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Technical Note

# Guidelines for reproducing geometrical aspects of intra-oral radiographs images on cone-beam computed tomography

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ABSTRACT

Human identification requires comparison of individual traits of a person, depending on the availability and reproduction of antemortem (AM) records. If there is no presumed identity or AM exams are not available for comparison, the production of postmortem (PM) records is impaired. The purpose of this research is to describe and test standards to enable the comparison of antemortem periapical radiographs to images extracted from the manipulation of postmortem CBCT exams in multiple identification simulations in a randomized blind study. In a simulation, 20 CBCT images from dry skulls were used as PM records and 3 periapical radiographs (total of 60) that were randomized and blinded from the first examiner. In each case, an intentional incidence error of 10° was added in four different directions. Three points were selected in the AM radiograph, and the angle, linear measurements and proportion between these distances were collected. The AM data were used to mathematically find similar image geometry on a CBCT maximum intensity projection. Possible identification by superimposition was achieved in all cases, and statistical analysis proved the success in the reproduction of angular and length proportion using CBCT incidence manipulation. Significant reproducibility was also observed on intra- and inter-observer tests. In conclusion, the images extracted from CBCT could be compared to any periapical radiographs by superimposition, providing acceptable evidence to establish human identification. The application of this protocol is suitable for forensic practices with the high level of reproducibility and could be used as PM record when no AM records are available at the time of the exam.



## 1. Introduction

Human identification requires procedures to individualize a person, which is an important task for legal, social, and personal matters [1]. In this context, dentistry can contribute with reliable and specialized techniques. Comparison of dental records aims to collate the particular anatomical and dental details from antemortem information, which is frequently presented by relatives, to postmortem records and images produced during the forensic examination [2]. This method is well accepted in court and has extensive scientific data available to support its usage [3,4]. Due to its ability to return fast, precise and low-cost results, the International Criminal Police Organization (INTERPOL) consider it a primary method as well as DNA and fingerprint comparison methods [4].

The use of oral radiography has been considered good clinical practice in the past decades and is broadly used in dentistry due to its importance in diagnosis [5]. Therefore, dentistry is well known for reliable production and maintenance of patient's records [1,3,6]. Digital exams are gaining ground because of image quality and the possibility of enhancements and adjustments by proper software [7,8].

The premise of forensic radiographic identification is to repeat the antemortem (AM) record in a postmortem (PM) exam. Concerning radiographs, the resulting images suffer great changes due to positioning and angle of incidence [9]. Therefore, in the PM exam, it is important to capture the same anatomical region and

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approximate the angle of the X-ray beam in relation to the structures to obtain similar images suitable for superimposition and comparison [3,9–11].

Despite the applicability of forensic radiographic identification, it is only possible to achieve an outcome if AM records are in fact available [2,3]. Dental charts and especially radiographs can offer important information of dental history and individual anatomical traits [3] that are usually stored for long periods of time [6]. Therefore, although the role of the forensic dentistry team's knowledge and experience is substantial, the analysis also relies on the general clinicians good practice to keep those records organized and available [2].

If presumed identities are not established during an identification exam, only secondary methods, such as facial reconstruction, can be applied [12]. Otherwise, it is common for the remains to be buried as unidentified. There is a significant number of missing people reported every day in major cities throughout the world. If an eventual suspect is found, exhumation process may be necessary to allow further investigations [13], which requires additional time and cost and is subjected to human error from body description to the location of a body. Disaster victim identification (DVI) situations are particularly exposed to such difficulties, which also includes finding the AM in time to avoid natural decay of the bodies and potential contamination risks [14].

The advance of computer sciences in the 1980s allowed refined forensic comparison with the aid of software and image editors [15]. Recent studies [16] have tested the efficacy of the use of Cone Beam Computed Tomography (CBCT) for forensic purposes. Indirect volume rendering, such as maximum intensity projection (MIP), can return images similar to regular radiographs through the creation of a 2D view of a region of interest (ROI) based on calculation of the highest-density voxel in a linear path that can be adjusted as an imaginary X-ray beam [17].

Among the different kinds of computed tomography, CBCT is suitable for the analysis of bone, tooth and dental material that is important to forensic exams [16]. In dry skulls it is possible to obtain good-quality CBCT exposures with adequate support and positioning [18].

The purpose of this research is to describe and test standards to enable the comparison of antemortem periapical radiographs to images extracted from the manipulation of postmortem CBCT exams in multiple identification simulations in a randomized blind study.

## 2. Methods

To achieve a level of similarity between the AM regular radiograph and the resulting view of in a cone-beam computed tomography (CBCT) exam, we propose a series of steps:

(1) CBCT acquisition and postmortem record,
(2) Analysis of the AM image and quantitative references,
(3) CBCT selection and adjustment of the point of view, based on AM references and
(4) Superimposition.

