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Published in:
Morphologie

DOI:
[10.1016/j.morpho.2024.100774](https://doi.org/10.1016/j.morpho.2024.100774)

Publication date:
2024

Licence:
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Document Version
Publisher's PDF, also known as Version of record

[Link to publication in Discovery Research Portal](#)

Citation for published version (APA):

Manica, S., Merdietio Boedi, R., Pandey, H., & Shields, C. (2024). Identifying teeth and tooth fragments from digital 3D models. *Morphologie*, 108(362), Article 100774. Advance online publication. <https://doi.org/10.1016/j.morpho.2024.100774>

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ORIGINAL ARTICLE

Identifying teeth and tooth fragments from digital 3D models

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KEYWORDS

Tooth identification ;
Dental anatomy ;
Tooth fragments ;
Animal tooth ;
Dental anatomy
education ;
3D models

Summary Dental anatomy is an essential skill for human identification in forensic odontology. With the advent of technology enabling virtual autopsies, there is scope for virtual consultation by forensic odontologists especially when the expertise is unavailable but needed in zones of conflict or disasters. This study aimed to investigate potential benefits and challenges of identifying intact and damaged teeth from 3D scanned digital models. Ten 3D tooth models – nine permanent and deciduous human teeth and one animal tooth were uploaded on a hosting platform. A 3-part survey was circulated among 60 forensic odontologists with questions about demography (P1), tooth identification of the scanned 3D models (P2) and the perceived usefulness of 3D models for tooth identification (P3). This was the first time that a survey required the identification of individual human teeth (intact or not) and animal tooth combined. The response rate for study participation was 58%. Substantial agreement among participants was seen in the determination of tooth classification (i.e., molars, premolars) or non-human and tooth within the same tooth class (i.e., lateral incisors, second molar) (both $k=0.61$). The least agreement ($k=0.21$) was seen in identification of tooth according to the FDI notation with a mean accuracy of 0.34. While most responders correctly identified the animal tooth, most incorrect responses were seen in the identification of the intact third molar. While 3D-scanned teeth have the potential to be identified virtually, forensic odontologists should continuously test their skills in tooth morphology and dental anatomy of humans (damaged or not) and animals. © 2024 L'Auteur(s). Publié par Elsevier Masson SAS. Cet article est publié en Open Access sous licence CC BY-NC-ND (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

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<https://doi.org/10.1016/j.morpho.2024.100774>

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Introduction

In dental schools, the subject of tooth morphology is an essential component of the curriculum. A good understanding of dental morphology, including tooth identification, is essential for clinical purposes of restorations, making prosthesis, and diagnosis of pathologies, syndromes, and treatment. Moreover, dental morphology is crucial for comparative dental identification as well as biological profiling and dental anthropology [1]. Traditional dental anatomy training comprises of dental anatomy textbooks with description of tooth from five aspects, laboratory crown wax-ups, wax carving of teeth, and drawings [2,3]. More recently, different teaching methods have been tested including the use of augmented reality (AR) and three-dimensional (3D) printed anatomical tooth reference models [4]. Three-dimensional images allow further discrimination into permanent three – rooted premolars, central tip, and dental diseases including deep caries and wedge – shaped defects [5].

More importantly, digital technology ensures fair quality education for all [6]. It is well known that extracted human teeth are used in education and research; however, since the enactment of the Human Tissue Act (HTA) in 2006, there has been a decline in research outputs from the United Kingdom using extracted teeth for research [7].

In forensic odontology, tooth identification is important for human identification however, forensic dentists might meet challenges such as tooth fragments found at the scene of crime, natural disaster or accident that may require identification of their species of origin. The distinction between human and animal teeth is a prerequisite in isolated teeth [3]. In similar fashion, small fragments of teeth may be found in foodstuffs, and it may be necessary to decide whether the tooth is from the same species or stands for a foreign body [8]. There are few qualified forensic odontologists (FO) worldwide and they may not always be available in regions of conflict, or areas in which deaths may occur by natural disasters. If the local dentist or dental practitioners who are untrained in forensic odontology can collect dental data by scanning the tooth remains, trained and experienced FOs could offer expertise remotely by examining the digital dental data collected by local practitioners.

