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ORIGINAL ARTICLE

Is post-mortem CT of the dentition adequate for correct forensic identification?: comparison of dental computed tomograpy and visual dental record

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Abstract The gold standard for identification of the dead is the visual dental record. In this context, several authors emphasize computed tomography (CT) as valuable supportive tool for forensic medicine. However, studies focusing on diagnostic accuracy of post-mortem computed tomography (PMCT) are still missing. Therefore, the aim of this study was to compare diagnostic accuracy of the visual dental record and post-mortem computed tomography (PMCT) of the dentition for identification of the dead. Ten whole skulls were included into the study. The entire dentition of each skull was first examined with the visual dental record as a gold standard and second using dental PMCT scans, performed on a 64-multi-detector CT (MDCT). 3D reformations, multi-planar reformations (MPR), and CT–orthopantomography (OPG) were performed in the post-processing. All examinations were analyzed by three independent investigators regarding the criteria for identification of the dead, e.g., in case of disaster. PMCT for the dental identification of the dead was difficult to perform and time consuming. Due to dental overlays and corresponding artifacts, the definite periphery of the dental fillings/inlays was not accurately defined resulting in 2.9% incorrect and 64.1% false negative findings, especially synthetic inlays were hardly or not recognizable at all. For the identification of the dead especially in case of disasters with large numbers of victims, the visual dental record is still to be considered the gold standard. In the identification process itself, there is no room for error at all, although some non-concordant information may occur. Thus, PMCT should only be performed for identification in individual cases due to the relatively high error rate.

Keywords Forensic science · Forensic odontology · Dental identification · Computed tomography

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Introduction

Radiological imaging methods gain increasing importance as supporting techniques in forensic medicine. In particular, multi-detector computed tomography (MDCT) allowing multi-planar reconstructions is emphasized by several authors. In this context, Hayakawa et al. analyzing the use of a mobile MDCT unit for post-mortem examination concluded that post-mortem computed tomography (PMCT) might be suitable as a screening tool [1]. Dedouit et al. reported about new identification possibilities with post-mortem multi-slice computed tomography [2].

The role of computed tomography (CT) in terminal ballistic analysis has been examined by Rutty et al., reporting that MDCT including 3D analysis allows for a reliable analysis of the projectile path as well as different firearms and projectiles [3].

In general, identification of the unknown dead depends on dental examination and accurate dental records, especially identification and analysis of dental fillings is essential. New composite, compomere, and ceramic filling materials imitate perfectly the natural dental tissue, thus making life difficult for the forensic odontologists. In overcoming this issue, Benthaus et al. suggested preparation of the jaw by etching with 37% acid and coloring the roughened dental tissue by an indicator [4]. In a different work, this group focused on post-mortem orthopantomography (PMOPT) as an aid in screening for identification purposes [5]. The authors reported that PMOPT may expand the spectrum of forensic radiology and also offers a reliable aid for the victim identification on the wake of a mass disaster where a large number of bodies have to be identified under great pressure.

In the recent literature, the role of dental radiographs and CT for the identification of human corpses especially with post-mortem alterations such as putrefaction and burning has been discussed [6]. Radiological identification most likely by dental radiographs is based on the ante-mortem (AM) and post-mortem (PM) images comparison and might be an alternative to fingerprints and/or DNA for identification especially in cases when fingerprints are no longer available. Modern forensic dental identification teams use with increasing extent computer-assisted dental identification software, e.g., in the tsunami catastrophe in Thailand [7]. However, the direct dental identification by experienced personnel, i.e., forensic odontologists, is regarded as the gold standard, which was proven by the statistical evaluation of the tsunami victim identification [7, 8]. The vast majority of identifications were based on the dental examinations and computer-aided comparison with a specialized software showing that the software is a valuable tool, but does not replace the work of forensic personnel.

In the recent years along with the development of multi-slice CT and the possibility of generating multi-planar reformats, CT scans of the dentition is performed more often, e.g., for planning of surgical intervention. In the literature, a few studies exist describing the general use of CT for forensic identification [9] as well as suggesting that CT of the dentition might be a practicable and reliable tool for easy and fast identification. To the best of our knowledge, the method has yet not been tested regarding the examination of whole dentitions as well as has only been performed in a low number of cases. However, the examination of the entire dentition is necessary as an exact examination is the basis for dental identification, especially considering the internationally used software (PLASS data) relying on exact post-mortem data.