### 2.1. Ethics

Twenty adult human dry skulls from a Brazilian sample were selected from an existing collection of the anthropology and forensic dentistry laboratory (OFLAB) of the University of São Paulo. The project was approved by the university's ethics in research committee under protocol number 43751115.6.0000.0075, and all authorizations were granted and stored. A CBCT unity was also made available in periods that could not jeopardize the service of the general public.

### 2.2. CBCT and postmortem records

The voxel size is relevant, as the best definition is achieved with smaller field of view (FOV) and voxel values [19,20]. In this test, better results were correlated to smaller *voxels*.

The postmortem CBCT exams in this report were made with a R100 unit (J. Morita Corp. Tokyo, Japan) with a FOV of 80 × 80 mm. To examine the dry skulls, a preset of 75 kV and 5 mA was selected with a voxel size of 0.125 mm and a 9.6-s exposure time. The images were reconstructed in iDiexel software (J. Morita Corp. Tokyo, Japan) with an isometric voxel size of 0.125 mm. The images acquired were exported in digital imaging and communications in medicine (DICOM) files to a CD or hard drive. The lowest kV and mA presets were chosen, as there was no need for soft-tissue barriers. A head-positioning device [18] was used to keep the skulls in position.

It was important to keep the mandibular teeth a few millimeters away from the maxillary teeth. If exposed in normal occlusion, future comparisons may be impossible due to the superimposition of the upper and lower teeth and possible image artifacts.

### 2.3. Analysis of the AM image and quantitative references

The AM periapical radiographs can be viewed with Adobe Photoshop (Version: 2015.1.2 20160113.r.355), and a sharpen mask filter was applied.

Three visible anatomical structures should be identified and marked with a reference point made with the brush tool in a new layer.

The image must be re-scaled using the 4-cm width of the film as a reference in the analysis tool. With the scale in millimeters, the ruler tool can be used to measure the two actual distances and the angle formed between the three selected points (Fig. 1A and B).

The proportions between the longer (L1) and shorter (L2) distances can be calculated with a “rule-of-three” equation. The preference for a percentage value was idealized due to distortions, which are common on radiographs.

### 2.4. CBCT selection and manipulation of the point of view based on AM references

DICOM files are imported to the OsiriX® viewer. A curved multiplanar reconstruction (curved MPR) provided a panoramic view, which is helpful to assess the level of similarity and locate the region of interests (ROI) in the volume to be analyzed. If it resembles the radiograph region and anatomy, one should try to repeat the incidence of the AM image by manipulating the point of view in linear 3D MPR sagittal views.

With the principle of the well-known Clark's technique [21], the structures of different depths in a volume will change their relationships with each other if the incidence angle is changed. Therefore, to repeat a radiograph image, this dynamic can be applied to search for the same geometry between structures in the resulting image, as analyzed in the AM image. For better results, the landmarks chosen in the AM films should be root apices, cusps and other identifiable prominences of different volume depths.

In the DICOM viewer's 3D MPR, it is possible to place ROI markers in the structure's actual position in the volume. To perform this step, one must locate the correct tooth, adjusting the position of reference planes to coincide with the long axis of the tooth or root. By scrolling through the axial slices, it is possible to find the summit of the selected structure and place a marker.