There is an increase of the use of 3D imaging in forensic odontology, for instance a recent study showed the applicability of this 3D method as a valuable tool in aiding dental identification using selfies [9]. Another study concluded that fragmented teeth may be reconstructed using three-dimensional surface scanning (3DSS) and 3D printing technology with high precision [10]. Legally, an advantage of 3D scanning teeth is to preserve as much dental information as possible from the site of the incident, before collecting and transporting loose, fragmented, or burnt teeth. In high-impact incidents such as plane crashes, car accidents, explosions, or fires, the impact may lead to the fracturing and fragmentation of teeth. These fragments may become very fragile and easily damaged while handling [10] and may get further damaged during collection and transportation from the incident site. 3D scanned loose teeth or fragmented teeth could be identified remotely to aid in separating human and animal remains as well as provide dental information for comparative identification and performing dental

superimposition or profiling. Experienced FOs could also assess damage to the teeth if the colors and textures can be included in the scanned model.

This was a novel study that aimed to investigate the potential benefits and challenges of identifying individual human teeth (intact or not) and animal teeth from three dimensional (3D) scanned digital models.

Materials and methods

Ten tooth models were produced. Six permanent human teeth, one deciduous human tooth and one animal (dog) tooth (intact teeth, heavily restored teeth or tooth fragments) were scanned using a Primescan® AC digital impression cart scanner. The 3D models (.ply filetype) generated from scanning were “tidied up”, where required, using ZBrush software (Maxon Industries, Inc.), and then uploaded to the Sketchfab 3D model hosting platform (<https://sketchfab.com/>). The background color in the scene for each model was selected to enhance contrast with the tooth/tooth fragment, to allow easy viewing by participants. Two further complete tooth models (one permanent and one deciduous human tooth) were created from scratch by a medical illustrator using Zbrush software (i.e. these two teeth were “ideal” models, rather than being generated from real scanned teeth). This gave 10 models of various types for use in the study.

An e-survey was created using JISC online surveys version 2 (<https://www.onlinesurveys.ac.uk/>) to investigate the feasibility of using the 3D scanned digital models for tooth identification. The anonymous survey was sent by email to 60 dentists involved with forensic odontology. It was composed of three parts (P1-P3) being P1 about participant demographic details and composed of four closed-ended questions (Q1-Q3b): Q1 - *What is your gender? (male, female and other)*; Q2 - *What is your age?*; Q3a - *Which of the following best describes your occupation/career stage? (Undergraduate student; postgraduate taught student; postgraduate research student; early career academic; academic and other)*; Q3b - *Approximately how many years' experiences do you have in a forensics/dentistry-related field? (years of training and years of practice)*.

The second part (P2) was about tooth identification and presented ten questions (Q4-Q13). Within each question page, interactive 3D models of the unnamed teeth were embedded from within Sketchfab, together with the following instructions: *Please study the 3D model of a tooth shown below. The tooth is X mm in length. You can rotate and zoom the model using the 3D controls - press the 3D play button (▶) and then use your mouse or fingers to manipulate the model, depending on which device you are using.* Images of the models, the question they appeared in, and respective descriptions are seen in Table 1. (NB From participants' point of view during the survey, each model was identified only by a code number: “Tooth N1”, “Tooth N2”, “Tooth N3” etc.).

For each tooth, sub questions (SQa – SQf) were presented as follows: SQa - *In your opinion, is this a deciduous tooth or a permanent tooth? (Deciduous, permanent, other, I could not identify this tooth)*; SQb - *If you answered “deciduous” above, please select the tooth from the dropdown menu*

Table 1 Images and description of teeth used in the survey.











Question code; tooth Code	Q4; Tooth N1	Q5; Tooth N2	Q6; Tooth N3	Q7; Tooth N4	Q8; Tooth N5
A view of the 3D model					
FDI notation; anatomical state	18 (permanent upper right third molar); intact	74 (deciduous lower left first molar); intact	15 (permanent upper right second premolar); 25% of dental crown lost and partially burnt	26 (permanent upper left first molar); 30% of dental crown lost	43 (permanent lower right canine); 30% of dental crown lost
Question code; tooth Code	Q9; Tooth N6	Q10; Tooth N7	Q11; Tooth N8	Q12; Tooth N9	Q13; Tooth N10
A view of the 3D model					
FDI notation; anatomical state	23 (permanent upper left canine); 50% of dental crown lost and burnt	65 (deciduous upper left second molar); 100% of dental crown heavily restored	Non-human premolar tooth (carnivore; dog); intact	21 (permanent upper left central incisor); crown shell	23 (permanent upper left canine); crown shell

Table 2 Overall description of the five categories.

