resulted in shorter times (mean 5.589, median 5.07, SD 2.176), and device C (CHAD) took the longest amount of time (mean 9.076, median 6.93, SD 4.763). Device B (MEAD) resulted in a mean time of 8.246 min, median time of 6.355, and a SD of 5.023.

Device Evaluation

When reporting ease of use, most participants felt in general all three devices were not difficult to use. The majority of participants (70%) reported using soft dental wax contributed to more technical errors, while 59% and 75% felt the MEAD and CHAD contributed to less errors, respectively. About 79% reported they would use the MEAD when imaging dental human remains, while 79% would choose the CHAD; a slightly smaller percentage preferred soft dental wax (71%). In general, device evaluation comments were positive and varied in rational for ease of use, observation of error, and device preference. When reporting ease of use, some participants liked having "less parts" to work with and others preferred having a holding device. In the observation of errors portion of the questionnaire, participants reported CHAD's helpfulness in achieving angulation and positioning of the sensor. Overall, several comments on device preference included recommendations for having all of these devices available when imaging human remains. Because CHAD was a new device, several dental hygienists reported that with more practice, they may be able to use it more efficiently; they also made specific recommendations for modifications. An unexpected result was participants recommending the CHAD as an "adjunct" holding device on live patients.

Device Evaluation of Radiographic Technique Errors

ANOVA was used to compare sum of the errors for each device (A, B, C). A significant difference was found at the 0.05 level between the three devices (*p* = 0.0015) (Fig. 3). Levene's test for homogeneity showed that the comparisons had the same equality and variation, and the ANOVA test was appropriate between devices A, B, and C (*p* = 0.8884). The test of pairwise difference was conducted and both the t-test and Tukey's test showed that devices A (M = 14.833) and C (M = 13.333) were different from device B (M = 9.583). The means showed that devices A and C performed about the same (*p* = 0.3152); however, devices A and C were significantly different from B. In other words, B had significantly lower errors than devices A and C. Devices B and C were now compared. As expected, device B performed better in terms of minimal error than device C (*p* = 0.0102). Comparing devices A and B, the *p*-value showed that there was a significant difference in overall errors (*p* = 0.0006).

The ANOVA test showed no significant difference in total "packet placement" errors between the three devices (*p* = 0.1716). In addition, no significant difference was found in total errors for all three devices within the "exposure" category (*p* = 0.6965). Significance was found for total errors within the

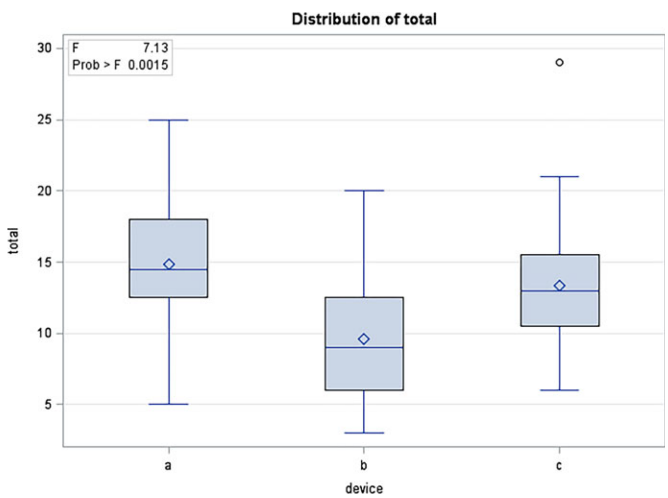

FIG. 3—*Total errors between devices A, B and C. [Color figure can be viewed at wileyonlinelibrary.com]*

miscellaneous other error category between the three devices with a *p*-value of 0.0206. However, the assumption of equality of variance between the three devices was not validated. Levene's test of equality of variance and the Brown–Forsythe test demonstrated the three devices did not have the same variation. These tests showed very small *p*-values, indicating the equality of variance was violated. Therefore, the *p*-values were not indicative of the difference between the three devices. Within the "angulation" category, ANOVA showed a significant difference in angulation errors between the three devices ($p < 0.0001$). Results are summarized in Table 2.