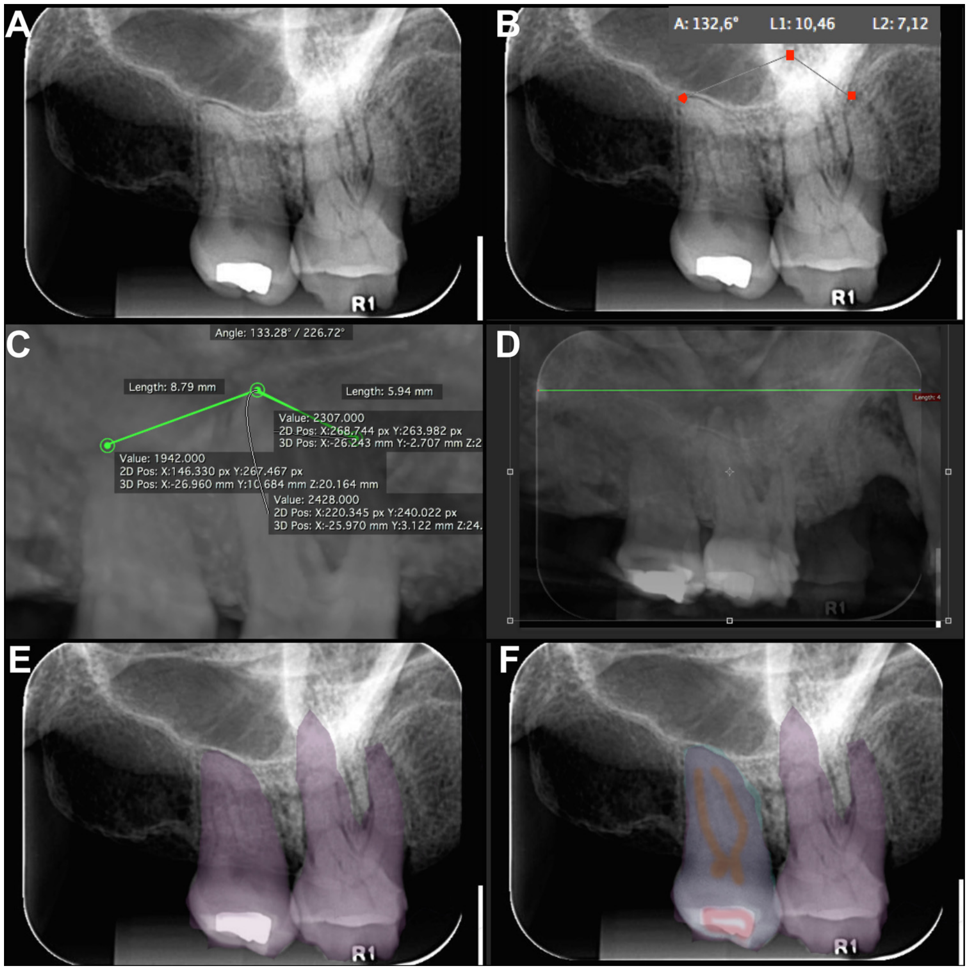


**Fig. 1.** Original AM image (A); angle and length 1 and 2 measurements in the radiograph (B); Similar angle and proportional linear measurement in the CBCT image (C); scaling of the CT exported image with the 4 cm length of the film (D); selection of a mask from a tooth in the CT superimposing the radiograph (E) and anatomical and restorative features, highlighting the coincidence and geometry of the images (F).

Once the markers are in position, the sagittal reference plane is placed over the alveolar bone in the axial window, and a minimum MIP thickness is activated to show the entire volume of bone and teeth, usually between 10–20 mm. It will simulate an image very close to a periapical radiograph.

When the sagittal reference line is moved in the coronal and axial windows, the incidence angle changes. The observer will see the resulting image in the sagittal window being altered in real time (Fig. 2). As a result, the reference markers move accordingly and should have the same geometry observed in the original AM image.

As CBCT is always precise, images will not appear to be elongated or shortened as is expected in traditional radiography. Therefore, the analysis should start with a reference at the most approximate angle and then a similar ratio of the distances between reference points with the aid of measuring tools (Fig. 1B).

### 2.5. Superimposition

The superimposition of teeth and other anatomical structures begins when images are exported from the DICOM viewer and imported to Photoshop as a new layer. To enable initial scaling, the image exported from OsiriX should have a 4-cm measure line when this image is captured (Fig. 1D).

Once the images from the CBCT are in Photoshop, with transparency adjustment, it is possible to determine the quality of the superimposition (Fig. 3D). The line in the imported PM screenshot will allow it to fit in relation to the 4 cm of the AM digital periapical width while maintaining the image proportions (Fig. 1D). To simulate radiograph distortions, image adjustment can be performed as proposed in previous studies [22].

The magnetic selection tool can separate tooth and other anatomic features from its surroundings. By duplicating the selection to a new layer, one can now superimpose part of the structures selected over the AM radiographs. This enhances the visual results, which are the baseline of human identification through the comparison of dental records, providing a more objective interpretation.

### 2.6. Method validation

To create and test this method, two forensic dentistry experts analyzed a sample of 20 skulls to simulate human identification in multiple cases. The first examiner, a post-graduation student in forensic dentistry, was responsible for postmortem record followed by CBCT exposures. To simulate antemortem exams, a second observer with a master's and doctoral degree in forensic dentistry randomized the subject's order and produced a series of periapical images.

The first examiner's main objective was to analyze the simulated AM exams, finding the corresponding PM records in a multiple-case situation and producing images for superimposition outcomes, as in a human-identification process.