Categories	Description of categories ^a
A	The tooth is permanent, deciduous, or non-human
B	Tooth region, this includes the region of permanent (1,2,3,4) and deciduous (5,6,7,8)
C	Tooth classification (i.e., molars, premolars, incisor, canine) or non-human
D	Tooth within the same tooth class (i.e., lateral incisors, second molar)
E	Tooth according to FDI notation (i.e., 16, 15, 51)

^a FDI notation uses a two-digit numbering system in which the first digit represents a tooth's quadrant, and the second digit represents the number of the tooth from the midline of the face.

below: (here, a full list of all possible deciduous teeth in FDI notation was provided e.g: 55 – deciduous upper right second molar); SQc - If you answered "permanent" above, please select the tooth from this dropdown list: (here, a full list of permanent teeth in FDI notation was provided e.g: 38 – permanent lower left third molar); SQd - If you selected "other" above, please provide an opinion (free text box); SQe - Please indicate to what extent you agree/disagree with the following statement: "I am confident about my identification of this tooth" (Strongly disagree; Disagree; Neutral; Agree; and Strongly agree); and SQf - Do you have any further comments/opinions as a forensic odontologist regarding the tooth in this model? (free text box).

The third part (P3) of the survey addressed the perceived usefulness of 3D model for tooth identification, and posed the three final questions (Q14-Q16): Q14- Please indicate to what extent you agree/disagree with the following statement: "I think this type of 3D model is a good way to identify teeth/tooth fragments" (Strongly disagree; Disagree; Neutral; Agree; and strongly agree); Q15 - Are there any reasons you wish to give for your response to the above question? (free text box); and Q16 - Do you have any other comments about the use of 3D models for identifying teeth,

Table 3 Overall interpretation of Kappa values.

Kappa value	Interpretation
< 0	Poor agreement
0.01–0.20	Slight agreement
0.21–0.40	Fair agreement
0.41–0.60	Moderate agreement
0.61–0.80	Substantial agreement
0.81–1.00	Almost perfect agreement

P3 was analyzed using Microsoft Excel version 2310 in the form of tables and graphs.

or anything else relating to the contents of this survey? (free text box).

The analysis of results for P1 and P2 investigated the levels of agreement for tooth identification subdivided in five categories from A-E (Table 2) and analyzed using Fleiss Kappa [11] with Kappa classification from Landis and Koch [12] as shown in Table 3. The non-human tooth (N8) was not counted for categories B, D and E. Accuracy was also calculated using the number of correct answers divided by the

Table 4 Distribution of responders according to career and experience.

Practice year	Career	n
0–4	Academic	8
	Other	4
	Postgraduate student	6
5–10	Academic	2
	Postgraduate student	3
Above 10	Academic	9
	Other	1
	Postgraduate student	2

total response for each question. Furthermore, the accuracy results between “Career” and “year of practice” were tested using ANOVA and Tukey Post-Hoc HSD to see if there was an accuracy difference between the groups. All analysis was carried out using R version 4.3.1.

Results

P1, demographic details

Response rate and characteristics of responders

A total of 35 (male = 20; female = 15) participants took part in the study, totalling a response rate of approximately 58%. The age of the participants ranged from 27 to 59 years old, with a mean age of 39 ± 9.8 years old. Participant characteristics based on their career and years of experience are shown in [Table 4](#).

P2, tooth identification

Overall agreement according to the categories A–E and career

Category A – The tooth is permanent, deciduous, or non-human. There is a moderate agreement ($k=0.567$) with 0.88 mean accuracy to determine whether the tooth is permanent, deciduous, or non-human, with the highest accuracy held by Tooth N2 (0.94). In terms of career and practice (year) groupings, there are no significant differences between the groups that tends to have higher or lower accuracy.

Category B – Tooth region, this includes the region of permanent (1,2,3,4) and deciduous (5,6,7,8). There is a fair agreement to determine the tooth region ($k=0.25$) with 0.47 mean accuracy. Tooth N2, N4 and N7 held the highest accuracy with no significant accuracy differences between groups.

