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Abstract: Forensic dentistry plays a major role in human identification. Teeth carry individual characteristics that differ among different individuals. Dental radiographs depict reality objectively, being the most reliable tool for dental identification. The first aim of this study was to evaluate the accuracy of dental identification of individuals with permanent unrestored teeth by visual comparison with radiographs of mixed dentition. The second aim was to learn which anatomical features were compared by examiners with different backgrounds. A total of 19 forensic experts participated in a web-based questionnaire to assess identification of 12 simulated cases; each case required the radiographic comparison of 1 dental PM radiograph to 3 dental AM radiographs, of which only one was the correct match. The examiners were given four options following the ABFO guidelines: established identification, possible identification, insufficient data and exclusion; the participants also explained the reason for each of their conclusions. The accuracy of the methodology was 75,4%, the sensitivity was 53,5% and the specificity was 86,4%. Overall, there was a tendency of the observers to overlook non-dental characteristics. Not surprisingly, dental identification by visual comparison of radiographs was not immune to subjectivity and, even analysing the same category of features, different conclusions and consequently different percentages of accuracy were reached. When matching the correct AM radiograph, most examiners compared the root morphology of the first molars and the shape of the maxillary sinus. When one of the AM radiographs was not matched, the examiners mostly asserted that there was insufficient data to reach a conclusion due to the lack of distinctive and comparable features. With AM and PM radiographs showing different development stages, accuracy was correlated to the age of the AM radiograph.

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**Accuracy of dental identification of individuals with unrestored permanent teeth by visual comparison with radiographs of mixed dentition**

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## Highlights

* Accuracy was moderately and positively correlated to the age of the AM radiograph.
* It was easier to exclude the incorrect radiograph than identify the correct one.
* Even when comparing the same features, examiners reached different conclusions.
* The morphology of the roots of the molars was frequently compared.
* Non-dental features were frequently overlooked.

# Accuracy of dental identification of individuals with unrestored permanent teeth by visual comparison with radiographs of mixed dentition

## ABSTRACT

Forensic dentistry plays a major role in human identification. Teeth carry individual characteristics that differ among different individuals. Dental radiographs depict reality objectively, being the most reliable tool for dental identification. The first aim of this study was to evaluate the accuracy of dental identification of individuals with permanent unrestored teeth by visual comparison with radiographs of mixed dentition. The second aim was to learn which anatomical features were compared by examiners with different backgrounds. A total of 19 forensic experts participated in a web-based questionnaire to assess identification of 12 simulated cases; each case required the radiographic comparison of 1 dental PM radiograph to 3 dental AM radiographs, of which only one was the correct match. The examiners were given four options following the ABFO guidelines: established identification, possible identification, insufficient data and exclusion; the participants also explained the reason for each of their conclusions. The accuracy of the methodology was 75,4%, the sensitivity was 53,5% and the specificity was 86,4%. Overall, there was a tendency of the observers to overlook non-dental characteristics. Not surprisingly, dental identification by visual comparison of radiographs was not immune to subjectivity and, even analysing the same category of features, different conclusions and consequently different percentages of accuracy were reached. When matching the correct AM radiograph, most examiners compared the root morphology of the first molars and the shape of the maxillary sinus. When one of the AM radiographs was not matched, the examiners mostly asserted that there was insufficient data to reach a conclusion due to the lack of distinctive and comparable features. With AM and PM radiographs showing different development stages, accuracy was correlated to the age of the AM radiograph.

Keywords: Dental Radiographs; Forensic Odontology; Forensic Identification; Mixed Dentition; Unrestored Teeth.

## 1. Introduction

The identification of the living and of the dead is a human right to be guaranteed for ethical, cultural, religious and economic reasons. Not less important, it contributes to criminal investigations in case of violent and suspicious deaths. Teeth are primary identifiers and could lead to the certain identification or exclusion of an individual without the aid of additional factors [1]. Identification by dental means is one of the fields of expertise of a forensic dentist (FD) and it is useful in singles cases as well as in mass disasters, when a significant number of bodies are recovered at the same time [2]. The pattern and combination of dental treatments, anatomic and pathologic features are hardly similar between different subjects [3,4]. Identification is conducted by comparing the post-mortem (PM) dental data collected during the autopsy to the ante-mortem (AM) dental records of alleged matches [1]. Intra-oral and extra-oral dental radiographs are often the key to this process, by objectively displaying anatomic and pathologic features that are not visible to the naked eye by external examination [5,6]. Visual comparison is the most inexpensive and commonly adopted method for the analysis of traditional films or digital radiographs for identification purposes. However, there are no standardized protocols and the final conclusion is susceptible to the personal interpretation of the operator, who might confirm or exclude identity based on a single trait [7,8]. Any scientific method that aims to produce evidence with medico-legal outcomes should follow the Daubert standard: be accepted by the scientific community, be repeatable, standardized and be subjected to peer-review and publication reporting an acceptable error rate [9]. Previous studies tested the accuracy of dental identification by visual comparison of radiographs with unrestored dentitions within samples of similar age ranges [10–12], whereas studies considering wide time intervals between AM and PM radiographs mostly included restored permanent dentitions [13]. The first aim of the research was to test if manual radiographic comparison is an accurate identification methodology when the PM radiograph depicted permanent sound dentition, the AM and the PM radiographs were separated by a significant time-lapse and the AM radiograph dated back to the age of mixed dentition. The second aim was to investigate which anatomic features visible in panoramic radiographs were analysed by experts in forensic identification.

