Forensic dental identification in complicated fractured skull conditions: case report with adapted algorithm for image comparison

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KEYWORDS

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ABSTRACT

Objective: To analyze the perspective of using an adapted algorithm for digital images comparison while providing forensic dental identification in complicated fractured skull conditions by ante-mortem and post-mortem radiographical data sets.

Materials and Methods: Ante-mortem orthopantomogram and post-mortem peri-apical X-ray images were converted in *.jpeg format with their further import into GIMP 2.10 software (The GIMP Development Team). Segmentation of OPG-image was provided in topographical projections of jaw segments obtained directly from the victim. Comparison of analyzed image segments was provided manually within GIMP 2.10 software using functions of "Layers" and "Opacity" through the proposed algorithm.

Results: Considering the fact that 20 positive concordant dental identifiers overall were verified during comparison of AM and PM X-ray datasets, we can conclude that odontological identity was established. All above-mentioned discrepancies could be classified as explainable. Inter-agreement rate between two investigators considering correspondence between AM and PM datasets reached Cohen's kappa level which is equal to 0,97, while positive 100% agreement was reached considering 21 out of 24 analyzed characteristics.

Conclusion: Available AM and PM radiographical datasets represent a sufficient information for effective forensic dental identification, even if such were obtained by different roentgenological techniques (orthopantomography and periapical radiography). Using of an adapted algorithm for digital images comparison with forensic dental purposes could potentially overcome cognitive bias and observer's effect, speed up the process of analysis and increase the accuracy and inter-agreement rate while referencing AM and PM datasets.

INTRODUCTION

Three principal methodologies of person identification by dental status include evaluation and comparison of ante- and post-mortem dental records, photographs and results of radiography.[1,2,3] However, there are several causes of inability to use dental records as a reliable source of personal information in Ukraine, such as: absence of mandatory insurance program, improper filling out medical documentation in state hospitals and dental departments specifically, detention of medical

documentation personally by patients during the treatment migration among different medical/dental facilities.[4-6] The latter tendency was also noted in recent systematic review demonstrated that only about 12% of dentists keeps all dental records of their patients.[7]

Based on possible condition of non-reliable person's dental record, other information also should be used for the identification purpose, which includes clinical photo and X-ray results (peri-apical, bite-wing, orthopantomograms, cone-beam computed tomographical scans).[4,6,8,9] In relevant real-life conditions orthopantomogram still considered to be one of the most significant ante-mortem source of evidences that could be effectively used for the forensic dental identification purposes.[9] Also considering problem of inconsistency of dental records, multidisciplinary approach should be provided in cases, where dental identification could not provide valued positive outcome.[5,6,8]

Nevertheless, some cases of individual identification remain complicated due to the severity of deformations, amount of pathological and iatrogenic changes, and sometimes due to the intentional actions aimed at dental status alterations. In such cases, several factors such as observer's effect or cognitive bias, could compromise the result of identification outcome while providing classic antemortem-postmortem data sets comparison especially if such held by specialists of different professional experience. Also, pronounced fragmentation of maxillo-facial region is slowing down the identification process and causing decrease of inter-agreement rate while interpreting experts' conclusions.

That is why the analyses of practical case reports of complicated identifications could be suggested as an educative measure for general dental specialists, considering legislative and procedural specifics of the forensic dental identification process in different countries. Taking into account digital conversion of dental practice in general, approbation of newly adapted methodologies using digital analysis instruments seems to be relevant and perspective within contemporary realities for solving issues of low inter-expert's agreement rate, observer's effect and cognitive bias in cases of involving dental specialists with different professional experience into forensic identification process.

OBJECTIVE

To analyze the perspective of using an adapted algorithm for digital images comparison while providing forensic dental identification in complicated fractured skull conditions by ante-mortem and post-mortem radiographical data sets.

MATERIAL AND METHODS

Present case report demonstrates possibility to compare ante-mortem (AM) orthopantomogram and post-mortem (PM) peri-apical X-ray images with obtaining of more than 12 ordinary characteristics to establish odontological identity through using for this purpose an adapted algorithm of digital images comparison.

Ante-mortem orthopantomogram was obtained during a patient's urgent visit to the Central Dental Policlinic of the Ministry of Defense in Ukraine, caused by persistent dental pain. OPG was obtained by Pax-I orthopantomography device (50-90 Kvp / 4-10 mA, focal spot – 0,5 mm; Vatech, Korea). Post-mortem peri-apical X-ray images were obtained from residual segments of maxilla and mandible manually using ProX intraoral X-ray unit (63 ±2 kV / 7 + 0.2 mA, focal spot – 0,4 mm; Planmeca, Finland).