Category C – Tooth classification (i.e., molars, premolars, incisor, canine) or non-human. There is a substantial agreement to determine tooth classification only (i.e., molars, premolars, incisors, canine) with no specific tooth (i.e. second molar, second premolar, etc) with $k=0.61$. The mean accuracy of category C is 0.78 with no significant differences between groups. The highest accuracy was to answer tooth N2 (0.94).

Category D – Tooth within the same tooth class (i.e., lateral incisors, second molar). There is a substantial agreement

($k=0.61$) to determine the tooth class (i.e., lateral incisors, second molar) without the region. The mean accuracy is 0.54 with the highest accuracy was to answer tooth N6 (0.91). There is no significant differences of accuracy between groups.

Category E – Tooth according to FDI notation (i.e., 16, 15, 51). There is a slight agreement ($k=0.21$) with 0.34 mean accuracy to determine the tooth FDI notation. The highest accuracy was to answer tooth N2 (0.49). In this category, the group career “Other” significantly tends to have a higher accuracy compared to the post-graduate students group by 2.6%, but not with the Academic group. Overall agreement values per categories is show in [Table 5](#).

Summary of free text/comments available for specific teeth

Table 6

P3, the perceived usefulness of 3D model for tooth identification

Results for statement on Q14: “I think this type of 3D model is a good way to identify teeth/tooth fragments” indicated that 19 responders (54.3%) agree, 11 (31.4%) are neutral, followed by 5 (14.3%) that strongly agree and no one disagrees or strongly disagrees.

Free responses (Q15 and Q16)

Considering Q15 (Are there any reasons you wish to give for your response to the above question?) and Q16 (Do you have any other comments about the use of 3D models for identifying teeth, or anything else relating to the contents of this survey?), one respondent stated that they would prefer to see the tooth fragments in person; two praised the exercise and considered it similar to physical examination of teeth and another six would like to be able to rotate the model more completely. In further comments for Q16, two responders praised the models especially for mentioning the total length of the teeth; however, three responders would have preferred a scale to be added directly to the models. Four responders suggested that the models would be beneficial if used in teaching.

Discussion

In a recent analysis of thousands of published online surveys, the average response rate was 44.1%, so the response rate in the current study (58%) was good for this type of survey [13]. Despite positive feedback on the 3D models’ development, the low average accuracy of 0.34 for determining tooth FDI notation (category E) in [Table 5](#) reveals possible challenges in its practical application. However, the slight agreement indicated by a kappa value of 0.21 suggests some inconsistency among observers despite the low accuracy. In contrast, a high kappa value with low accuracy would point to consistent misrepresentation by the model rather than observer disagreement. If this discrepancy occurs (i.e., high agreement with low accuracy), then the 3D model would need major rework. As the current

Table 5 Distribution of agreement values per categories (A-E) and teeth (N1-N10).

Category	Tooth										Average per category
	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	
A	0.86	1	0.97	0.91	0.97	0.94	0.89	0.71	0.8	0.74	0.88
B	0.34	0.71	0.46	0.6	0.43	0.34	0.54	NA	0.34	0.46	0.47
C	0.8	0.94	0.86	0.89	0.4	0.91	0.91	0.71	0.74	0.63	0.78
D	0.29	0.58	0.54	0.71	0.4	0.91	0.67	NA	0.74	0.63	0.61
E	0.11	0.49	0.29	0.46	0.17	0.34	0.43	NA	0.34	0.4	0.34
Average per Tooth	0.48	0.74	0.62	0.71	0.47	0.69	0.69	0.71	0.59	0.57	

NA means that the tooth did not counted for that particular category question.

Table 6 Free text/comments according to teeth followed by quotes.

Tooth	Summary of comments	Representative responder quotes
Tooth N1	Three responders would have liked to see a clearer occlusal surface. One responder mentioned limited ability to rotate the model to the desired orientation.	“Occlusal surface needs to be more clear.” “Improvement of occlusal anatomy.” “The tooth does not rotate to look like as a lower tooth [sic].”
Tooth N3	Two responders valued the realism of the models, especially the cemento-enamel junction (CEJ) and the fractured region	“The pathological appearance of the model looks real and convincing, still good enough to identify the tooth.”
Tooth N4	Two responders could not identify the tooth properly because the loss part of the dental crown; one praised the model but could not fully rotate the model	“Loss part of crown [sic] caused some difficulty in identifying this tooth.” “Realism of the model; model cannot be rotated fully to account for the correct anatomical position of the tooth.”
Tooth N6	Two responders complained about the loss part of the dental crown but could identify the tooth; one responder praised the realism of the model.	“The slopes of the crown are not well defined but good enough for identification.”
Tooth N8	Four responders mentioned ‘dog tooth’; two mentioned ‘herbivore tooth’; two mentioned ‘carnivore tooth’; and six mentioned ‘animal tooth’. One responder mentioned ‘human tooth with anomaly’.	Not shown.
Tooth N9	Two responders complained about the level of tooth destruction	“Too much tissue destruction to be sure.” “Side identification is difficult from this fragment, although I’m fairly confident it is a permanent maxillary central incisor.”
Tooth N10	Three responders could identify as a canine or premolar; one responder considered the loss of tissue great; other responder could not identify the side of the arch (right or left)	“Side and arch identification is difficult, although I’m certain it is a permanent canine.” “Loss of root make decision even worse [sic]”