## 2. Materials and methods

A total of 100 forensic dentists (FD), forensic anthropologists (FA) and radiologists (R) were contacted via email to participate in a web-based survey. Volunteers were searched within University lecturers and forensic international organizations (ABFO, ABFA, BAFO, IOFOS). The field of expertise and the number of years of experience were self-reported in the survey; however, they were not asked to state the level of qualification (i.e.: MS, PhD) and the number of forensic identifications performed throughout their career. The radiographic database of three Italian private dental clinics were scrutinized. A total of twelve panoramic radiographs (OPGs) depicting complete shedding, permanent and unrestored dentition were selected as simulated PM radiographs; individuals who had received and completed an orthodontic treatment or had a fixed orthodontic retainer visible only in the PM radiograph were included; the OPGs of the same subjects showing mixed dentition with at least initial eruption of the first molar or the central incisor worked as simulated AM radiographs; if the deciduous teeth were decayed or filled but all permanent teeth were sound, the radiographs were included. Individuals with oral manifestations of genetic syndromes, dental agenesis, malformations of cranio-facial structures, cavities, fillings or other dental treatments of the permanent dentition and retained primary teeth in PM radiographs were excluded. Twenty-four more OPGs of children with mixed dentition and respecting the criteria were selected and worked as false matches or False Positive (FP).

The time-lapse between the AM and PM radiographs was between 3 and 18 years. The age of the individuals of the AM radiographs ranged between 8 and 13 years. The selected radiographs, if traditional films, were photographed using a Nikon D90 camera (© 2017 Nikon Corporation) and digitalized. The web-based survey was created on Google Forms (© 2015 Google Inc.) and was only accessible by private invitation. The questionnaire included twelve cases, each one showing one PM radiograph paired to three AM radiographs; all the radiographs were cut into halves at the midline of both dental arches using Microsoft Foto Windows 10 (© 2017 Microsoft Corporation); consequently, six cases showed the right side and six the left side of the original radiographs. The examiners were not informed that only one AM radiograph in each case belonged to the same individual as the PM. Because the first aim of the study was to test the accuracy of dental identification by visual comparison of radiographs alone, no extra medical or dental information about the subjects was provided. Each section included one multiple-choice question and one open-ended question for each AM radiograph; the former asked to reach a conclusion of identification or exclusion providing four options, according to the ABFO guidelines (established identification, possible identification, insufficient data, exclusion) [14]; the latter asked to explain the reason for the conclusion with no word-limit or directions of any kind. Radiographs of each section were available for download, zooming or digital enhancement by accessing an on-line folder (© Dropbox Inc). The examiners could not proceed further before filling all the questions within each case. The Author who collected the radiographs and prepared the questionnaire did not participate. The acquisition of the answers was automatic once all the sections were completed and the results were immediately and exclusively visible to the Authors on an Excel spreadsheet. The answers to the multiple-choice question were analysed quantitatively to calculate the total number of correct identifications or True Positive (TP), correct exclusions or True Negative (TN), incorrect identifications or False Positive (FP) and incorrect exclusions or False Negative (FN) of each operator. The percentages of sensitivity, specificity, accuracy by examiner and by case were calculated. The level of confidence of the examiners when answering to the multiple-choice questions was also measured: the percentages of Established (E) and Positive (P) identifications were calculated for both TP and FP; the percentages of Insufficient Data (IND) and Exclusions (X) were calculated for both TN and FN. Additionally, a linear regression model was applied to investigate the correlation between accuracy and AM-PM time lapse, age of the AM radiograph and experience of the examiners.

The answers to the open-ended questions were analysed qualitatively by thematic analysis to investigate which features were compared by examiners according to their performance [15]; firstly, the examiners were divided into four groups (1 to 4) according to the percentage of sensitivity and specificity: the cut-off point chosen was 80%. Only one type of answer was analysed for each group of examiners: explanations to the TP (Type A) from examiners with sensitivity equal to or higher than 80% (Group 1); explanations to the FN (Type B) from examiners with sensitivity lower than 80% (Group 2); explanations to the TN (Type C) from examiners with specificity equal to or higher than

80% (Group 3); explanations to the TP (Type D) from examiners with specificity lower than 80% (Group 4). Thematic analysis was performed on the four types of questions by searching for specific keywords in the text. Two main categories were established. The first category included "dental features"; subcategories I were "anatomy" and "number", while sub-categories II were "type of tooth" and "part of the tooth". The second category was "non-dental features" and subcategory I was "anatomy", which collected all the responses quoting any cranio-facial structures other than teeth. It was then calculated the percentage of times that the features from each category and sub-category were mentioned.

## 3. Results

A total of 19 volunteers, 15 FD and 4 FA, accepted and completed the questionnaire; 3 FD and 2 FA from the UK, 1 FA from USA, 4 FD from Canada, 4 FD from Brazil, 1 FD from Mexico, 1 FA from Italy, 1 FD from Iceland, 1 FD from Mauritius and 1 FD from Australia. The number of years of experience ranged between 1 and 30 years (Table 1): only 2 out of 19 examiners (11%) had less than 2 years of experience; 10 examiners (57%) had between 2 and 15 years; 6 examiners (31%) had at least 16 years, with one examiner (FD) practicing for 30 years.