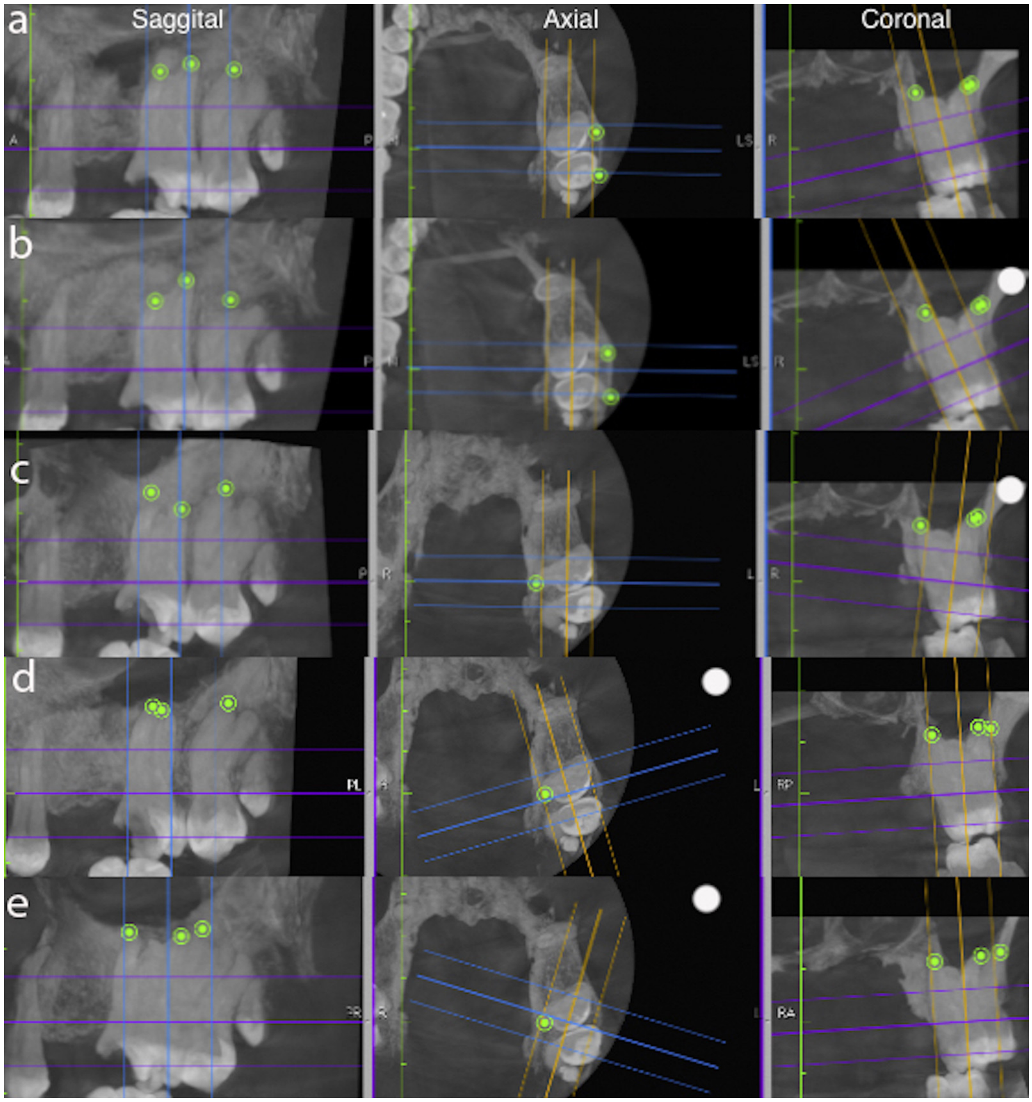


**Fig. 2.** At the sagittal window, evidence of different ROI markers' relationships with a normal incidence (a); moving the axial plane up and down in the coronal window (b and c); and the coronal plane anteriorly and posteriorly at the axial window (d and e).

The numbered PM list was randomized into alphabetical order using the random.org website tool, and from each specimen, three regions were selected and periapical radiographs were obtained with the aid of a clinical film holder with the parallelism technique to serve as AM records in this simulation. Digital scanners were used with a Yoshida Kaycor, model X-70S, 70 kVp—15 mA, set for an exposure of 0.25 s.

From the three radiographs, there was one with an intentional incidence alteration obtained by changing the X-ray tube position 10° in the upper, lower, mesial and distal angulation in relation to the film holder. This step, also randomized, was used to assure the use of CBCT images to offer satisfactory results when compared to periapical exams at a standard incidence angle or with technical errors, which are common in forensic situations.

The software WinID (ABFO-*Copyright*© 2013 *James McGivney, DMD. Available for download at* http://www.abfo.org/winid/) was used to store the AM and PM information. The clinical information obtained from the radiographs was collected in the dental charts as AM records and the skull records as PM information. Once the AM and PM databases were registered, the data comparison tool was used to return probable matches. The WinID software correctly matched 75% of the cases as the top three suspects. The use of the database cross reference and narrowed searches, saving time in this multiple-case, blinded and randomized simulation. Once the correspondent CBCT was found, the method was followed to produce superimposition comparison of all 60 radiographs.

To assure reproducibility, the first and second examiners repeated the process and comparisons of 10 radiographs (16.6% of the sample), five of which had intentional altered incidence.

To test the difference in measurement between the radiographs and the tomography, the variation coefficient, Student T test and the difference of averages were calculated. In addition, the Pearson P test and the correlation coefficient verified the reproducibility.