Plausible reasons for establishing this method as a valuable identification tool should primarily include the highest accuracy and reliability of the results possible, and should be usable in cases of mass catastrophes. Effectiveness must be considered as well, defined as a proportion of accuracy versus speed and cost. Since the identification of the dead should be a comparison of ante-mortem and post-mortem data, the evaluation of a CT-aided method should answer the following questions: Which technical requirements are necessary? Which diagnoses are the important ones? Which kinds of errors occur determining the quality of the process? Finally, the overall accuracy has to be determined.

Therefore, the aim of our study was to assess sensitivity and specificity of dental PMCT and to compare its diagnostic accuracy to the gold standard visual dental record concerning identification of the dead.

Materials and methods

Computed tomography of the dentition of the skulls collected at the Institute of Forensic Medicine was performed. The upper and lower jaws of the skulls were examined separately from each other; however, they were not exarticulated. The examinations were performed on a dual 64-slice CT scanner (Somatom Definition, Siemens Medical Solutions, Erlangen, Germany). Scanning parameters were as follows: raw data acquisition using a dental CT examination protocol (140 kV, 1,199 mA effective/slice, slice 0.6 mm, increment 0.3 mm, reconstruction kernel H60) as well as using a temporal bone (inner ear) examination protocol (140 kV, 410 mA effective/slice, slice 0.6 mm, increment 0.3 mm, reconstruction kernel H70). For both scanning protocols, the extended CT scale option was used during raw data acquisition for reconstruction purposes.

Regarding post-processing of the CT raw data, multiple panoramic and cross-sectional views were generated at a Leonardo workstation for post-processing.

At first, an orthopantomography-like reconstruction was performed using the syngo dental CT application available on the Leonardo reconstruction workstation. The user has to define a curved line on an oblique cross-section adapted to the jaw, defining the center of the teeth. The software creates panoramic images along this line in a user-defined thickness with the possibility to create a panoramic reformatted image containing the information of the entire jaw comparable to a conventional radiograph in terms of an orthopantomography. In addition, multiple thin sections can

Table 1 Results of the three readers (radiologist, forensic pathologist, forensic odontologist) given as means ± standard deviation (SD)

	Forensic odontologist	Radiologist	Forensic pathologist	Mean
True positive (SD)	296 (±17.27)	271 (±15.55)	302 (±21.61)	
True negative (SD)	1,243 (±20.01)	1,235 (±22.47)	1,226 (±28.70)	
False positive (SD)	29 (±2.46)	45 (±2.95)	37 (±4.47)	
False negative (SD)	32 (±4.66)	49 (±7.46)	35 (±5.83)	
Sensitivity	90.2%	84.7%	89.6%	88.2%
Specificity	97.7%	96.5%	97.1%	97.1%
Positive predictive value	91.1%	85.8%	89.1%	88.7%
Negative predictive value	97.5%	96.2%	97.2%	97.0%

be created in parallel to the defined line from buccal to lingual allowing for a more detailed dental assessment. Subsequently, the software draws multiple-numbered lines perpendicular to the curved line, defining where the periapical images of each single tooth will be reformatted.

Secondly, the axial raw data was processed using a volume rendering software also available with the post-processing Leonardo workstation (InSpace 3D, Syngo, Siemens Medical Solutions, Erlangen, Germany).

Regarding the evaluation, at first, the visual dental records of the skulls' dentitions were performed by an experienced forensic odontologist, considered as a gold standard using a standard form for dental recording. Two weeks later, one radiologist, one forensic pathologist, and one forensic odontologist performed the evaluation of the CT examinations separate from each other also using the dental recording form. For the CT evaluation, both reformats of the raw data were available. The most important findings the readers were looking for were as follows: missing tooth/teeth AM or PM, exact location of dental filling (tooth, buccal, occlusal, palatinal/lingual, distal, mesial), type of material used (gold, amalgam, composite), tooth/teeth coloring (compound, ceramics), and special dental works, such as crowns, bridges and implants. Because of the vast number of different materials being used in dentists' daily routine, it seems not practical to perform an exact material diagnosis of the recognized dental works since the software used for identification purposes (PLASS data) in case of a mass disaster only distinguishes between the major classes of possibly used materials. All findings were recorded on the dental form to be able to evaluate whether it is possible to identify a person by performing dental CT.

Since one tooth consists of five surfaces which have to be described when containing fillings, crowns, or inlays, true positive findings were assumed when a filling, crown, or dental bridge was identified at the same position as in the original dentition with all five surfaces being correctly described.

True negative findings were defined when all surfaces of a tooth were correctly diagnosed without a filling or other dental work, as well as healthy teeth being described at the correct position.