### 3.1 Quantitative analysis of the multiple-choice question

#### 3.1.1 Sensitivity, specificity, accuracy

Out of the 684 answers collected by 19 examiners, 122 were TP, 394 TN, 62 FP and 106 FN. Table 1 shows the percentages of TP, FN, TN, FP by examiner. Sensitivity, or the capability to identify the correct matches, was obtained by the following formula TP/(TP+FN); specificity, or the capability to detect the incorrect AM radiographs, corresponded to the percentage of TN out of the total radiographs (TN+FP); accuracy was the estimation of the overall performance and corresponded to the percentage of the correct answers (TP+TN) out of the total answers (TP+FN+TN+FP). The sensitivity of the examiners fluctuated significantly between 0% and 100% and the accuracy varied between 55,5% and 91,7%; the specificity was 33,3% for only one examiner and varied between 66,7% and 100% for the remaining participants (Table 1). The percentages of sensitivity, specificity and accuracy in each case of the questionnaire are shown in Table 2: the sensitivity ranged between 26,3% and 78,9%, the specificity between 71,1% and 94,7% and the accuracy between 66,7% and 78,9%. Overall percentages of sensitivity, specificity and accuracy were the mean values obtained by the examiners and were 53,5%, 86,4% and 75,4%, respectively (Table 3). Table 4 depicts the level of confidence of the examiners when answering to the multiple-choice question; out of the total number of TP, 41 (34%) were established (E) and 81 (66%) were possible (P) identifications; out of the total number of FN, there were 20 (19%) exclusions (X) and 86 (81%) insufficient data (IND); out of the total number of FP, there were 2 (3%) established (E) and 60 (97%) possible (P) identifications; out of the total number of TN, 177 (45%) were exclusions (X) and 217 (55%) insufficient data (IND).

### 3.1.2 Correlation between accuracy and years of experience of each examiner

The percentage of total correct answers by examiner, or accuracy, is depicted in Table 1. It was investigated how this was related to the number of years of experience. The scatter plot in Figure 1 illustrates that in our sample the relation was weakly negative, being Pearson R very close to zero (-0,25).

### 3.1.3 Correlation between accuracy and field of expertise of each examiner

The rate of accuracy ranged widely between 55,5% and 91,7% for the FD; the rate of the FA varied less significantly, being between 63,9% and 80,5% (Table 1). Because of the disparity between the number of FA and FD, it was not investigated if accuracy was correlated to the field of expertise.

### 3.1.4 Correlation between accuracy and the AM-PM interval

The time-lapse between AM and PM radiographs is shown in Table 2. The relationship between the two variables, investigated by a linear regression model, was weakly negative being Pearson R -0,19 (Figure 2).

### 3.1.5 Correlation between accuracy and age of the correct AM radiograph

The age of the subjects in the correct AM radiographs is shown in Table 2. The correlation to the accuracy in each case was moderately positive; the linear regression model produced a Pearson R value of 0,64 (Figure 3).

## 3.2 Qualitative analysis of the open-ended questions

Thematic analysis was performed to investigate the reason to the multiple-choice questions and learn which anatomic features were compared. The examiners were divided into four groups according to the rate of sensitivity and specificity, choosing 80% as threshold; the number of examiners in relation to the rate of sensitivity and specificity and the corresponding number and type of answers analysed are shown in Table 4. The total number of answers analysed was consequently 518 out of 684. Table 5 illustrates the percentages of frequency of the features most frequently mentioned in each type of answer, divided by category (cat.) and subcategories (sub-cat I and II). A total of 64 (91,4%) Type A answers reported dental similarities between AM and PM radiographs, 67,7% of which quoted the lower first molars; all the 54 answers reporting specific anatomical dental features referred similarities of the roots; 29 answers (41,4%) compared also, but not only, non-dental features, 58,6% of which specifically referring to the pattern of the maxillary sinus. A total of 67 (64,4%) of Type B answers did not refer to specific teeth or cranio-facial characteristics; 62,7% of them explained that the early development stage of the AM radiograph, the immature permanent dentition and the lack of comparable and distinctive characteristics, such as dental treatments or missing teeth, prevented from reaching a conclusion; a total of 29 answers (27,8%) analysed dental features, 34,5% of which asserting that the absence or the different location of the third molars in the AM radiograph were unacceptable inconsistencies. For what concerns Type C answers, a total of 165 (55,5%) did not refer to specific teeth or cranio-facial characteristics; 81,2% of them explained that the early development of the AM radiograph, the immature permanent dentition and the lack of comparable and distinctive characteristics such as dental treatments and missing teeth prevented from reaching a conclusion; a total of 129 (43,4%) of Type C answers quoted dental features, 79,1% of which compared the molars; out of 90 answers referring to dental anatomy, 43,3% reported dissimilarities in the root morphology. A total of 34 Type D answers (72,3%) mentioned dental similarities, 76,5% of which referred to the anatomy of the molars; out of 26 answers quoting a specific portion of the tooth, consistencies in the root morphology accounted for 57,7%.

Table 1

Overall percentages of correct matches (TP), incorrect exclusions (FN), correct exclusions (TN), incorrect identifications (FP) and total correct answers (CA) obtained by each examiner; FD = forensic dentist, FA = forensic anthropologist; TP(%), TN(%) and CA(%) correspond to sensitivity, specificity and accuracy, respectively.