Sixty simulations of identification by superimposition were made, and all (100%) showed sufficient evidence for positive identification results, based on the number of individual traits of the human oral anatomy. The positive results achieved are directly correlated to the pursuit of similar relationships between ROI markers on CBCT based on the pre-measurements made in the AM radiographs. All cases were performed and recorded properly, Fig. 3 shows examples of radiographic superimpositions. Fig. 4 depicts the inter- and intra-observer results.

Most of the superimposition results were qualitative, but the reference measures are numerical guidelines to achieve the

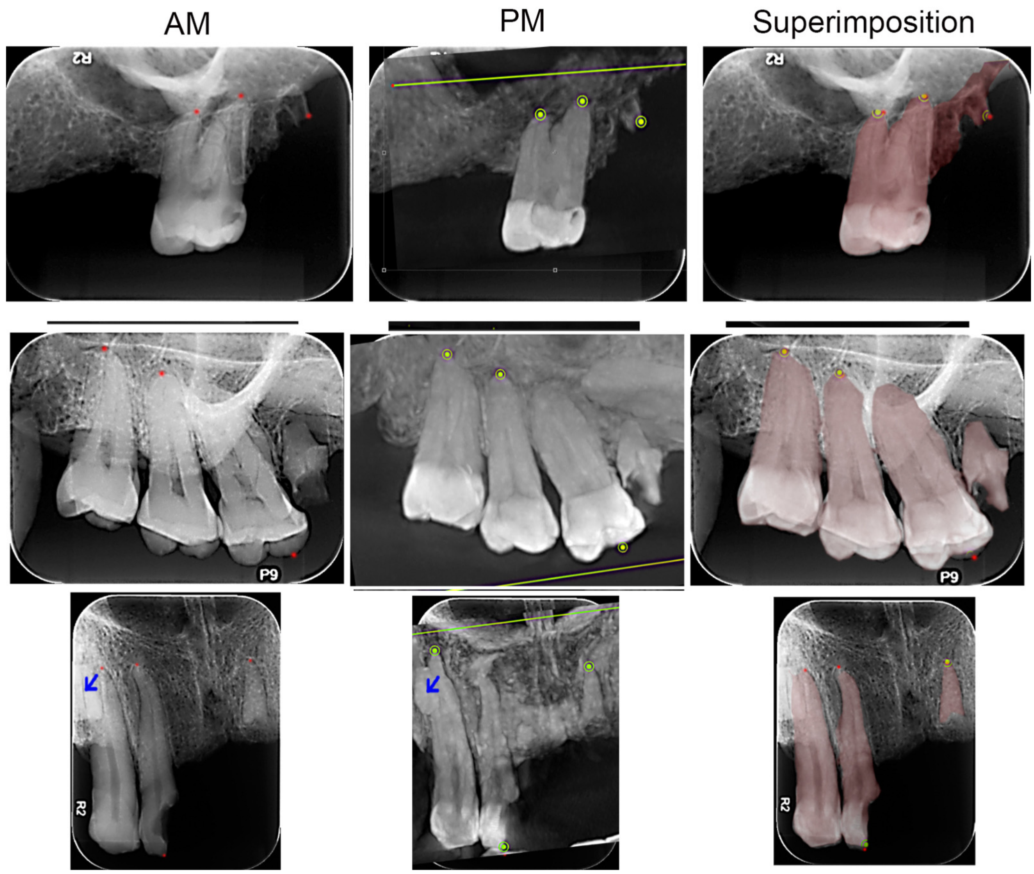


**Fig. 3.** Radiograph (AM), image from CBCT (PM) and superimpositions of 3 cases.

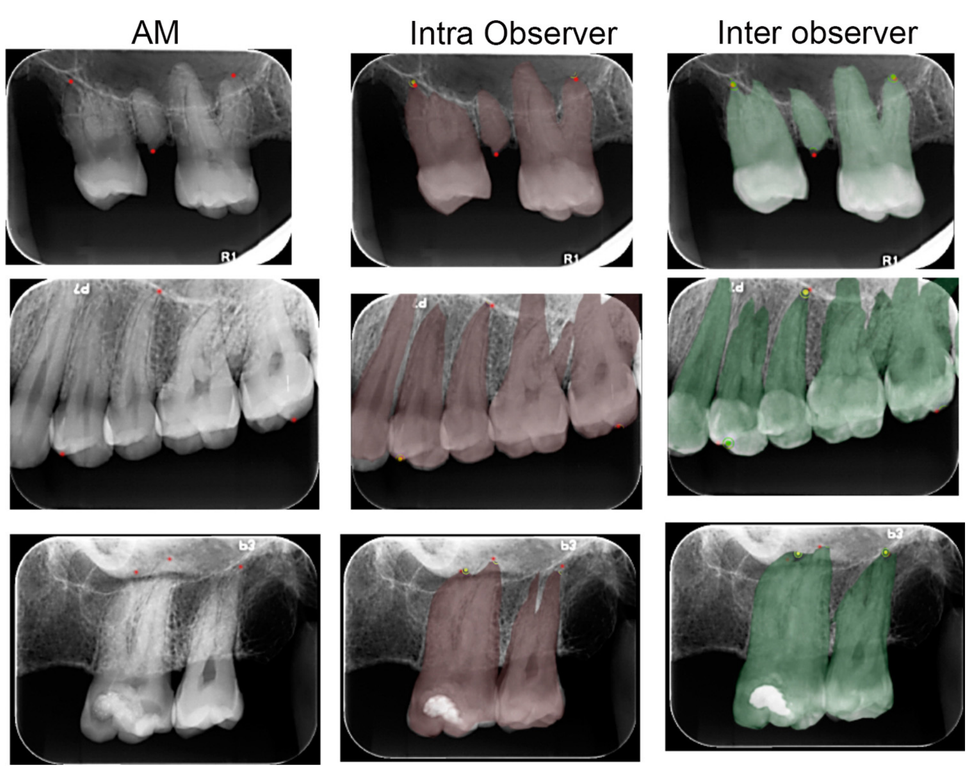


**Fig. 4.** Comparison of 3 inter and intra observer repetition.

**Table 1**
Correlation between measures on radiographs and CBCT.

| | Variable | CC | Pearson P | p |
|---|---|---|---|---|
| Correlation coefficient | L1R/L1T | 0.97 | 0.99 | 0.001 |
| | L2R/L2T | 0.98 | 0.99 | 0.001 |
| | AR/AT | 0.99 | 0.99 | 0.001 |
| | PR/PT | 0.99 | 0.99 | 0.001 |

superimposition. A descriptive statistical analysis was conducted to all quantitative variables (L1, L2, Angle and Proportions) between the radiographs and tomography and also between the main results and inter and intra-observer repeatability test.

A normal distribution was observed and the higher variation coefficient was observed in L1 (6.58) and the smaller for angle variation (1.06). The proportions between L1 and L2 had the second-lowest variation (3.41). This result support the use of this ratio as a substitute for the direct linear measures, which were expected to present alterations in regular radiographic techniques contrasting with the dimensional precision of CBCT [23,24].

Tables 1 and 2 show the reliability of the measures on radiographs and CBCT, as well as the results of the reproducibility tests.