False positives were regarded as filling or other dental work described at a wrong position compared to the position in the original dentitions, the fillings were described with more surfaces than in the visual record described, or a filling was mistaken as a crown, bridges, and/or inlays described as crowns.

False negative findings were defined as generally missed dental work, described fillings including too little surfaces, or described missing teeth which were already missing ante-mortem not post-mortem.

Results

In total, the dentitions of ten skulls collected at the Institute of Forensic Medicine were examined by CT. Fifty-three

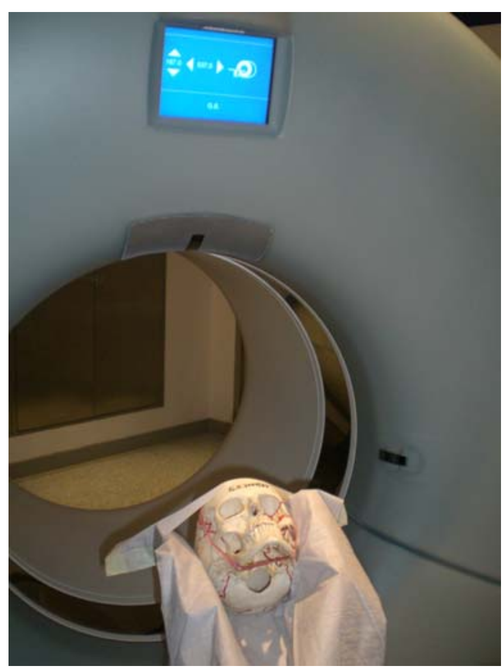


Fig. 1 CT examination of an upper jaw of a skull

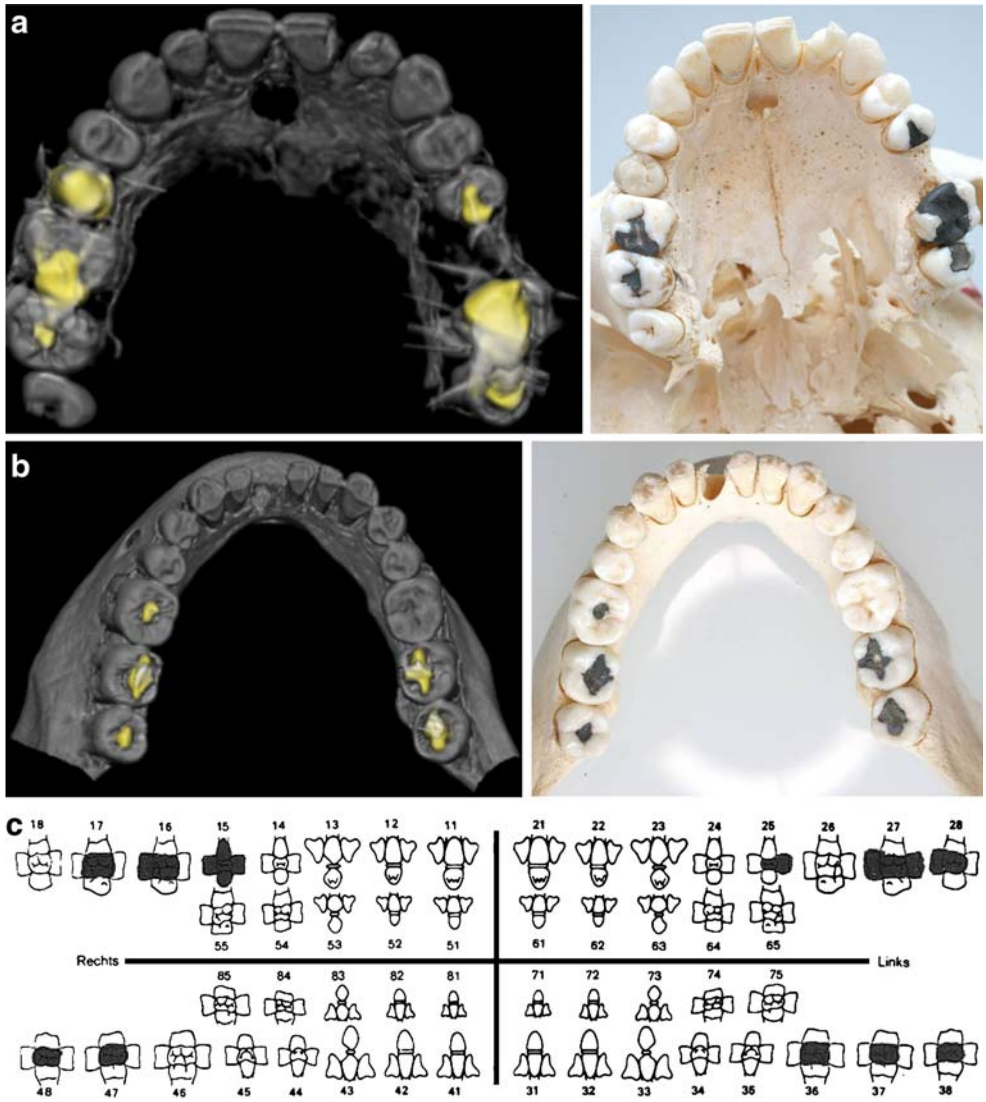


Fig. 2 **a** These figures present the real upper jaw and the corresponding 3D-CT reformat. **b** These figures present the real lower jaw and the corresponding 3D-CT reformat. **c** This figure shows the direct dental record assessed by the forensic odontologist in terms of the gold standard. **d**–**f** Here are the CT evaluations of the forensic pathologist (**d**), the forensic odontologist (**e**), and the radiologist (**f**) shown. Only one report corresponds completely to the gold standard findings (**c**)

teeth were already missing ante-mortem and four teeth were missing post-mortem, leading to a total of 267 teeth, and accordingly, 1,335 surfaces to be evaluated.