| Examiner | Field | Experience (y) | TP (%) | FN (%) | TN (%) | FP (%) | CA (%) |
|---|---|---|---|---|---|---|---|
| 1 | FD | 27 | 100 | 0 | 33,3 | 66,7 | 55,5 |
| 2 | FD | 28 | 50 | 50 | 87,5 | 12,5 | 75 |
| 3 | FA | 20 | 41,7 | 58,3 | 100 | 0 | 80,5 |
| 4 | FD | 25 | 0 | 100 | 100 | 0 | 66,7 |
| 5 | FD | 10 | 0 | 100 | 95,8 | 4,2 | 63,9 |
| 6 | FD | 26 | 58,3 | 41,7 | 100 | 0 | 86,1 |
| 7 | FD | 10 | 50 | 50 | 100 | 0 | 83,3 |
| 8 | FD | 15 | 100 | 0 | 79,2 | 20,8 | 86,1 |
| 9 | FD | 15 | 100 | 0 | 66,7 | 33,3 | 77,8 |
| 10 | FD | 30 | 25 | 75 | 87,5 | 12,5 | 66,7 |
| 11 | FA | 4 | 0 | 100 | 100 | 0 | 66,7 |
| 12 | FD | 5 | 91,7 | 8,3 | 79,2 | 20,8 | 83,3 |
| 13 | FD | 4 | 100 | 0 | 70,8 | 29,2 | 80,5 |
| 14 | FD | 6 | 66,7 | 33,3 | 87,5 | 12,5 | 80,5 |
| 15 | FA | 7 | 25 | 75 | 100 | 0 | 75 |
| 16 | FD | 12 | 50 | 50 | 91,7 | 8,3 | 77,8 |
| 17 | FA | 1 | 41,7 | 58,3 | 75 | 25 | 63,9 |
| 18 | FD | 1 | 91,7 | 8,3 | 91,7 | 8,3 | 91,7 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 19 | FD | 5 | 25 | 75 | 95,8 | 4,2 | 72,2 |

Table 2

Percentages of sensitivity, specificity and accuracy for each case in the questionnaire.

| Case | Age of correct AM (y) | Correct AM-PM interval (y) | Sensitivity (%) | Specificity (%) | Accuracy (%) |
|---|---|---|---|---|---|
| 1 | 9 | 18 | 47,4 | 89,5 | 75,4 |
| 2 | 12 | 3 | 63,2 | 81,6 | 75,4 |
| 3 | 13 | 3 | 73,7 | 84,2 | 80,7 |
| 4 | 9 | 18 | 52,6 | 86,8 | 75,4 |
| 5 | 12 | 3 | 47,4 | 94,7 | 78,9 |
| 6 | 9 | 5 | 47,4 | 92,1 | 77,2 |
| 7 | 9 | 5 | 26,3 | 94,7 | 71,9 |
| 8 | 13 | 3 | 78,9 | 84,2 | 82,5 |
| 9 | 13 | 5 | 68,4 | 89,5 | 82,5 |
| 10 | 9 | 9 | 31,6 | 89,5 | 70,2 |
| 11 | 12 | 5 | 47,4 | 78,9 | 68,4 |
| 12 | 13 | 6 | 57,9 | 71,1 | 66,7 |

Table 3

Sensitivity, specificity and accuracy of the methodology.

| Sensitivity (%) | Specificity (%) | Accuracy (%) |
|---|---|---|
| 53,5 | 86,4 | 75,4 |

Table 4

Percentages of TP, TN, FP and FN in relation to the level of confidence of the examiners when answering to the multiple-choice question. (E=established; P=Possible; IND=Insufficient Data; X=Exclusion).

| TP (%) | | TN (%) | | FN (%) | | FP (%) | |
|---|---|---|---|---|---|---|---|
| E | 34 | ID | 55 | ID | 81 | E | 3 |
| P | 66 | X | 45 | X | 19 | P | 97 |

Figure 1

Scatter plot obtained by the linear regression that show the relationship between the accuracy of each examiner and the number of years of experience (Pearson R = -0,25).

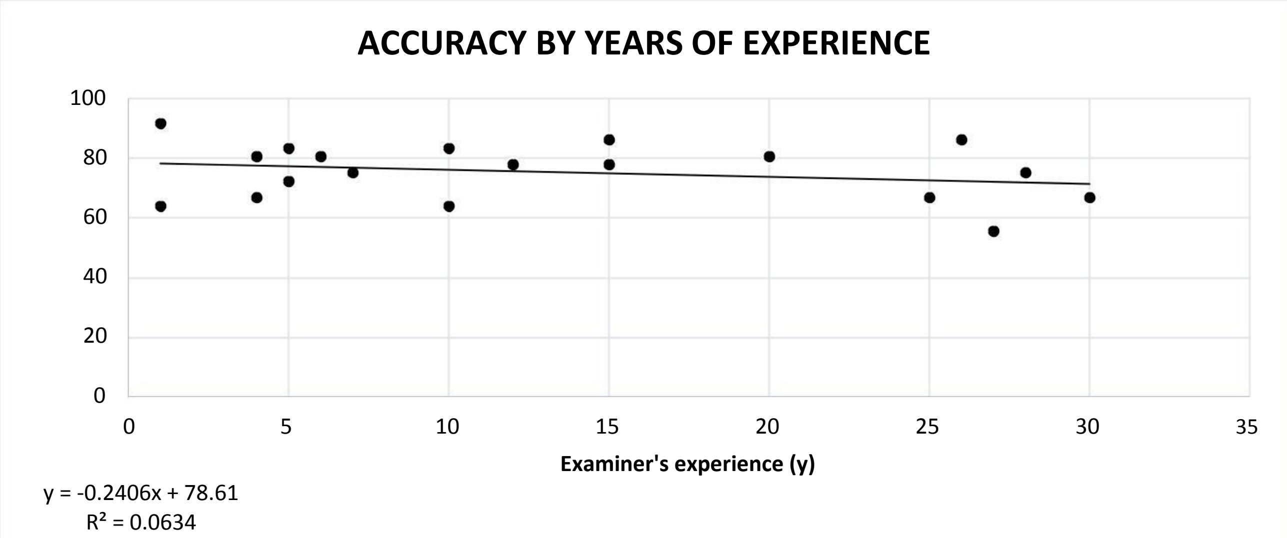


Figure 2

Scatter plot depicting the relationship between the accuracy for each case and the interval between PM and correct AM radiographs (Pearson R = -0,19).