Fig. 5 presents the greater variation on linear measures when radiograph (R) and tomography (T) are compared. Lengths, in centimeters, had greater values in the radiographic images than in the maximum intensity projection of the compared regions on CBCT, while more stable and horizontal lines can be observed on angular measurements and proportions.

The references from pre-measurements in the AM radiographs were advantageous to perform a difficult and time-consuming task, if working in regular radiographs. The statistical analysis not only showed success achieving the desired similarities but also demonstrated good replication of the exam in a second analysis and by other observer.

**Table 2**
Variance coefficient (VC), average difference (DIFF), concordance coefficient, and *p* value (P) between intra-observer (intra) and inter-observer (inter) first and second measurements.

| | Variable | CV | DIFF | p | CCC | *p* |
|---|---|---|---|---|---|---|
| Intra | L1M1/L1M2 | 2.34 | −0.01 | 0.948 | 0,999 | 0.001 |
| | L2M1/L2M2 | 3.83 | −0.01 | 0.961 | 0,999 | 0.001 |
| | AM1/AM2 | 0.81 | 0.68 | 0.900 | 0,999 | 0.001 |
| | PM1/PM2 | 3.79 | 0.58 | 0.61 | 0,999 | 0.001 |
| Inter | L1EX1/L1EX2 | 2.60 | −0.01 | 0.958 | 0,999 | 0.001 |
| | L2EX1/L2EX2 | 2.50 | −0.01 | 0.931 | 0,999 | 0.001 |
| | AEX1/AEX2 | 0.91 | 0.78 | 0.930 | 0,999 | 0.001 |
| | PEX1/PEX2 | 4.10 | 0.67 | 0.62 | 0,999 | 0.001 |

### 2.7. Practical application

In forensic dentistry and radiology, it is intended to repeat the AM records with special attention to the region, incidence angle and adjusted exposure of the original radiograph [2,9,11]. Image quality is relevant to enabling a rapid and reliable comparison [3,15,25,26].

On the other hand, if no presumed identity is presented for investigation and no AM records are available, the comparative methods and analysis are useless. Furthermore, depending on the legislation of the country, if a radiograph is found for comparison after burial, an exhumation would be necessary to access the human remains for examination. A CT exam could substitute this act [13] in order to assure the identity before physical access to the corpse. Therefore, CBCT could be used to repeat any AM record that is presented for comparison at any time.