result proves otherwise, the improvement of the current 3D model may involve enhancing the unique anatomical details that each tooth has for easier identification based on specific features. Alternatively, increased user interface interactivity (e.g. allowing complete and free rotation and addition of a scale) could allow manipulation of the model with different viewing angles and zooming capabilities for better examination; however, current inbuilt limit to rotation was not severe. Also, a scale being added to the models would be impossible considering the zooming. Implementing these changes could improve accuracy and user experience in identifying teeth using the 3D model;

however, when the tooth is unknown, it is unpredictable to choose the better angle for assessment. Moreover, the incorrect answers can also be related to the skills of the responders.

The intact animal tooth, a premolar of a dog (N8), was correctly identified by almost as many participants as N2 and N4 (FDI 74 and 26, respectively). These were the three teeth that were correctly identified by the greatest number of participants. Conversely, the tooth that was incorrectly identified by most participants was N1, the intact third molar (FDI 18). A forensic dentist should readily be able to recognize a non-human tooth and be able to say, at

the very least, if it originated from a carnivorous, herbivorous or omnivorous mammal [14]. Dogs are carnivores, and their premolars present a large triangular mesial cusp and small distal cusp, quite distinctive from human teeth, which present characteristics of omnivores [15]. Third molars are the most variable teeth in the dentition [16] and most often, they are not given the same time and attention while studying dental anatomy compared to other teeth in the dentition. In clinical dentistry, third molars are extracted more than they are restored, and, in biological profiling, the assessment of third molar anatomy and eruption represents an established method for age assessment of adult individuals [17].

The identification of molars, both deciduous (N2, N7) and permanent teeth (N4), was the most successful, and the reasons could include the size of teeth and the individual shape of the roots, which are widely displayed, and the very bulbous shape of the crown. Deciduous molars are unlike any of the permanent molars, so they can be identified by elimination [14]. A previous study provided supporting information to correctly identify loose deciduous molars when dealing with skeletal remains of fetal, perinatal and infant individuals highlighting the importance of such teeth in the forensic context [18]. More specifically, tooth N7 presents a cemented full metallic crown which has not impeded the tooth identification because the shape created by the laboratory was reliable. Individual dental crowns attached to roots found at the scene provide important information in identification studies due to their durable structure and, in addition, the information presented in the dental files corroborate to the comparative dental analysis [19].

Interestingly, the identification of crown shells was relatively successful across the models and one might argue that the presence of intact angles on dental crowns of anterior teeth or grooves on the dental crowns of posterior teeth could have assisted with the assessment, but a recent study suggested that during tooth shape recognition the external shape tends to be preferable in comparison to the assessment of the occlusal view [20]. Another indication that the responders might have used the external shape of dental crown is the result for the most substantial agreement amongst responders for category C, tooth classification (i.e., molars, premolars, incisor, canine) or non-human. The four classes of teeth have very distinctive shapes: molars are square shaped with an occlusal area, premolars are trapezoidal in shape, whilst canines are triangular, and incisors are rectangular or square in shape with an incisal edge. Analysing dental remains demands a detailed knowledge of dental anatomy and the ways in which heat/fire affects teeth to reconstruct the dentition for assessment [21]. More importantly, the lack of root does not always jeopardize severely the assessment of dental anatomy, as much information is available from the dental crowns.