One hundred sixty possible locations could be interpreted as artificial with regard to crowns and other complex dental restorations, but the "cut-down" to an easy data assessment proved to be necessary for evaluation purposes, which are the most urgent questions in such a setting.

The findings of the three readers are shown in Table 1, as well as the resulting sensitivity, specificity, and the mean values of true positive, false positive, true negative, and false negative findings. The highest number of true positive findings was described by the forensic pathologist followed by the forensic odontologist and the radiologist. For the number of true negative findings, the most were described by the forensic odontologist followed by the radiologist and finally by the forensic pathologist. For both findings in terms of false positives and false negatives, the radiologist detected the most followed by the forensic pathologist and the forensic odontologist. This resulted in an individual sensitivity/specificity as follows:

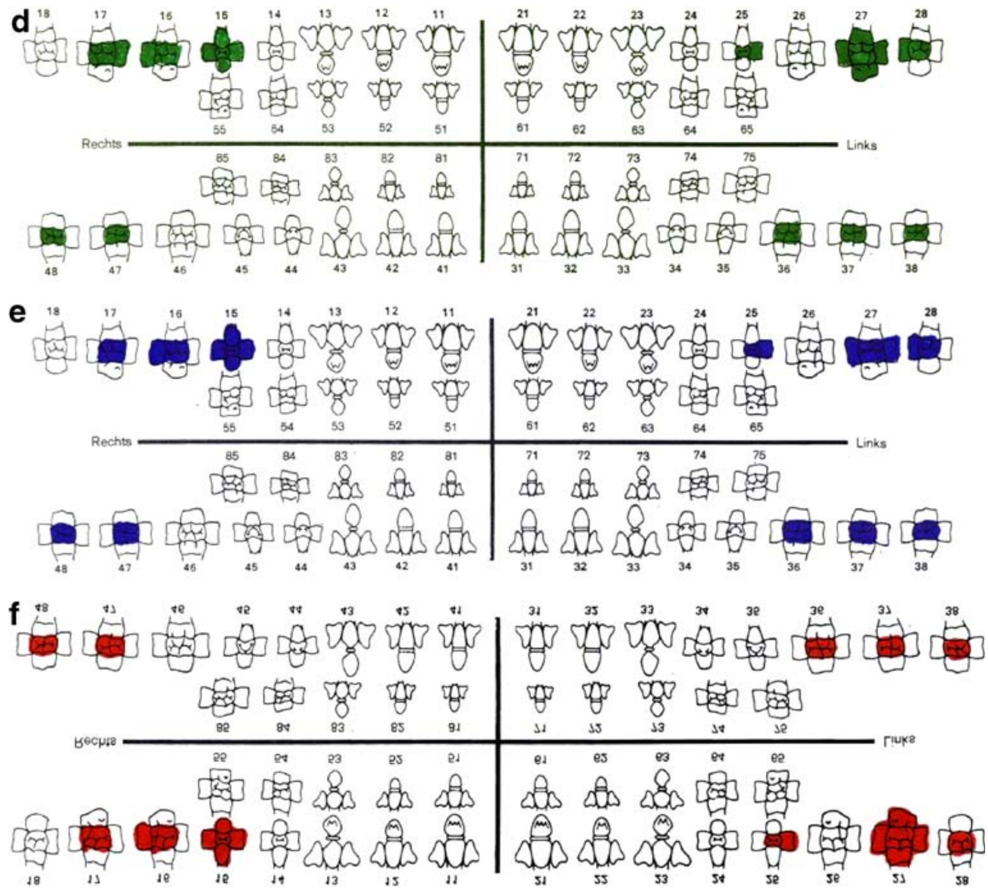
- Forensic odontologist: sensitivity = 90.2%; specificity = 97.7%
- Radiologist: sensitivity = 84.7%; specificity = 96.5%
- Forensic pathologist: sensitivity = 89.6%; specificity = 97.1%

The resulting overall mean sensitivity of 88.2% and corresponding specificity of 97.1% resulted from the dental CT scan regarding the identification of the examined dentitions.