Nowadays it is possible to exchange a large amount of data in a fast and secure way through the internet [16]. Therefore, CBCT of the unknown body prior to inhumation or in case of a DVI situation could offer valuable information to forensic services [27,28].

The quantitative guidelines presented, working with angle, lengths and proportions, are the unique aspects of this technical

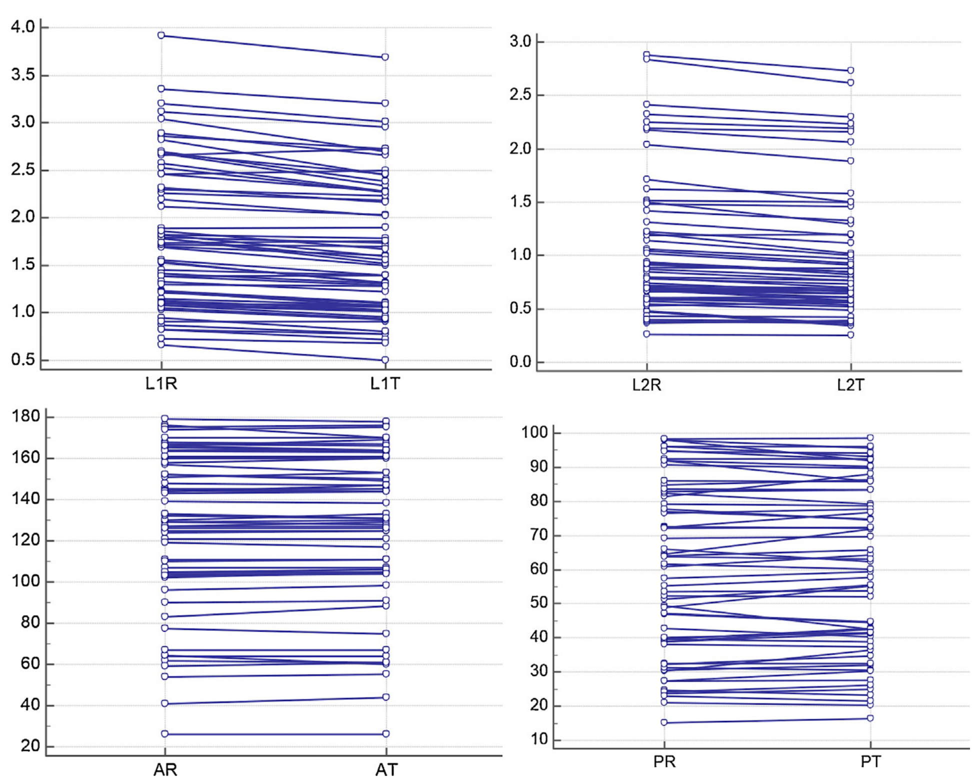


**Fig. 5.** Graphs with the difference of the average of the four variables on radiographs (R) and tomography (T).

note. When moving the CBCT's planes, real-time changes of ROI position allow the operator to search similar image geometry based on mathematical references.

Previous investigation [16] also concluded that intra-oral like images could be produced from FBCT, but this was the first study to test real superimposition results, offer quantitative guidance for incidence angle and include non-gold-standard AM images with high levels of success.

Even though perfect superimposition is not mandatory to establish positive identification, the interpretation is correlated to the level of experience of the examiner [5]. Therefore, we believe that the results, provided by the superimposition of images are more objective, as it is the visual expression of the expert's conclusion. This provides a rich material for a forensic report to be used in court or analyzed by professionals outside of the medical field.

## 3. Conclusion

The proposed method enabled the use of CBCT for reproduction of incidence and image geometry observed on any conventional radiographs, including situations with technical errors. The images extracted from CT could be compared to the periapical radiographs by superimposition, providing acceptable evidence to establish human identification. The application of this protocol is suitable for forensic practices due to the high level of reproducibility and is advisable when no AM records are available at the time of the exam.