Both OPG and peri-apical X-ray images were saved in *.jpeg format with their further import into GIMP 2.10 software (The GIMP Development Team), where images were cropped and optimized by the orientation and intensity/contrast parameters to minimize the influence of image background on further comparison process (Fig.1).[10,11]

Segmentation of OPG-image was provided in topographical projections of segments obtained directly from the victim ("a1" – maxillary segment from 12th to 17th tooth with visualization of maxillary sinus floor; "a2" – maxillary segment from 21st to 25th tooth; "a3" – maxillary segment from 26th to 27th tooth; "a4" – mandibular segment from 37th to 38th tooth, "a5" – mandibular segment from 42nd to 43rd tooth) (Fig. 1).

Figure 1. Example of image optimization before comparison phase in the software environment: 1) periapical PM image obtained after orientational and contrast/intensity optimization; 2) periapical PM image obtained right after periapical X-ray examination before optimization; 3) cropped segment of AM orthopantomogram in projection of PM image segment.

Further comparison of analyzed segments was provided manually within GIMP 2.10 software using function of "Layer" and "Opacity" according to the next developed algorithm:

1) both segmented and previously optimized AM and PM images were imported into software as two separate layers (superimposed) of the same size;
2) operator marked unique points/lines/contours on the outer layer (PM image) with "Brush tool";
3) after all unique components were marked, operator changed the opacity of the outer layer (PM image) from 100% to 0%, while monitoring the correspondence of previously marked points/lines/contours to the inner layer (AM image);
4) if marked unique points/lines/contours from the outer layer (PM image) corresponded to the similar structures at the inner layer (AM image), operator registered results of identification according to Keiser-Nielsen principles.

Comparison of AM and PM image segments was held independently by two experts using the same algorithm described above. Inter-agreement rate between two investigators considering correspondence between AM and PM datasets was evaluated with the use of Cohen's kappa and reproducibility percentage value.[12]

Subjective expert's assurance considering concordance of dental identifiers was evaluated by experts themselves using 0-100% scale, within which 0% stands for "Completely uncertain" and 100% for "Completely certain". Specification of each scale values between 0-100% were not provided in order to not disturb the process of expert subjective grading considering the level of the personal assurance.

Results of identification were classified according to the Keiser-Nielsen principle considering ordinary concordant details: 1) odontological identity is established (12 or more unique concordant points); 2) odontological identity is probable (6-12 unique concordant points); 3) odontological identity is possible (less than 6 unique concordant points).[13]

In Ukraine forensic documentation designs do not include separate forensic dental report, so all the findings were noted in the general report of forensic expert.

Some details of the abovementioned case (date, exact territory, supposed age, gender, names and affiliations) could not be revealed considering ongoing law enforcement investigation, but details of forensic dental identification as component of general forensic examination could be represented considering ethical principles and full anonymous design of present case demonstration with agreement of all associated policies and state authorities.

Systematization, categorization and tabulation of the data was conducted in Microsoft Excel software environment (Microsoft Office 2019, Microsoft).[14]

RESULTS

Unidentified skeletonized body parts with fractured fragments of the skull and body bones were found at the territory of the Eastern Ukraine at the area of military conflict. Skull part consisted of 82 independent fractured fragments of