Discussion

In general, for the identification of the dead, the comparison/evaluation of similarities and relevant features associ-

Fig. 2 (continued)



ated with the dentition is the main objective. As previously reported, post-mortem CT can help in managing mass disaster scenarios [6]. All aspects of the teeth/jaw and body can be used identification purposes especially when comparing available AM and PM data.

Validity

However, utmost importance in an identification process is the reliability of the method. This means that errors leading to an exclusion or wrong inclusion during software-aided AM–PM data comparison are fatal to the entire identification process. Therefore, a precision of 100% is desirable to provide a reliable result without the necessity of too many revisions. This means that contradictory results especially false positive findings are such findings which might lead to a false rule out of persons during the identification process. When an identity is ruled out, the whole process starts all over again, so a false positive finding might lead to an unnecessary delay in the identification. If a diagnosis needs to be re-established, only the CT data could be available due to the remote location of bodies and data processing. In the CT data review, the same error may occur or the diagnosis can only be marked as uncertain. Summarizing our results in terms of a mean positive predictive value of only 88.7%, it has to be stated that this method is not yet sufficient for an identification of the dead that can be called reliable. Taking this into account, that there was only one dentition that was diagnosed completely correct by evaluating the CT dataset, leaving nine primarily unsuccessful or even wrong identifications at hand. Thus, in a real scenario, CT identification is time consuming, expensive, and leaves the user with the worst fact with psychological devastating errors. At this time point, CT-based identification is not accurate enough to provide a reliable tool for this task although additional data can support the identification process in complicated cases or cases with no or at least not complicated dental restorations, where other features are needed for identification purposes.

Practical diagnostic process

As described in the recent literature by Jackowski et al. [9], multi-slice CT covering the entire dentition can be performed within 1–2 min. However, the initial 2D-CT images are not of significant value for the identification, but 3D data and corresponding reformations definitely are needed to increase the possibilities. Using the software