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## References

[1] S. Sengupta, V. Sharma, V. Gupta, H. Vij, R. Vij, K. Prabhat, Forensic odontology as a victim identification tool in mass disasters: a feasibility study in the Indian scenario, J. Forensic Dent. Sci. 6 (2014) 58–61.
[2] K. Shahin, L. Chatra, P. Shenai, Dental and craniofacial imaging in forensics, J. Forensic Radiol. Imaging 1 (2013) 56–62.
[3] D. Sweet, Forensic dental identification, Forensic Sci. Int. 201 (2010) 3–4.
[4] INTERPOL, Disaster Victim Identification Guide, (2009) .
[5] S.A. Sholl, G.H. Moody, Evaluation of dental radiographic identification: an experimental study, Forensic Sci. Int. 115 (2001) 165–169.
[6] O. Malik, M. Abdi-Oskouei, N. Mandall, An alternative to study model storage, Eur. J. Orthod. 31 (2009) 156–159.
[7] A. Banumathi, B. Vijayakumari, A. Geetha, N. Shanmugavadivu, S. Raju, Performance analysis of various techniques applied in human identification using dental X-rays, J. Med. Syst. 31 (2007) 210–218.
[8] V. Pushparaj, U. Gurunathan, B. Arumugam, An effective dental shape extraction algorithm using contour information and matching by Mahalanobis distance, J. Digit. Imaging 26 (2013) 259–268.
[9] R.E. Wood, Forensic aspects of maxillofacial radiology, Forensic Sci. Int. 159 (Suppl. 1) (2006) S47–S55.
[10] R.E. Wood, S.L. Kogon, Dental radiology considerations in DVI incidents: a review, Forensic Sci. Int. 201 (2010) 27–32.
[11] I.A. Pretty, D. Sweet, A look at forensic dentistry—part 1: the role of teeth in the determination of human identity, Br. Dent. J. 190 (2001) 359–366.
[12] S.V. Tedeschi-Oliveira, R.F. Melani, N.H. de Almeida, L.A. de Paiva, Facial soft tissue thickness of Brazilian adults, Forensic Sci. Int. 193 (127) (2009) e1–e7.
[13] M. Skinner, D. Alempijevic, A. Stanojevic, In the absence of dental records, do we need forensic odontologists at mass grave sites, Forensic Sci. Int. 201 (2010) 22–26.
[14] M.M. Leite, A.C. Amorim, T. Gomes, M. Prado, R. Silva, A importância da atuação do odontolegista no processo de identificação humana de vítimas de desastre aéreo, Rev. Odontol. Bras. Central (2011) 20.
[15] S.P.M. Carvalho, R.H.A. da Silva, C. Lopes-Júnior, A.S. Peres, Use of images for human identification in forensic dentistry, Radiol. Bras. 42 (2009) 125–130.
[16] D.A. Trochesset, R.B. Serchuk, D.C. Colosi, Generation of intra-oral-like images from cone beam computed tomography volumes for dental forensic image comparison, J. Forensic Sci. 59 (2014) 510–513.
[17] W. Scarfe, Z. Li, W. Aboelmaaty, S. Scott, A. Farman, Maxillofacial cone beam computed tomography: essence, elements and steps to interpretation, Aust. Dent. J. 57 (2012) 46–60.
[18] T.L. Beaini, P.E. Dias, R.F. Melani, Dry skull positioning device for extra-oral radiology and cone-beam CT, Int. J. Legal Med. 128 (2014) 235–241.
[19] J.B. Ludlow, M. Gubler, L. Cevidanes, A. Mol, Precision of cephalometric landmark identification: cone-beam computed tomography vs conventional cephalometric views, Am. J. Orthod. Dentofacial Orthop. 136 (2009) 312 e1–e10.
[20] Z. Fourie, J. Damstra, P.O. Gerrits, Y. Ren, Accuracy and reliability of facial soft tissue depth measurements using cone beam computer tomography, Forensic Sci. Int. 199 (2010) 9–14.
[21] C.A. Clark, A method of ascertaining the relative position of unerupted teeth by means of film radiographs, Proc. R. Soc. Med. 3 (1910) 87.
[22] D.J. Flint, S. Brent Dove, P.C. Brumit, M. White, D.R. Senn, Computer-aided dental identification: an objective method for assessment of radiographic image similarity, J. Forensic Sci. 54 (2009) 177–184.
[23] M. Berco, P.H. Rigali, R.M. Miner, S. DeLuca, N.K. Anderson, L.A. Will, Accuracy and reliability of linear cephalometric measurements from cone-beam computed tomography scans of a dry human skull, Am. J. Orthod. Dentofacial Orthop. 136 (2009) 17 e1–e9.
[24] C. Tomasi, E. Bressan, B. Corazza, S. Mazzoleni, E. Stellini, A. Lith, Reliability and reproducibility of linear mandible measurements with the use of a cone-beam computed tomography and two object inclinations, Dentomaxillofac Radiol. 40 (2014) 24–34.
[25] B. Gelbrich, G. Gelbrich, R. Lessig, Does the quality of dental images depend upon patient's age and sex?—explanations from the forensic sciences, J. Forensic Odontostomatol. 27 (2009) 2–11.
[26] S.I. Kvaal, Collection of post mortem data: DVI protocols and quality assurance, Forensic Sci. Int. 159 (Suppl. 1) (2006) S12–4.
[27] P. Pittayapat, R. Jacobs, E. De Valck, D. Vandermeulen, G. Willems, Forensic odontology in the disaster victim identification process, J. Forensic Odontostomatol. 30 (2012) 1–12.
[28] C. Jackowski, E. Aghayev, M. Sonnenschein, R. Dirnhofer, M.J. Thali, Maximum intensity projection of cranial computed tomography data for dental identification, Int. J. Legal Med. 120 (2006) 165–167.