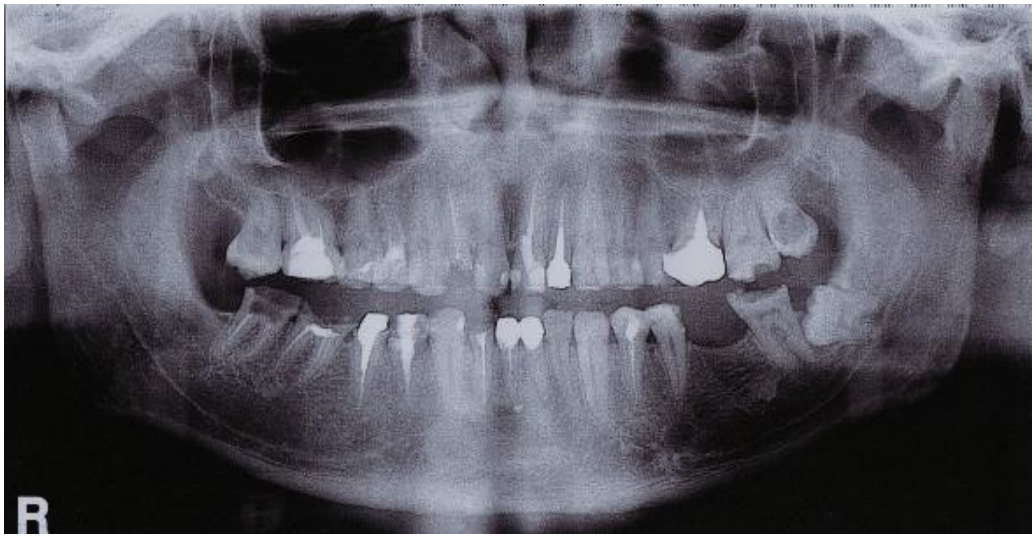
different patterns. Primary investigation of skull fragments revealed 5 residual segments of mandible and maxilla, which potentially could be analyzed for the person's identification purpose (Fig. 2-3).

Figure 2. Initial view of all skull fractured fragments.

Figure 3. Initial view of the residual segments of maxilla (a1, a2, a3) and mandible (a4, a5)

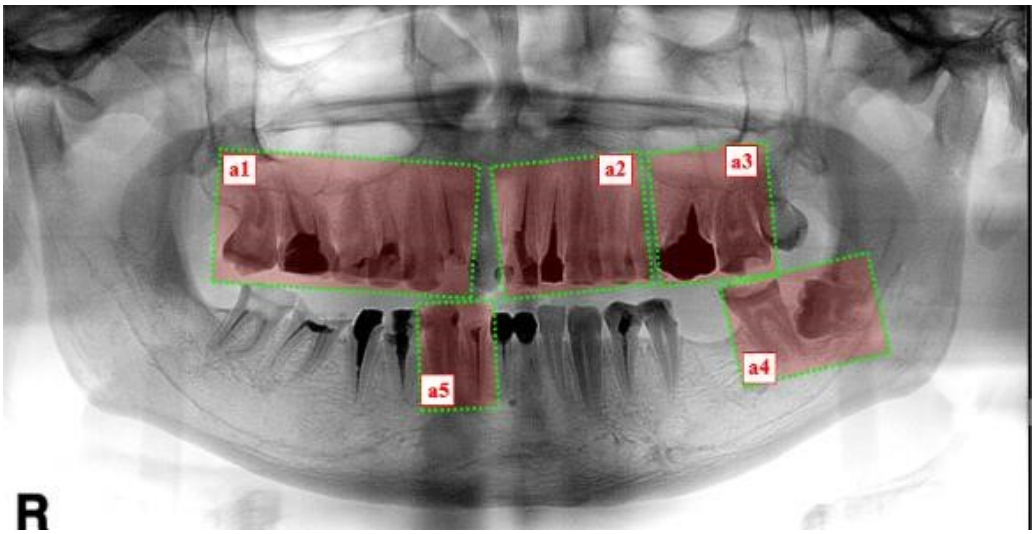
Because of totally fractured conditions of the skull bones it was impossible to get a post-mortem orthopantomogram of the victim. To overcome such issue peri-apical images of fractured mandibular and maxillary fragments were obtained with the intraoral X-ray device.
Previously obtained orthopantomograms and dental X-rays of all soldiers considered to be missing during military conflict were collected from the Central Dental Polyclinic of Ministry of the Defense in Ukraine by the forensic examination bureau responsible for the identification procedures within military personnel.
Among number of analyzed orthopantomograms one demonstrated signs of previous dental interventions and unique teeth characteristics, that were similar to those, registered at the peri-apical X-ray images, obtained from residual mandibular and maxillary fragments of the victim (Fig. 4).