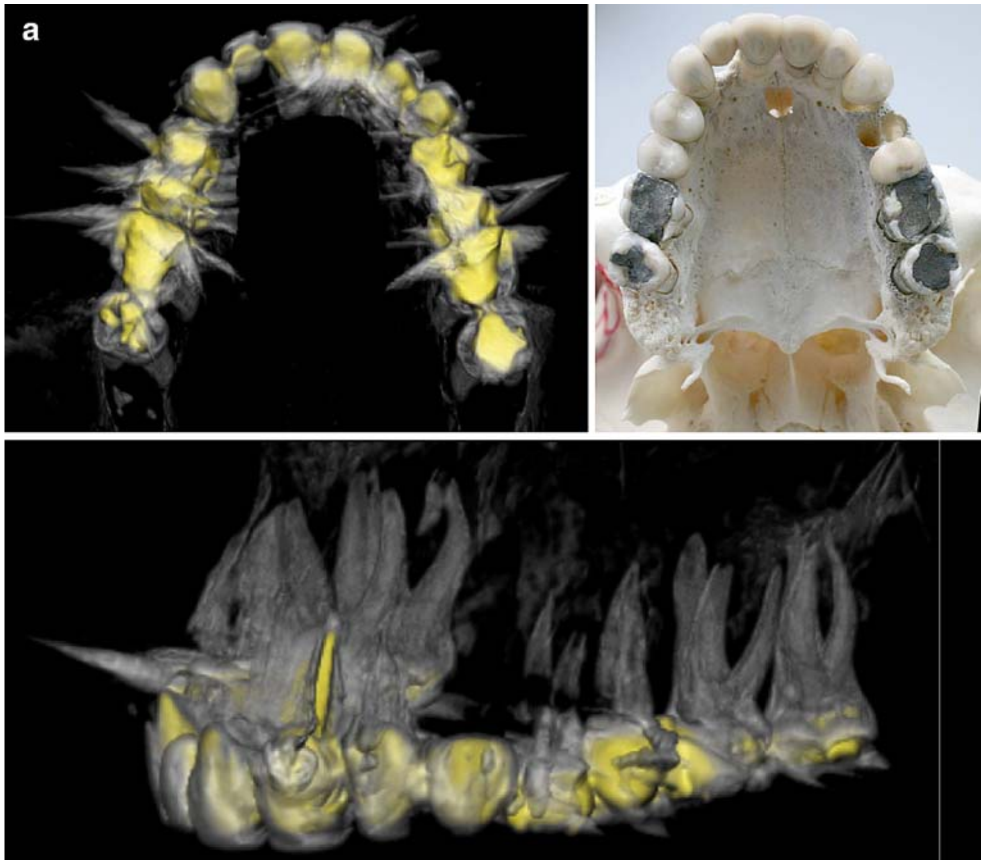
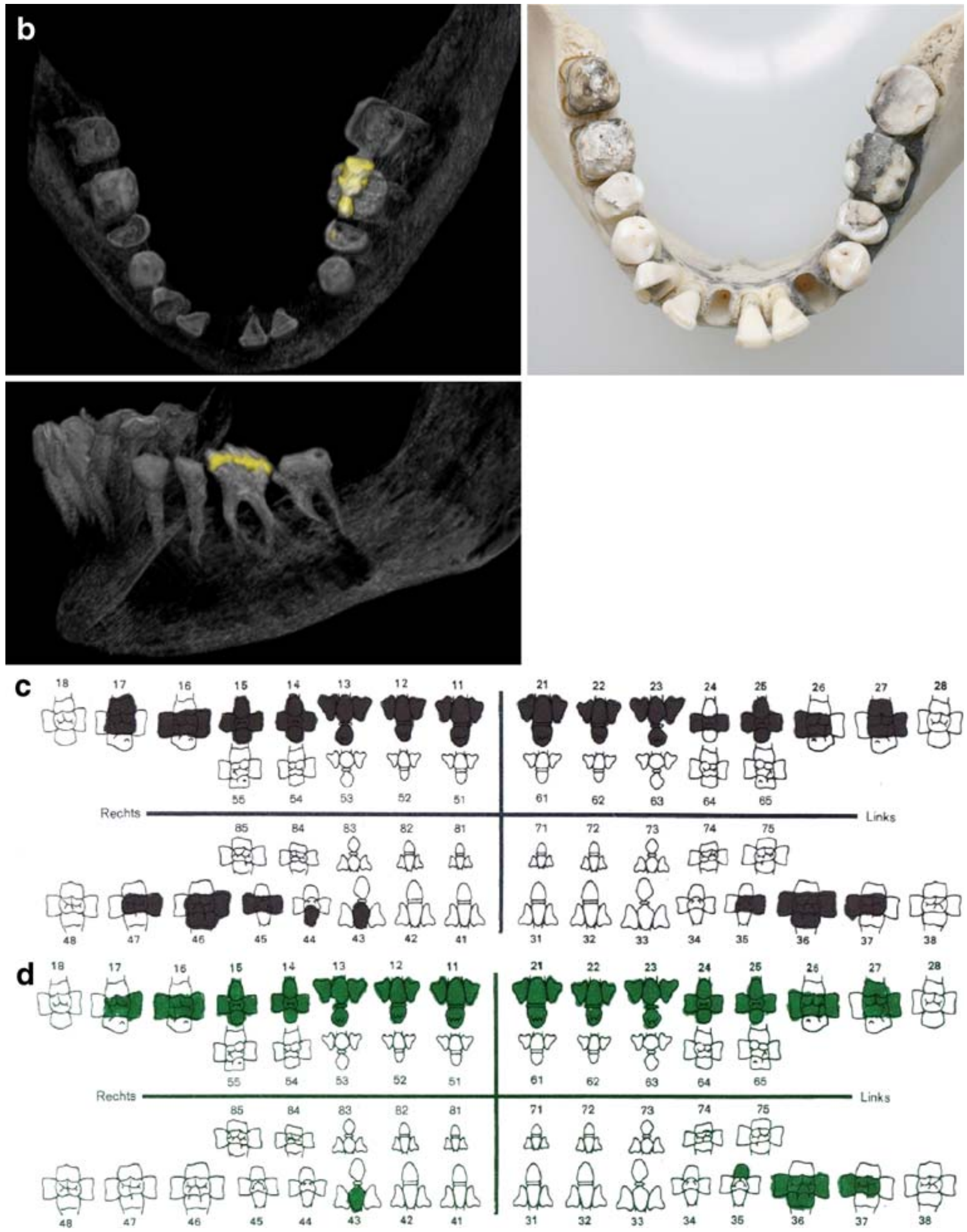