The significant difference within the angulation category was explored further to determine which device had the least amount of error. When comparing the total angulation error sum for devices A and B, a significant difference was found—B performed better than A ($p < 0.0001$); however, there was no significant difference between devices A and C ($p = 0.5105$). Devices A and C performed very similarly, with device C having slightly less mean angulation errors than device A. Interestingly, between devices B and C, a significant difference was also found in total angulation errors ($p = 0.0005$). From the above analysis, we can conclude that device B had less total angulation errors than A and C. A post hoc t-test was conducted to determine which specific error type out of: incisal edge/apices cutoff (Angulation 4 error), elongation/foreshortening (Angulation 5 error), horizontal overlap (Angulation 6 error), and cone cut (Angulation 7 error) had the highest amount of errors for device B. The t-test analysis found there was significant difference between all four of the subcategories of angulation errors (Angulation error 4-7) ($p < 0.0001$) with incisal edge/apices cutoff as the highest number of errors (M = 4.500) and horizontal overlap as the next highest error (M = 1.083) within device B (Table 2).

TABLE 2—*Total and angulation error subcategories for Devices A, B, and C.*

	Mean	Standard Deviation	*p* value
Total error scores			
Device A	14.833	5.18	0.0015
Device B	9.853	4.63	
Device C	13.333	5.05	
Packet placement errors			
Device A	4.250	2.967	0.1716
Device B	2.958	2.255	
Device C	4.208	2.750	
Angulation errors			
Device A	7.166	2.098	<0.0001
Device B	4.500	4.500	
Device C	6.750	6.750	
Miscellaneous other errors			
Device A	0.041	0.204	0.6965
Device B	0.125	0.612	
Device C	0.041	0.204	
Angulation subcategories			
Device A	0.042	0.204	0.0206* 0.0498† 0.0206‡
Angulation 4	0.666	1.167	
Angulation 5	0.250	0.608	
Angulation 6	1.041	1.267	
Angulation 7	1.292	1.398	<0.0001
Device B			
Angulation 4	4.500	1.933	
Angulation 5	0.333	0.963	
Angulation 6	1.083	0.974	
Angulation 7	0.250	0.675	<0.0001
Device C			
Angulation 4	6.750	2.251	
Angulation 5	0.125	0.448	
Angulation 6	1.958	1.681	
Angulation 7	0.042	0.204	<0.0001

M, Means; SD, standard deviations; *p* values for comparisons of each technique by total error scores and error scores by category.

*ANOVA.

†Levene's test for homogeneity.

‡Brown and Forsythe's test for homogeneity.

Discussion

The purpose of this research was to test a new 3D printed combined holding and aiming device (CHAD) and to compare it to existing devices and techniques used in forensic dental radiology. This study supports the need for technological advances in forensic odontology science and radiology (4,8,9). A radiology laboratory and MFI simulation using six intraoral periapical radiographs was chosen for the study—the current literature indicates the need to compare single PM images to determine positive and negative identifications (1). This study follows recommendations from the literature including a "*hands-on*" test of imaging dental fragments with portable hand-held radiographic equipment; this type of practice simulates forensic odontology real-world experiences without the pressure of time and resources often depleted during a missing persons or MFI (4,8,9,15). Future studies could be conducted on cadavers when access to a local morgue or University anatomy laboratory is available to researchers. Additionally, when an actual imaging decision is being made, AM radiographs should be evaluated to determine and follow similar technique; however, this is not always possible during MFIs and was not included in this study to follow "real-world" scenarios. Future studies could also include simulation of AM radiographs to facilitate comparisons prior to taking PM radiographs.