Figure 4. Orthopantomogram of suspected person



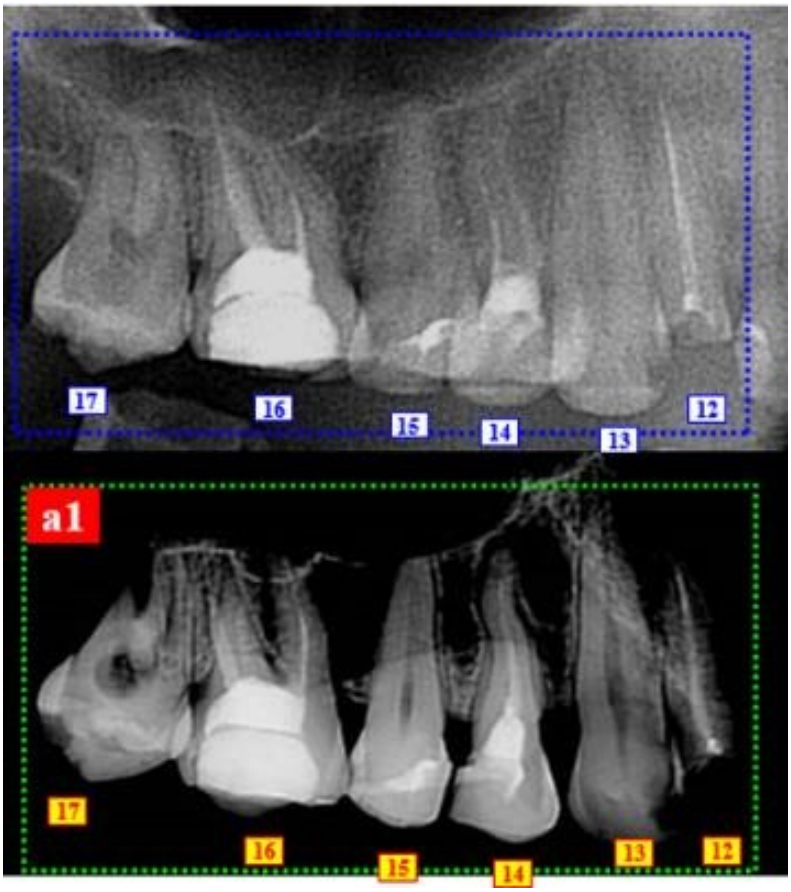
Before any superimposition of the images, they were optimized by size, orientation and contrast/intensity parameters to eliminate the influence of background on the subjective comparison process.
Further phase of identification included superimposition of the obtained periapical X-ray images with analogical topographical projections at selected segmented orthopantomogram according to the layer-on-layer principle and consistent change of outer layer (PM image) opacity. At the first stage the superimposition process was held subjectively by the operator's visual inspection, and after that unique components were marked and traced through the two analyzed layers of images (Fig. 5).

Figure 5. Primary topographical projection of segments obtained from victim on OPG of suspected person



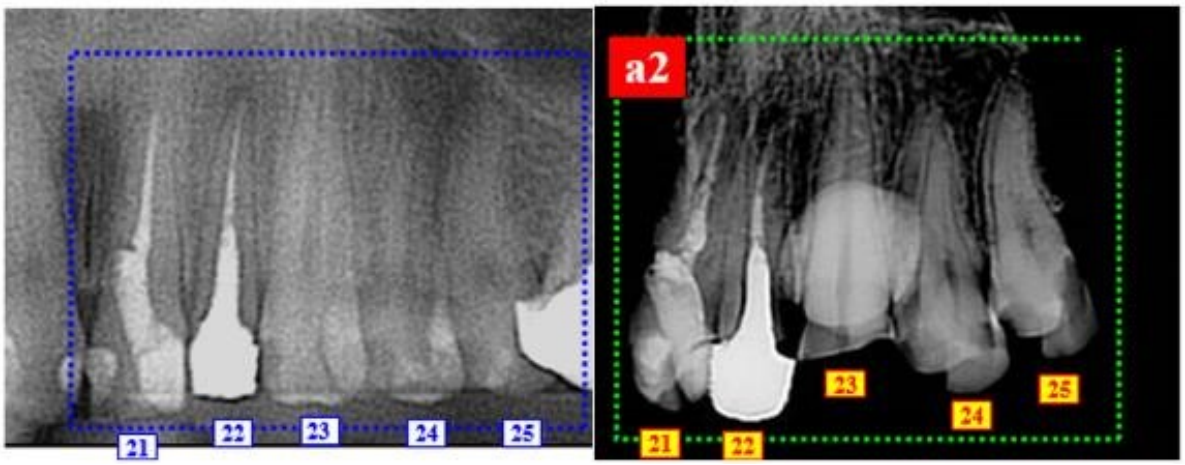
"a1" maxillary segment of PM periapical image demonstrated identical unique characteristics with AM OPG-image segment by means of: 1) root canal treatment of 12th tooth; 2) lost coronal part of 12th tooth; 3) caries at mesial surface of 13th tooth; 4) specific form of apical third of 14th tooth (curved); 5) root canal treatment of 16th tooth; 6) filling of the 16th tooth; 7) contour of maxillary sinus floor (Fig. 6).