Fig. 3 **a** These figures present the upper jaw of the skull and the corresponding CT-reformat in two different views. **b** These figures present the lower jaw of the skull and the corresponding 3D-CT reformats in two different views. **c** This figure shows the direct dental record assessed by the forensic odontologist in terms of the gold standard. **d**–**f** Here are the CT evaluations of the forensic pathologist (**d**), the forensic odontologist (**e**), and the radiologist (**f**) shown. None of the three CT reports corresponds exactly to the gold standard findings (**c**)

provided by the CT scanner manufacturer for dental CT post-processing which is comparable to ante-mortem data, panoramic dental radiographs can be reconstructed [5, 10]. In our study, the panoramic dental CT as well as a 3D-model of the upper and lower jaw was generated and evaluated. Certainly, the major advantage of the CT technique is the possibility to adapt the direction of post-mortem dental 3D-CT to the ante-mortem X-rays at the time of comparison. Thus, the forensic pathologist or odontologist is able to choose exactly the same view on the PM model as on the AM radiograph with the possibility of directly comparing/matching general as well as special features such as crowns, composite fillings, or other dental works. In addition, the identifying person gets an idea of the bony structures of the jaw, missing teeth, and previous existing fractures (Figs. 1, 2 and 3) [11–13].

However, even taking all the advantages of CT into account, still several disadvantages persist. The major disadvantage in terms of streak artefacts resulting from metallic dental works is still present decreasing the 3D image quality. Correspondingly, the detailed documentation of the single tooth or dental restoration is less precise and hard to assess compared to classical dental radiographs. However, we tried to overcome the streak artefacts by implementing the results from the study of Jackowski et al. in terms of using the extended CT-scale modus [14]. Accordingly, we can unfortunately not agree with the results of Jackowski et al. who stated that these artefacts can be overcome by performing the reconstruction with the extended CT scale. Secondly, we do not conform to their statement saying that the minor disadvantage regarding the discrimination between dental metallic works with a radio-opacity of more than 30.710 HU will be possible with CT scanners of the latest generation providing a greater extended CT-scale modus since our study was performed on the most recent CT scanner generation, but still we had to deal with severe streak artefacts especially in jaws with much and more complicated, extensive material and dental work combination. This problem leads to the point of not being able to define the exact borders of the single tooth and/or filling, crown, etc. with correspondingly increasing evaluation time frames. In a just recently published paper by Jackowski et al. [15], the authors describe the possibility of discriminating ceramic and composite fillings by dual source CT examinations of prepared single teeth. They report about their results providing the scientific background for the application of 3D volume rendering to visualize the human dentition for forensic identification purposes. However, there exists an innumerable variety of dental work material so it is not at all possible to

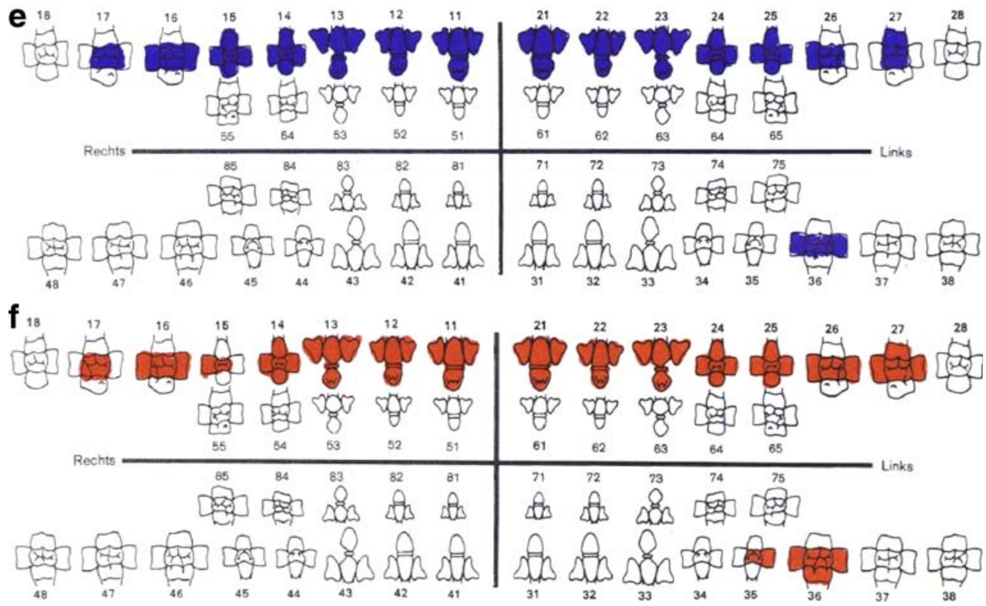
Fig. 3 (continued)