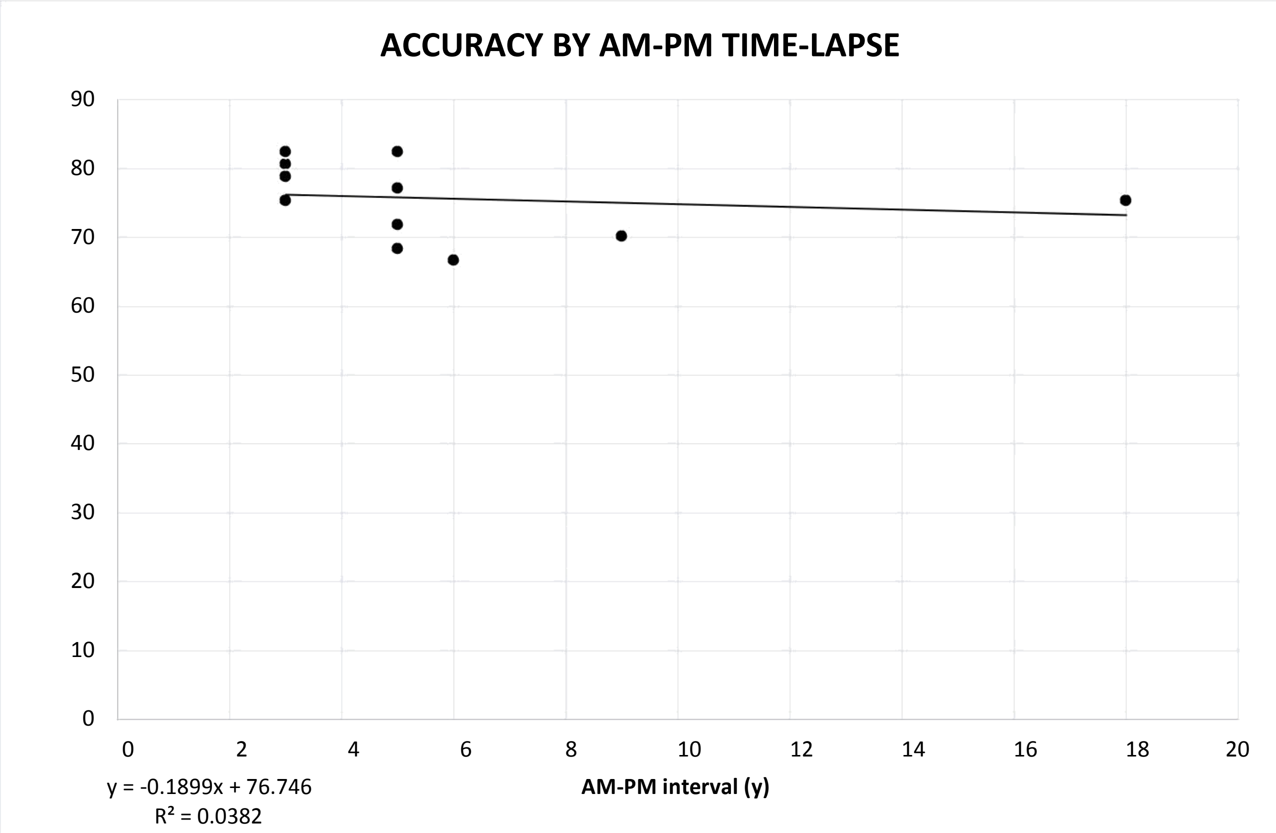


Figure 3

Scatter plot depicting the correlation between the accuracy and the age of the correct AM radiograph in each case (R = 0,64).