Figure 6. Comparison of OPG-image segment topographically identical with periapical X-ray image, obtained from the a1 maxillary segment



"a2" maxillary segment of PM periapical image demonstrated identical unique characteristics with AM OPG-image segment by means of: 1) post and core build-up within 22nd tooth; 2) root canal treatment of 22nd tooth; 3) periapical lesion at 22nd tooth; 4) root canal treatment of 21st tooth; 5) filling of the 21st tooth (Fig. 7).

Figure 7. Comparison of OPG-image segment topographically identical with periapical X-ray image, obtained from the a2 maxillary segment



"a3" stics

with AM OPG-image segment by means of: 1) post and core build-up within 26th tooth; 2) occlusal caries at 27th tooth (Fig. 8).
"a4" mandibular segment of PM periapical image demonstrated identical unique characteristics with AM OPG-image segment by means of: 1) position of 38th tooth in the relation to 37th tooth (impaction of 38th tooth); 2) developmental stage of 38th tooth; 3) coronal defect of 37th tooth (Fig. 9).
"a5" mandibular segment of PM periapical image demonstrated identical unique characteristics with AM OPG-image segment by means of: 1) root canal treatment of 42nd tooth; 2) lost coronal part of 42nd tooth; 3) restoration on the mesial surface of 43rd tooth (Fig. 10).

Figure 8. Comparison of OPG-image segment topographically identical with periapical X-ray image, obtained from the a3 maxillary segment

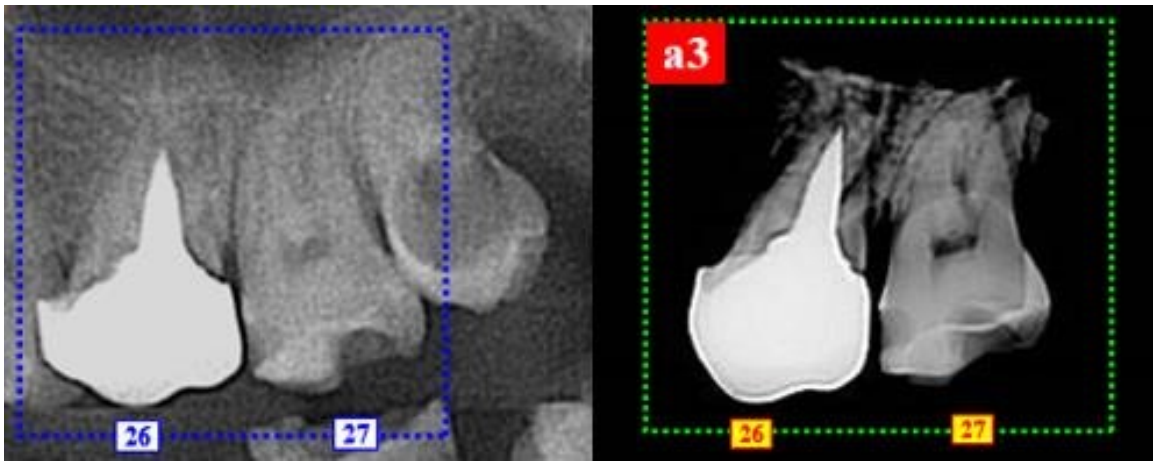


Figure 9. Comparison of OPG-image segment topographically identical with periapical X-ray image, obtained from the a4 mandibular segment