With the advent of 3D scanning technology in dentistry, both external and intraoral, software availability, 3D printers and easy access to technology in the form of mobiles, laptops, tablets, etc. digital learning is becoming an integral part of the dentistry curriculum and there is evidence of the use of digital learning and 3D technology to study dental anatomy [22,23]. A study conducted among dental students comparing in-person and virtual tooth identification showed that the students had comparative average test scores and

were as effective in identifying the teeth using both the virtual and physical specimens [24]. In our research, although 69% of responders agreed that 3D models were a good way to identify teeth, it was observed that 31% were neutral or did not agree. Some responders preferred examining the original teeth over 3D scanned teeth, which could potentially boost the level of confidence in their answers. This could be attributed to the seriousness of the identification process for forensic application, the severe implications of misidentification for the justice system and victims' families, and above all violation of human rights for the deceased.

An online dental learning platform of micro-computed tomography-based three-dimensional (3D) tooth models with pulp cavity was tested and the results indicated that adding digital 3D resources to a traditional dental curriculum may have a positive effect on academic achievements [5]. 3D printed tooth models have the potential to be used for dental anatomy training as dental students have rated 3D printed tooth models as easier to use than extracted teeth in a study [25]. Moreover, established facts can affect the quality of tooth morphology teaching: many universities and institutions face difficulty in attracting and retaining qualified staff, reductions in the number of teaching hours and the difficulty to retain good quality extracted teeth [26] so eventually the 3D teaching could be a doable option.

Human identification through assessment of dental remains, restorations and materials and comparison of this postmortem information with a person's dental records and other data collected before death is often difficult [27]. A recently published case study demonstrated that 3D printing can be used to produce a physical model bearing sufficient detail to allow a comparative dental identification to be made to the satisfaction of HM Senior Coroner [28]. The correct tooth identification will facilitate the re-association of commingled and fragmented remains that might be necessary. This is strong evidence that forensic dentists must have excellent skills on tooth identification, whether they are intact or not, considering the feasibility of such identification. Dentists in general practice tend to forget the details of dental anatomy as they are not required to identify individual teeth outside the mouth [14]. For this reason, this novel study aimed to challenge the responders combining individual human teeth (intact or not) and animal tooth, but the results should have been better considering that the responders have exposure to Forensic Odontology.

Good knowledge of dental anatomy is also important to avoid errors in dental charting. When a tooth is not present in the mouth, its designation must be determined from the positions and anatomy of the existing teeth. For example, permanent mandibular second premolars are congenitally absent in roughly 3% of modern humans but determination of whether it is the first or second premolar that is missing depends on the clinician's differential diagnosis [29]. Also, the third molar may drift into the slot of a previously lost second molar, especially when early extractions have been performed and this is possible in both the maxilla and the mandible [30]. Incorrect data can impact how successful the comparative dental analysis performed by the forensic dentists might be [31].

Limitations of the method of this study includes the assessment to equipment for recording 3D dental data and safely transferring the collected digital information

to a remote FO that may be challenging in some regions of the world, especially in conflict zones. Therefore, we recommend future studies using accessible equipment and technology like mobile cameras and photogrammetry for a more practical approach. Ideally, we would have compared 3D model identification combined with the identification of real teeth but the limited numbers of available forensic odontologists in situ would make this practically difficult.

Comparative research including 3D models and the original teeth is also suggested. The level of accuracy and confidence with virtual reality glasses and 360 video could also be explored for the purpose of virtual examination of dental evidence.

Conclusions

Most responders agreed that three dimensional (3D) scanned digital models is a good way to identify teeth/tooth fragments. Animal tooth was the most successful tooth identification as opposed to the third molar which was the least; however, the judgments cannot only be related to the material assessed but also to the intrinsic knowledge on dental anatomy. Continued training in dental anatomy and a serious approach to tooth identification in forensic odontology is important to avoid misidentification of human remains. Digital models may assist with the teaching of dental anatomy considering the scarcity of teeth and tooth identification considering remote work and preservation of damaged teeth. Clarity and texture of the scanned model, and the ability to manipulate and visualize the 3D model freely for a realistic experience and confident conclusion is pertinent to correct tooth identification.

Disclosure of interest

The authors declare that they have no competing interest.

Funding

This research received no external funding.

Informed consent statement

Not applicable.

Publisher's note

The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s).

Acknowledgments

We would like to thank the digital artist Emily Mc Dougall who created two of the 3D models (Tooth N1 and Tooth N2) with advice from Andrew Mason and Mark Roughley and Richard Boyle, lecturer, who scanned the other samples.

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