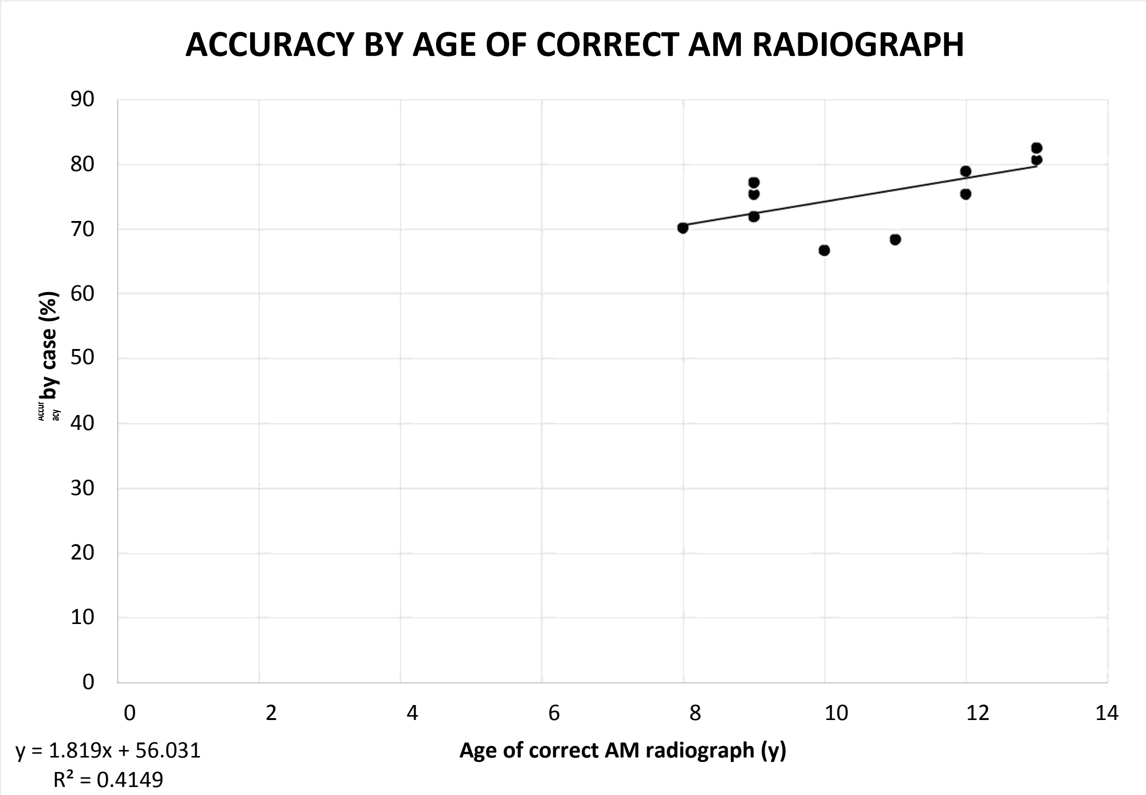


Table 4

Type and number of answers to the open-ended question that were analysed according to the percentages of sensitivity and specificity of the examiners.

| Group of examiners | No of examiners | Type of open-ended answer | No of answers |
|---|---|---|---|
| 1. Sensitivity ≥ 80% | 6 | A. reason to the TP | 70 |
| 2. Sensitivity < 80% | 13 | B. reason to the FN | 104 |
| 3. Specificity ≥ 80% | 13 | C. reason to the TN | 297 |
| 4. Specificity < 80% | 6 | D. reason to the FP | 47 |

Table 5

Percentages of frequency of the dental and non-dental features most frequently mentioned in the open-ended answers A, B, C and D divided by categories (Cat.) and sub-categories I and II (Sub-cat.).

| Answers Anatomical features | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Type** | **Cat.** | **%** | **Sub-cat. I** | **% (out of Cat.)** | **Sub-cat. II** | **% (Out of Sub-cat. I)** | **% (out of Tot Answers)** |
| **A** | Dental | 91,4 | Anatomy | 84,4 | Lower first molars | 67,2 | 61,4 |
| | | | | | Root anatomy | 100 | 77,1 |
| | Non-dental | 41,4 | Anatomy | 100 | Maxillary sinus shape | 58,9 | 24,3 |
| **B** | Dental | 27,8 | Number | 24,1 | Third molars | 34,5 | 9,6 |
| | | | Anatomy | 51,7 | | | |
| | Other | 64,4 | No distinctive features | 68,6 | - | - | 44,2 |
| **C** | Dental | 43,4 | Anatomy | 69,8 | Molars (upper and lower) | 79,1 | 34,3 |
| | | | | | Root anatomy | 43,3 | 13,1 |
| | Other | 55,5 | No distinctive features | 92,7 | - | - | 51,5 |
| **D** | Dental | 72,3 | Anatomy | 76,5 | Molars (upper and lower) | 73,5 | 53,2 |
| | | | | | Root anatomy | 57,7 | 31,2 |
| | Non-dental | 6,4 | Anatomy | 100 | Maxillary sinus shape | 66,7 | 4,3 |
| | | | | | Inferior alveolar canal | 66,7 | 4,3 |