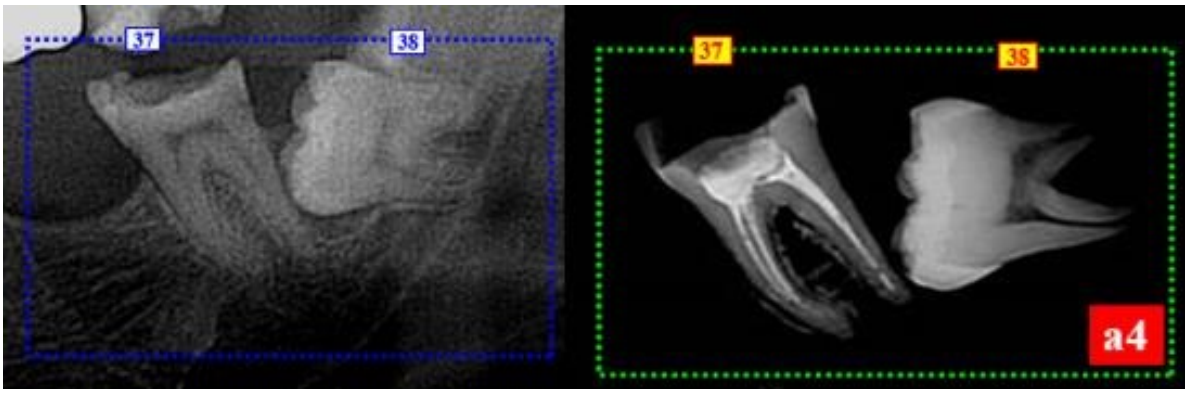
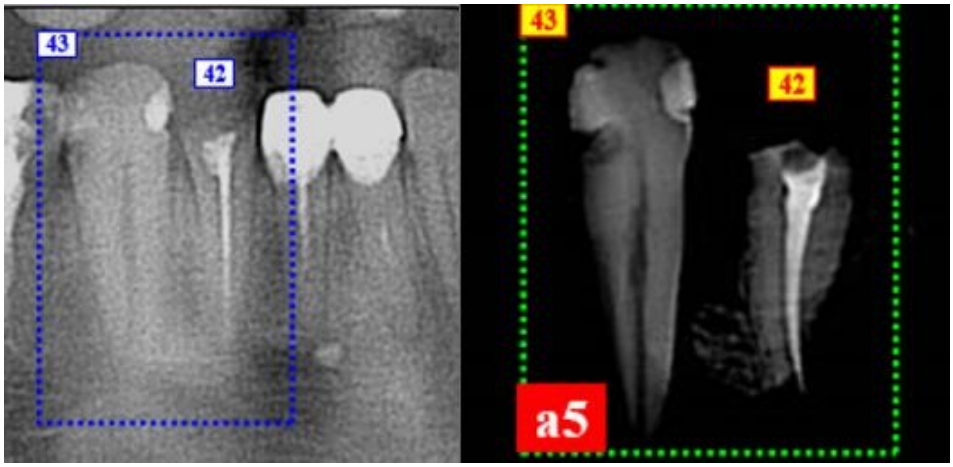


Figure 10. Comparison of OPG-image segment topographically identical with periapical X-ray image, obtained from the a5 mandibular segment



Considering that overall 20 positive concordant dental identifiers were verified during comparison of AM and PM X-ray datasets, we can conclude that odontological identity was established. Some inconsistencies also were verified during comparative images analysis: 1) "a1" postmortem periapical X-ray image demonstrated highly contrasted results of 14th tooth's root canal treatment, which could not be recognized at AM orthopantomogram; 2) "a2" postmortem image demonstrated broken crown of 23rd tooth, which was not altered at AM image; 3) also "a4" PM image demonstrated signs of 37th tooth's root canal treatment, which were absent at AM orthopantomogram (Table 1).

Table 1. Consistency of identification points between AM and PM image datasets, established by two independent experts

№	Segment	Identification point	AM image (OPG)	PM images (periapical X-rays)	Consistency of the identification point concordance between AM and PM images Expert 1/Expert 2	Subjective Expert 1 assurance	Subjective Expert 2 assurance
1	a1	Root canal treatment of 12th tooth	Present	Present	+/+	100%	100%
2	a1	Caries at mesial surface of 13th tooth	Present	Present	+/+	100%	100%
3	a1	Specific form of apical third of 14th tooth (curve)	Present	Present	+/+	100%	100%
4	a1	Root canal treatment of 14th tooth	Questionable	Present	-/-	70%	60%
5	a1	Root canal treatment of 16th tooth	Present	Present	+/+	100%	100%
6	a1	Lost coronal part of 12th tooth	Present	Present	+/+	100%	100%
7	a1	Filling of the 16th tooth	Present	Present	+/+	100%	100%
8	a1	Contour of maxillary sinus floor	Present	Present	+/+	100%	80%
9	a2	Post and core build-up within 22nd tooth	Present	Present	+/+	100%	100%
10	a2	Root canal treatment of 22nd tooth	Present	Present	+/+	100%	100%
11	a2	Periapical lesion at 22nd tooth	Present	Present	+/+	100%	100%