Dental hygienists, with over 10 years of clinical and dental radiology experience, were chosen to complete this study; previous studies by Bruhn et al. (4) have used dental hygiene student participants. This study supports Bruhn et al.'s (4) recommendations to use licensed dental hygienists in forensic dental radiology or MFI research applicable to dental hygiene theory and practice. Dental hygienists exposed images with a hand-held dental X-ray system and a direct digital sensor; three different devices were used to secure the direct digital sensor to the teeth being imaged. Total errors were compared among devices A, B, and C. It was hypothesized that the mean errors for CHAD (device C) would be less than the mean errors for both the wax (Device A) and MEAD (Device B) and that device C would require less time in terms of completing the series of six radiographs. Overall, total errors were higher in device A (soft dental wax only), and devices B and C performed better than device A —these results support existing literature on the use of holding devices in PM radiographic imaging. It is important to note, dental hygienists may prefer using devices and techniques they are familiar with in private practice settings when participating in forensic work, as reflected by device B outperforming device C and the prescreening questionnaire which found that most dental hygienists used a holding device in practice settings. Modification of familiar devices can be effective for quality PM imaging; however, making modifications during an MFI or forensic victim identification work may delay efforts. A device that needs little to no modification or other props is optimal. Also, devices that allow for parallel sensor placement may be preferred by some dental hygiene radiographers and dependent on conditions of remains over soft dental wax, which must incorporate the bisecting technique. While literature suggests use of techniques without holding devices for optimal PM images, the present study found a modified holding device performed with the least amount of error and the new holding device had slightly less error than soft dental wax alone.

There was no significant difference found for the subcategories of placement, exposure, or other errors between the three devices used in the study—wax (device A), MEAD (device B), and CHAD (device C). Radiographic images were deemed acceptable quality in all subcategories, except for angulation. This supports other forensic odontology literature on the limitations of radiographic identifications based on fragmented dental remains and PM image quality—that often these radiographs contain insufficient dental anatomy for differentiation among teeth and other dental anatomy (1,3). This study also supports that most technique errors occur in angulation and orientation of the film packet and/or sensor (2). Also, recent research by Bruhn et al. (4) on protocol for forensic dental radiographic imaging and technique found that using the paralleling technique yielded less angulation errors; the results of this study also found that angulation errors are common in PM radiographs. Devices A and C performed very similarly for total angulation error (which was higher error than B) A, B, and C performed about the same in all other error categories.

Exploring new technologies is important for forensic advancement. Device B (MEAD) performed with the least total errors; however, new devices like device C (CHAD) could offer additional advantages over wax or using modified existing holding devices when exposing PM radiographs. The CHAD combines the benefit of being an "all-one" device because it is able to be 3D printed with its own holding and aiming mechanisms. Additionally, it needs no modifications or wax for use. The CHAD is compatible with portable X-ray equipment and facilitates alignment of an aiming ring to the PID of the portable X-ray equipment. The CHAD also does not need props to facilitate device to tooth alignment—in this way, the CHAD can keep the X-ray sensor or film in place while postmortem X-rays are taken. The CHAD can be customized to fit any single tooth in the absence of occlusion. This device is also disposable; necropsy literature on infection control recommends disposable equipment be used (18).

A disadvantage found when participants used the CHAD was the time used to attach the holding mechanism to the teeth of interest; the CHAD can be used on any tooth so slight adjustments had to be made depending on size of the anterior or posterior tooth being imaged. For the CHAD to work, the holding mechanism needed to be adjusted slightly smaller than the anatomical dimensions of each tooth to create enough tension for securing the tooth into the holding device. Participants may have also been too cautious about making these adjustments and breaking the holding mechanism during placement. Not bringing the CHAD device into contact with the tooth could have contributed to an increase in angulation error of not imaging the apex in periapical radiographs. Perhaps with more practice in use, a radiographer using the CHAD device would have a decrease in angulation errors. While the present study found the CHAD took the longest amount of time, researchers did not assess total amount of time to obtain quality images (retakes) for each device. Future studies could find less time overall to obtain a set of PM images per victim remain when this is considered.