## 4. Discussion

Dental identification relies on the similarities and inconsistencies between AM and PM data; for this reason, clinical and radiographic visibility of dental restorations and anatomic abnormalities are very useful to provide a conclusion of identity or exclusion [16–18]. When the number of comparable distinctive characteristics decreases and the development stages differ significantly, identification is expected to be more challenging [13,19]. The percentages of sensitivity, specificity and accuracy in our research were inconsistent with previous studies testing dental identification by visual comparison of radiographs; MacLean et al. [20] concluded that identification using dental bitewing was 93% accurate even with few or no restorations and a time-lapse between 1 and 15 years; however, both AM and PM radiographs were of permanent dentition; according to Kogon et al. [10], the methodology was 88% accurate, but the study was conducted exclusively on children with restored dentition; Sholl et al. [21] estimated that the average sensitivity was 93,3%, however the samples were 22 dry skulls from the collection of the Royal College of Surgeons of Edinburgh, which could not show any anatomical difference or development change between the simulated AM and PM radiographs; more recently, Fridell et al. [12] concluded that the sensitivity within samples of children with unrestored dentitions was 88,3%; Pretty et al. [22] found that the mean accuracy was 85,5%, but the study included restored dentitions; Pinchi et al. [8] estimated that accuracy ranged between 76% and 97%, but identifications were performed on samples with both restored and unrestored teeth. In our study, the increase of the time interval between AM and PM radiographs was weakly correlated to the decrease of accuracy of the examiners (Figure 2). On the other hand, as the age of the AM radiograph increased, the accuracy also escalated (Figure 3); it can be assumed that the advancement of age and development stage of the AM OPG resulted in a bigger number of similar traits with the corresponding PM radiograph, facilitating the identification. According to the literature, training and experience in forensic identification influence the performance [8,22,23]; for this reason, only practitioners with a forensic background were recruited (Table 1); in our study, the relation between accuracy and years of experience was very weak and negative (Figure 1); this means that, although not statistically significant, there was a tendency of more experienced professionals to be less accurate. The web-based questionnaire allowed to contact volunteers worldwide, facilitating the communication with the Authors; this approach demonstrated to be a valid, accurate and reliable method to test error rate of forensic identification by comparison of dental radiographs [22]. In our study, some radiographs did not respond to high-quality resolution standards, particularly some traditional films which were photographed and digitalized; additionally, the Authors did not have control over the clarity and resolution of computer monitors of the participants, which might have also affected the quality of some images; however, in real forensic cases, radiographs hardly come from machines of the same make and AM high-quality are not always available, due to factors such as time since exposure, development techniques or storage conditions. Although all cases were simulated, the examiners face a true-to-life situation, in which the PM data of one deceased is often compared to the AM data of several missing individuals. Full mouth-radiographs were preferred over intra-oral radiographs to offer an overview of the whole dentition as well as of various cranio-facial structures, including the nasal spine and turbinates, the maxillary sinus, the condyle and the TMJ, the ramus and body of the mandible, the inferior alveolar canal and the mental foramen [5]. It was decided to upload half OPGs instead of the whole radiographs for two reasons: 1) finding a bigger number of cases respecting all inclusion criteria was a difficult task and the two halves of one radiograph were used for two separate cases; 2) comparing 3 sets of radiographs per case was time consuming and the Authors did not want to overwhelm the participants. The results of sensitivity and specificity of each examiner and of each case showed that the identification of the correct match was more challenging than the exclusion of the incorrect radiographs (Table 1 and 2). However, when reasoning why the radiographs were not matched, most examiners stated that there was insufficient information to reach a conclusion rather than listing specific anatomical inconsistencies. Overall, only a few examiners fully appreciated the various anatomical traits visible in the radiographs and dental characteristics were mentioned more frequently than non-dental features. Different assumptions can be elucidatory: firstly, 15 out of 19 examiners were dentists; supposedly, that they felt more comfortable in analysing mainly dental characteristics; it is also possible that not all examiners were confident with the type of radiograph used in this project: on an every-day clinical practice, dentists handle intra-oral radiographs (periapical and bitewings) more frequently; this would suggest that dentists should master their knowledge of all anatomical structures and their familiarity with any type of radiographic image; secondly, there is not a standard procedure for comparing dental radiographs with identification purposes [8] and the literature has not provided enough statistical evidence on the reliability of maxillo-facial traits other than teeth for identification when comparing panoramic and intra-oral radiographs [6,19,24]. As opposed to what expected by the Authors, FA did not contribute significantly in providing information on which bone characteristics had identification validity. Examiners tended to analyse the same category of dental characteristics when identifying or excluding a radiograph, mainly the root morphology of the molars; this finding was consistent with previous studies [21,25]; this can be explained by the first molars being the first permanent teeth to be erupted or at an advanced development stage by the time a child takes the first dental radiograph; additionally, compared to the crown, the roots are less prone to natural modifications by erosion and abrasion and show significant variability in terms of inclination, curvature, divergence and proximity to adjacent teeth. The explanations to the FP showed that, even examining the same category of characteristics within the same case, examiners reached different conclusions and consequently different levels of sensitivity, specificity and accuracy. It must be also noted that the absence or the different location of the third molars in the AM radiographs were considered by examiners with sensitivity <80% was considered a sufficient factor to exclude the correct match; it can be assumed that examiners did not acknowledge that the development stage of the AM radiograph was to early to see the germs. There were some limitations in this study: firstly, the intra-rater agreement was not tested to verify the consistency in the examiners' answers after a significant amount of time; secondly, only four anthropologists and no radiologists participated; the disparity between the number of FD and FA prevented from comparing the performance and the features mentioned in the open-ended questions, according to the field of expertise; the analysis of the correlation between accuracy and experience of the examiners did not take into account differences in degrees, qualifications or number of positive identifications performed during their forensic practice. Further research with a bigger number of participants and a larger variability of professional background is recommended to confirm the preliminary findings of this study and the intra-rater reliability. The contribution by radiologists would be extremely beneficial because of their training in recognizing similarities and inconsistencies in radiographic records.

## 5. Conclusions

The study tested the accuracy of dental identification of individuals with unrestored teeth by visual comparison of radiographs with mixed dentition. Overall sensitivity, specificity and accuracy of the methodology were 53,5%, 86,4% and 75,4%, respectively; in other words, excluding the incorrect individuals was easier than matching the correct radiographs. However, more than half of the correct exclusions were assessed due to insufficient data rather than distinctive inconsistencies. The accuracy was weakly correlated to the experience of the examiners and the AM-PM interval; on the other hand, it was moderately and positively correlated to the age of the AM radiographs. Qualitative analysis of the explanations to the conclusions was also performed. The thematic analysis showed that, even comparing the same characteristics, different examiners reached different conclusions. Similarities in the anatomy of the molars and in the pattern of the maxillary sinus were mentioned to explain the identification of both the correct and the incorrect AM radiographs. Most exclusions were explained as the impossibility to detect comparable features because of the early development stage of the AM radiograph and the lack of dental treatments; non-dental features were frequently overlooked. Finally, the absence of the third molars in the correct AM radiograph was considered a sufficient factor for some examiners to exclude a positive match; in other words, it was not acknowledged that the germs can develop and become radiographically visible at a later age.

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## Bibliography

[1] R. Carabott, Dental human identification, in: Forensic Odontol. An Essent. Guid., John Wiley & Sons, Ltd, Chichester, UK, 2013: pp. 65–115. doi:10.1002/9781118526125.ch5.