12	a2	Filling of the 21st tooth	Present	Present	+/+	100%	100%
13	a2	Root canal treatment of 21st tooth.	Present	Present	+/+	100%	100%
14	a2	Broken crown of 23rd tooth	Absent	Present	-/-	100%	100%
15	a3	Post and core build-up within 26th tooth	Present	Present	+/+	100%	100%
16	a3	Occlusal caries at 27th tooth	Present	Present	+/+	100%	100%
17	a4	Position of 38th tooth in the relation to 37th tooth	Present	Present	+/+	100%	100%
18	a4	Developmental defect of 38th tooth	Present	Present	+/+	100%	100%
19	a4	Coronal defect of 37th tooth	Present	Present	+/+	100%	100%
20	a4	Root canal treatment of 37th tooth	Absent	Present	-/-	100%	100%
21	a5	Root canal treatment of 42nd tooth	Present	Present	+/+	100%	100%
22	a5	Lost coronal part of 42nd tooth	Present	Present	+/+	100%	100%
23	a5	Restoration on the mesial surface of 43rd tooth	Present	Present	+/+	100%	100%
24	a5	Caries lesion at distal surface of 43rd tooth	Questionable	Present	-/+	60%	70%

All the abovementioned discrepancies could be classified as explainable, since endodontic treatment and crown's trauma could be provided/ occurred after initial OPG was obtained. The issue of caries at distal surface of 43rd tooth at "a5" segment remained controversial, considering points of two experts' view (Fig. 11)

Inter-agreement rate between two investigators considering correspondence between AM and PM datasets reached Cohen's kappa level which was equal of 0,97, while positive 100% agreement was reached considering 21 out of 24 analyzed characteristics.

Figure 11. Comparison of OPG-image and actual residual fragments of the maxilla and mandible

DISCUSSION

There are several components of the dental status that potentially could be used as important identification criterions during ante- and post-mortem data comparison. Latter includes teeth themselves and their specific characteristics (impaction, rotation, displacement, hypo- or hyperodontia), signs of caries or periodontal pathologies, coronal and hidden restorations, bone patterns and landmarks as well as its individual and pathological changes, air-borne spaces.[9, 15]

Morphological features of teeth and jaws have been categorized as the most validated dental identifiers used for person's identification.[16] At presented case the curved shape of 14th tooth's apex and position of 38th tooth (impaction) with its specific developmental stage could be interpreted as so-called morphological identifiers with high level of uniqueness. Potentially AM OPG could represent a greater amount of unique dental characteristics, but due to the lack of PM jaws segments such could not be used during AM-PM comparison in the present case.

Differentiation of dental patterns based on the OPG-image could be provided by 11 prespecified grouped parameters (virgin, missing, filling, defect, crown, residual root, bridge pontic, dental implant, endodontic treatment, impacted and dental anomaly), which consist of strictly defined derivates.[17] Within present case 6 parameters could be verified, including missing, virgin, crown, filling, impacted and defect, which is optimal for reliable identification of dental pattern based on OPG-image. Previously, authors mentioned that "6 parameters-pattern" stands for 99,95% specific pattern among dental status diversities, and in this means is analogical to "11 parameters-pattern".[17]

Brkic et al. reported that prosthetic appliance were the most frequently registered environmental dental findings with sufficient identification potential.[18] Also, disturbance of tooth eruption as identification criterion was noted in 22% of analyzed cases.[18] In present case AM and PM images of the person demonstrated the presence of post-and-core build-up constructions and specific impacted position of 38th tooth, which due to the previous Brkic's findings could be interpreted as characteristics with sufficient potential for positive identification outcome. Silva et al. highlighted the importance of periapical radiographs with registered signs of endodontic treatment for forensic identification purposes.[19,20] In present case 7 out of 20 positive concordant points (35,0%) were related to root canal treatment outcomes registered both at PM and AM X-ray images.

Effectiveness of forensic dental identification based on the available AM and PM periapical radiographs demonstrated direct statistical association with investigators' level of experience, while even unexperienced undergraduates showed

acceptable results, but postgraduates obtained the results which were characterized with 89,3%, 92,3% and 90,5% of sensitivity, specificity and accuracy respectively.[21] Similar results were also reported by Pinchi et al., due to which experienced forensic odontologists demonstrated high levels of accuracy and repeatability (0,97-1) during comparative analysis of available datasets.[22] In analyzed case report reproducibility level between two investigators regarding uniqueness of evidences and level of their full correspondences between X-ray datasets reached high Cohen's kappa level and more than 90% of inter-concordance.