Conclusion

Testing a new device for use in forensic odontology provided valuable information on advantages and disadvantages of current and emerging devices used to imaging human remains. This study provides opportunity to learn more about modifications needed to perfect holding devices. Identification of ways to minimize retake errors is needed to ensure radiographers can take accurate dental X-rays with proper angulation and in an efficient way for AM and PM records comparison and victim identification efforts. Future research which incorporates new technologies is needed to advance current devices, equipment, and victim identification techniques used in forensic odontology.

References

1. Richmond R, Phil M, Pretty IA. Identification of the edentulous individual: an investigation into the accuracy of radiographic identifications. J Forensic Sci 2010;55(4):984–7.
2. Senn DR, Weem RA, editors. Manual of forensic odontology, 5th edn. Boca Raton, FL: CRC Press, 2013.
3. Tohnak S, Mehnert A, Mahoney M, Crozier S. Synthesizing dental radiographs for human identification. J Dent Res 2007;86(11):1057–62.
4. Bruhn AM, Newcomb TL, Giles B. Evaluating imaging techniques for intraoral forensic radiography with the dental hygienist as part of the forensic radiology team. Journal of Forensic Identification 2016;66 (1):22–36.
5. Pittayapat P, Thevissen P, Fieuws S, Jacobs R, Williams G. Forensic oral imaging quality of hand-held dental x-ray devices: comparison of two image receptors and two devices. Forensic Sci Int 2010;194:20–7.
6. Stansbury JW, Idacavage M. 3-D printing with polymers: challenges among expanding options and opportunities. Dent Mater 2016;32(1):54–64.
7. Ebert L, Thali M, Ross S. Getting in touch-3D printing in forensic imaging. Forensic Sci Int 2011;211(201):e1–6.
8. Newcomb T, Bruhn A, Giles B. Critical issues: the role of the dental hygienist in mass fatality incidents, are we prepared? J Dent Hyg 2015;89(3):143–51.
9. Newcomb TL, Bruhn AM, Ulmer L, Diawara N. Performance of dental hygiene students in mass fatality training and radiographic imaging of dental remains. J Dent Hyg 2015;89(5):313–20.
10. Ferguson DA, Sweet DJ, Craig BJ. Forensic dentistry and dental hygiene: how can the dental hygienist contribute? Can J Dent Hyg 2008;42(4):203–11.
11. Brannon R, Kessler H. Problems in mass-disaster dental identification: a retrospective review. J Forensic Sci 1999;44(1):123–7.
12. Brannon LM, Connick CM. The role of the dental hygienist in mass disasters. J Forensic Sci 2000;45(2):381–3.
13. Hincliffe J. Forensic odontology part 2: major fatality's. Br Dent J 2011;210(6):271–3.
14. Rawson R, Nelson B, Koot A. Mass disaster and the dental hygienist: the MGM fire. Dent Hyg 1983;57(12):12–8.
15. Stoeckel DC, Merkley PJ, McGivney J. Forensic dental training in the dental school curriculum. J Forensic Sci 2007;52(3):684–6.
16. Hermsen KP, Jaeger SS, Jaeger MA. Radiation safety for the NOMAD™ portable x-ray system in a temporary morgue setting. J Forensic Sci 2008;53(4):917–21.
17. Danforth RA, Herschaft EE, Leonowich JA. Operator exposure to scatter radiation from a portable hand-held dental radiation emitting device (Aribex™ NOMAD™) while making 915 intraoral dental radiographs. J Forensic Sci 2009;54(2):415–21.
18. Kieser JA, Laing W, Herbison P. Lessons learned from large-scale comparative dental analysis following the south Asian tsunami of 2004. J Forensic Sci 2006;51(1):109–12.

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