[2] R.E. Wood, S.L. Kogon, Dental radiology considerations in DVI incidents: A review, Forensic Sci. Int. 201 (2010) 27–32. doi:10.1016/j.forsciint.2010.04.018.

[3] S. Martin-de-las-Heras, A. Valenzuela, J. de D. Luna, M. Bravo, The utility of dental patterns in forensic dentistry, Forensic Sci. Int. 195 (2010) 166.e1-166.e5. doi:10.1016/j.forsciint.2009.11.004.

[4] B.J. Adams, Establishing personal identification based on specific patterns of missing, filled, and unrestored teeth., J. Forensic Sci. 48 (2003) 487–96. http://www.ncbi.nlm.nih.gov/pubmed/12762515 (accessed September 29, 2017).

[5] M.D. Viner, J. Robson, Post-Mortem Forensic Dental Radiography - a review of current techniques and future developments, J. Forensic Radiol. Imaging. 8 (2017) 22–37. doi:10.1016/j.jofri.2017.03.007.

[6] R.E. Wood, Forensic aspects of maxillofacial radiology, Forensic Sci. Int. 159 (2006) S47–S55. doi:10.1016/j.forsciint.2006.02.015.

[7] A.B. Acharya, J.A. Taylor, Are a minimum number of concordant matches needed to establish identity in forensic odontology?, J. Forensic Odontostomatol. 21 (2003) 6–13.

[8] V. Pinchi, G.A. Norelli, F. Caputi, G. Fassina, F. Pradella, C. Vincenti, Dental identification by comparison of antemortem and postmortem dental radiographs: Influence of operator qualifications and cognitive bias, Forensic Sci. Int. 222 (2012) 252–255. doi:10.1016/j.forsciint.2012.06.015.

[9] D.S. Bell, From Frye to Daubert, Aust. J. Forensic Sci. 32 (2000) 61–64. doi:10.1080/00450610009410798.

[10] S.L. Kogon, A.E. McKay, D.F. Maclean, the Validity of Bitewing Radiographs for the Dental Identification of Children, J. Forensic Sci. 40 (1995) 1055–1057. doi:10.1520/JFS13875J.

[11] R.E. Wood, N.J. Kirk, D.J. Sweet, Digital dental radiographic identification in the pediatric, mixed and permanent dentitions., J. Forensic Sci. 44 (1999) 910–6.

[12] S. Fridell, J. Ahlqvist, The use of dental radiographs for identification of children with unrestored dentitions, J. Forensic Odontostomatol. 24 (2006) 42–46.

[13] S.L. Kogon, D.F. MacLean, Long-term validation study of bitewing dental radiographs for forensic identification., J. Forensic Sci. 41 (1996) 230–2.

[14] ID & Bitemark guidelines | ABFO :: American Board of Forensic Odontology, (n.d.). https://abfo.org/resources/id-bitemark-guidelines/ (accessed September 26, 2017).

[15] V. Braun, V. Clarke, Using thematic analysis in psychology, Qual. Res. Psychol. 3 (2006) 77–101. doi:10.1191/1478088706qp063oa.

[16] G. Merlati, C. Savio, P. Danesino, G. Fassina, P. Menghini, Further study of restored and un-restored teeth subjected to high temperatures, J. Forensic Odontostomatol. 22 (2004) 34–39.

[17] D. De Angelis, C. Cattaneo, Implant Bone Integration Importance in Forensic Identification, J. Forensic Sci. 60 (2015) 505–508. doi:10.1111/1556-4029.12640.

[18] K. Khalid, S. Yousif, A. Satti, Discrimination potential of root canal treated tooth in forensic dentistry, J. Forensic Odontostomatol. 34 (2016) 19–26.

[19] H. Borrman, H.G. Grondahl, Accuracy in establishing identity in edentulous individuals by means of intraoral radiographs, J. Forensic Odontostomatol. 10 (1992) 1–6.

[20] D.F. MacLean, S.L. Kogon, L.W. Stitt, Validation of dental radiographs for human identification., J. Forensic Sci. 39 (1994) 1195–200.

[21] S.A. Sholl, G.H. Moody, Evaluation of dental radiographic identification: An experimental study, Forensic Sci. Int. 115 (2001) 165–169. doi:10.1016/S0379-0738(00)00305-4.

[22] I.A. Pretty, R.J. Pretty, B.R. Rothwell, D. Sweet, The reliability of digitized radiographs for dental identification: a Web-based study., J. Forensic Sci. 48 (2003) 1–6.

[23] H. Soomer, M.J. Lincoln, H. Ranta, A. Penttilä, E. Leibur, Dentists' qualifications affect the

accuracy of radiographic identification., J. Forensic Sci. 48 (2003) 1121–6. doi:10.1520/JFS2003142.

[24] T.A. Xavier, A.S.S. Dias Terada, R.H.A. da Silva, Forensic application of the frontal and maxillary sinuses: A literature review, J. Forensic Radiol. Imaging. 3 (2015) 105–110. doi:10.1016/j.jofri.2015.05.001.

[25] D.T. Van Der Meer, P.C. Brumit, B.A. Schrader, S.B. Dove, D.R. Senn, Root Morphology and Anatomical Patterns in Forensic Dental Identification: A Comparison of Computer-Aided Identification with Traditional Forensic Dental Identification*, J. Forensic Sci. 55 (2010) 1499–1503. doi:10.1111/j.1556-4029.2010.01492.x.