Such outcome could be directly related to the fact that both dental specialists were previously trained within the framework of post-graduate specialized dental courses provided under the IOFOS umbrella. Also, use of adapted algorithm for digital image comparison optimized the identification process both by means of high-level inter-agreement rate and by means of unambiguousness of obtained outcomes interpretation. Such perspectives of proposed algorithm for digital image comparison is highly relevant, especially in the context of young dental specialists involving in complicated dental identification cases.

Previously, the influence of cognitive bias and observer's effect on the outcome of identification efficiency, especially during comparison examinations, were highlighted.[22] Considering these facts, in present case report we have used not only subjective comparison of AM and PM images, but also we have developed algorithm for its phased comparison with use of layer-to-layer superimposition principle and tracing of unique characteristics through the images layers. In such way, we tried to compensate cognitive bias influence, mentioned in a previous study: proposed objective contour-to-contour comparison through images layering excluded any ambiguity regarding dental identifiers in the process of analyzing complicated fractured case with the absence of post-mortem OPG.

Relevant improvements in OPG analysis with forensic identification aim include methods of speeded up robust features and convolutional neural network.[23,24,25] In previous research it was shown that semi-automated approach could provide high accuracy of mandibular structure analysis in the manner of finger-print based on matching protocol consisted of region of interest verification, voxel-based registration and further results classification.[26] Also Lin P.-L. demonstrated the high efficiency of using weighted Hausdorff distance during comparisons of bitewing dental radiographs.[27] Proposed method was based on contouring of specific dental features with contour's further realigning among comparator images.[27]

In present case we implemented somewhat similar, but simpler algorithm of 2D images comparative analysis, which consisted of the image segmentation, optimization, layer-by-layer superimposition and further tracing of unique characteristics by opacity changes. Even though presented case was characterized with high level of inter-agreement rate between two investigators regarding correspondence between AM and PM datasets, in future research we will analyze changes of such rate while providing image optimization with layer-to-layer comparison and within conditions of ad oculus analysis of AM and PM datasets.

Use of segmentation process described in proposed protocol of OPG and periapical X-ray image superimposition argumented by the results of systematic review, which demonstrated that similar approach supports the noise reduction and enhances the accuracy of the image for the comparative analysis.[28] Image preprocessing with reasonable purpose represent the useful tool for forensic dental practice during comparative and reconstructive identification, age estimation and bite mark analysis. Nowadays, new software packages and mobile application aimed at X-ray image improvement could be effectively implemented in forensic dental practice after precise evaluation of their validness, sensitivity and specificity parameters.[28]

Future trends in forensic dental identification are closely related to the digitalization shift in the field, which are associated with possibility to gain larger amount of unique criterions during individual and mass cases of ante-mortem and post-mortem dental datasets comparison.[29] Digitalization itself expands the number of comparative elements due to analog-to-digital conversion and supports their processing with use of adaptive algorithms and software. But on the other side, the progressive increase of identification points associated with the diversity of their identification value and level of their uniqueness, so we need to assure an adequate attention to the process of their phased

stratification and differentiation with further categorization according to actual identification impact and importance. Also, there is still a gap in translation of modern achievements within digital dentistry into forensic dental practice, which could be compensated by the cooperation of corresponding societies and associations from both sides. For instance, modern approaches of image and 3D-objects superimposition, previously used for surgical and prosthetic treatment planning, and consisted of several techniques as nurb-to-nurb, mesh-to-mesh and point-to-point overlapping, potentially could improve the algorithm of comparative forensic dental post- and ante-mortem analysis.[30,31]

CONCLUSIONS

Available AM and PM radiographical data sets represent sufficient information for effective forensic dental identification, even if such were obtained by different roentgenological techniques (orthopantomography and peri-apical radiography). The accessibility of adequate AM data volume (provided by orthopantomogram), possibility of X-ray assessment for mandibular and maxillary residual segments and registration of previously provided iatrogenic interventions and associated changes (being assessed as important identification criterions) were the key components of successful identification outcome, despite complicated fractured conditions of the skull. Nevertheless, modern approaches of graphical superimposition expand the possibilities for person's identification by dental status and could be effectively implemented in forensic dental practice especially under the condition of deficiency or total absence of dental and medical records. Moreover, use of an adapted algorithm of digital images comparison with forensic dental purposes could potentially overcome cognitive bias and observer's effect, speed up the process of analysis and increase accuracy and inter-agreement rate while referencing AM and PM datasets.

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