differentiate between, e.g., ceramic and composite or even a mixture of different materials by HU or radioopacities in general. A gross differentiation between the most used materials is possible, although for the general identification process the recognition of the materials itself is not necessary. One certain limitation of their study to be mentioned is the problem of examining only single prepared teeth but no entire dentition, so that they do not have to deal with the problems of streak artefacts at the boarder of the teeth especially when, for example, a crown and a huge filling are implanted next to each other. For small metallic restorations, for example, concerning a single small occlusal amalgam filling, diagnoses were easily made including satisfying results with regard to identification. This effect currently seems to be the greatest technically unsolved problem that causes a majority of errors that ultimately hinder positive identification.

Other foreign dental materials caused less diagnostic problems, but the Hounsfield unit range of “tooth-colored” materials like compound and ceramics was often very similar to the radioopacity of natural dental materials like dentin and enamel. This fact made it necessary to vary the color coding and HU ramp to allow a precise localization of these restorations. Almost every material needed a special setting, resulting in a very time-consuming process with the goal of an exact topographic localization. However, in an

Fig. 3 (continued)



examination of the living, this would have been easily and quickly described as tooth-colored material. To establish dental post-mortem CT as a fast method, the used material in the unknown body needs to be identified in advance such as from written records of the treating dentist to choose the right CT settings.

The present work is suffering from one limitation since we did not examine the human teeth in a completely realistic way because the maxilla and mandibula were examined separately due to the appearance of streak artefacts, despite the extended CT scale, and partial volume effect, causing additional artefacts due to fused upper and lower dentition. Also, the anatomy of the mandibles and teeth made it rather complicated to reconstruct the occlusal sides of the teeth. Taking this into account and comparing it with the known circumstances in mass disaster catastrophes such as after a tsunami, direct handling of the dead bodies would be necessary to allow for a reasonable scanning and image quality. Obviously, a lot of time would be needed just to scan one corpse for identification even though performing a whole body post-mortem CT including dental CT.

The evaluation of the data also showed that the quality of the result was linked to the examiners' experience, which cannot be assumed for every dentist possibly working at the scene of a mass disaster. Indeed, the quality of the results increased over the time period the readers were evaluating the CT examinations, as their experience with the 3D-rendered pictures and CT–OPG grew. As a consequence, CT-based identification should only be performed by highly trained and experienced personnel. Before this is possible in a routine manner, some technical problems have to be solved. Despite the technical problems, the costs as well as logistical problems have to be considered. For example, in the tsunami area, the main problem would have been the availability of electricity necessary to perform CT scans. Further transport capacities were limited, and in the beginning, any capacity (land, air, and water) had to be used for humanitarian purposes and emergency medicine. Further, the Thai authorities demanded original AM data. So from our point of view, we do not agree with the statement of Jackowski et al. who said that a mobile CT can be installed everywhere and the scanning procedures as well as the evaluation of the images do not significantly differ from clinical settings. These authors also stated that for mass casualties CT would allow for a detailed dental matching including the entire dentition with AM data not available at post-mortem dental status documentation. The data acquisition would be accelerated because there is no need to wait for any radiography to be developed. However, as mentioned above, there are several counter-arguments regarding the use of a mobile CT for the identification of the dead in mass disasters most likely because these areas, e.g., where natural disasters take place, do not have the adequate infrastructure.

Conclusion

Our study shows that the CT-aided documentation of the dental status with 3D reconstructions provides some interesting and promising aspects in dental diagnosis for forensic identification. Some diagnoses can be made much more easily or are only possible by CT. CT and especially 3D-volume rendering technique provides excellent documentation due to its technical possibilities of data handling.

Despite these promising features, some major problems exist with the currently available devices and evaluated method. The evaluation of the errors occurring during the virtual identification performed in our study, especially in terms of streak artefacts and partial volume, shows that CT does not yet present as a reasonable tool for forensic identification. Too many errors arising from the CT scan make an accurate and reliable identification primarily impossible. Secondly, the evaluation of the CT examination is still time consuming and expensive, since in most cases a second opinion will be needed. This does not mean that CT-based forensic identification will be unavailable in the future or is already used in our university setting in singular cases when there is enough time for the evaluation, but the severe problems in diagnosis described have to be addressed more intensively in further studies to possibly use CT may be in the future in mass catastrophes to facilitate identification processes.

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