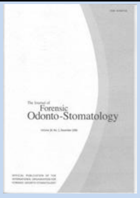

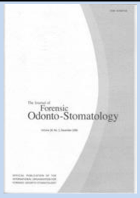

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SECTION IDENTIFICATION

Can mandibular lingual canals be used as a forensic fingerprint?

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The authors declare that they have no conflict of interest.

ABSTRACT

Objectives: This study aimed to identify whether the lingual canals of the mandible can be used as a unique fingerprint when dealing with forensic victim identification.

Materials and Methods: The study consisted of two parts; an observational part and an objective image analysis part. In the observational part a total of 100 in vivo high resolution CBCT datasets of human mandibles were included in the process of simulated matching of ante-mortem (AM) and post-mortem (PM) data. For the objective image analysis part 10 dry human mandibles were scanned with 2 different Cone Beam Computed tomography (CBCT) machines. In the observational part of the study trained observers attempted to correctly identify matching pairs of images taken from the same mandible out of a series of 100 mandibles. The aim was to simulate matching of the neurovascular structures on AM and PM mandibular midline images and determine the percentage of mandibles identified correctly. In the objective image analysis part, simulated matching was carried out using a specific CBCT dataset acquired to mimic a PM dataset and 10 datasets acquired from a different CBCT device which served as the source of potential AM cases. Comparison between AM and PM datasets resulted in the matching of the AM data and PM data obtained from the same mandible, leading to an assumed correct identification.

Results: The observational part of the study showed an average 95% correct identification of the mandibular midline neurovascular structures. Registration of mandibles resulted in perfect overlap of the same mandible from 2 different CBCT machine with an error distance equalling zero, while the registration of different mandibles deviated on average error distance 0.13mm to 0.18mm.

Conclusion: The percentage of fit for the simulated AM and PM data of the same mandible was 100%. This finding together with the significant deviations noted for the non-matching cases, may have a potential role in forensic identification in the same way that fingerprints are recognised as being a unique identifying feature.

***KEYWORDS*:** mandibular lingual canals, forensic odontology, victim identification, finger print.

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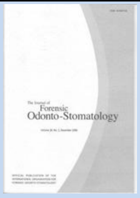

INTRODUCTION

The degree of uniqueness as determined by the morphology of the various dental structures is an essential feature used in forensic odontology especially in cases involving human identification.[1] The mandible is the strongest bone of the facial skeleton and is often the best preserved component after death. In mass disasters such as air crashes, wars, railway accidents and floods it is sometimes necessary to use unknown variables to describe the skeletal remains in order to establish victim identification.[2]

Interest in anatomical features and anatomical variations in the human mandible has increased in recent years due to the widespread use of cone-beam computed tomography (CBCT).[3,4] This imaging technique generates multiple high quality images enabling three dimensional (3D) visualization and complete osseous anatomical information. In forensic dentistry CT is often used for purposes of identification; numerous studies reported in the literature have used CT as auxiliary imaging method in the identification of unknown decedents. [5-8] CBCT is a relatively new CT system designed to focus on the head and neck region; an X-ray beam and detector system move around the part of the body being examined. CBCT is the preferred choice of methodology for diagnosis in almost all fields of dentistry including endodontics, orthodontics, periodontics, maxillofacial surgery and forensic dentistry.[9] CBCT is a more compact and cost-effective methodology when compared with systems based on multi-detector computed tomography (MDCT) and loses none of the reliability and accuracy of the MDCT images. [10-14]

Several techniques are available and used for purposes of identification.[15-19] This study addresses forensic victim identification when only limited PM material is available (e.g. mandibular fragments found in the PM datasets).The fact that US officers leaving for international missions in areas at risk receive a CBCT prior to departure to serve as an AM identification dataset has further triggered the present study.

While teeth have been proven to be valuable sources of information in disaster victim identification, the potential value of mandibular bony fragments has not yet been evaluated. Previous research has indicated that the mandible contains many accessory foramina and canals, particularly on the lingual side, with a significant anatomical variation amongst individuals.[3,20] Accessory foramina on the lingual side of the mandible can be divided into two main groups, namely medial and lateral lingual foramina.[3,21] The mandibular midline foramina are variable in number, size, intraosseous canal structures and morphology.[22,23] The significant variations in appearance make these midline structures unique for a particular individual.[24]

It might thus be hypothesized that these mandibular midline neurovascular canal structures might serve forensic identification, considering the unique appearance in each individual. This study, using both an observational and an image analysis approach, aimed to assess the appearance of the mandibular midline neurovascular canal structures and to determine whether perfect matching of simulated ante-mortem (AM) and post-mortem PM datasets could be demonstrated. If so this could be considered as a forensic fingerprint.

MATERIAL AND METHODS

The study, based on CBCT image datasets of in vivo and ex vivo mandibular samples, consisted of two parts; an observational part and an image analysis part.

For the observational part, a total of 100 in vivo high resolution CBCT datasets (3D Accuitomo 170, J.Morita, Kyoto, Japan) of human mandibles were included in the process of the simulated matching of ante mortem (AM) and post mortem (PM) data. Consecutive CBCT scans of human mandibles were selected retrospectively from patients referred to the Dentomaxillofacial Radiology Centre (University Hospitals, University Leuven). Ethical approval was obtained from the local Commission for Medical Ethics of the University Hospitals Leuven: S57587.

A total of 146 CBCT datasets were evaluated, with 46 of these being excluded. The exclusion criteria were:

1- Inadequate CBCT image quality (patient movement, operator error, etc).
2- Fracture in the lower jaw;
3- Any pathological lesions in the interforaminal region of the mandible.

The age range of the patients in the remaining 100 CBCT datasets, which were included in the present study, was 19-78 years with mean value of 45years. These 100 CBCT scans, obtained from the 3D Accuitomo CBCT (J.Morita, Kyoto, Japan) with a voxel size 0.08mm, were reformatted using the i-Dixel (J.Morita, Kyoto, Japan) software tools in order to obtain cross-sectional images for the mandibular midline showing the lingual canals.

In addition, 10 dry human mandibles were scanned with 2 different CBCT machines (Promax 3D Mid, Planmeca, Helsinki, Finland with the following exposure parameters 90kV, 10mA and volume size 40 x 50 mm; 3D Accuitomo 170 using 90kV,8mA, and volume size 40 x 40 mm).

Simulated matching of AM and PM data

The study was carried out to assess the usefulness of the mandibular midline neurovascular structures to serve as a forensic fingerprint. As indicated this was done in two parts, an observation part and an image analysis part. In the observational part, reformatted cross-sectional images were prepared for all mandibles. These views were then anonymised and labelled by the operator. The views were then mixed randomly and inserted into selection charts presented as slides in a regular PowerPoint file. Each PowerPoint slide contained 12 views representing 11 different mandibles. Only 2 of the 12 cross-sectional views presented on each PowerPoint slide were derived from the same mandibular midline.

Five trained observers (four dental radiologists and one oral surgeon) were presented with 100 PowerPoint slides of 12 different cross-sectional views of the symphyseal region and midline of randomly selected mandibles. A training session was organized prior to the final observations for explanation of the procedure. Observers were seated in front of an observational monitor, and asked to identify and note down the matching pairs of mandibles in each selection chart (Fig. 1). Two weeks later a similar second observational trial was carried out but used a different set of selection charts prepared following re-randomised of the views that had been used previously in the first trial.

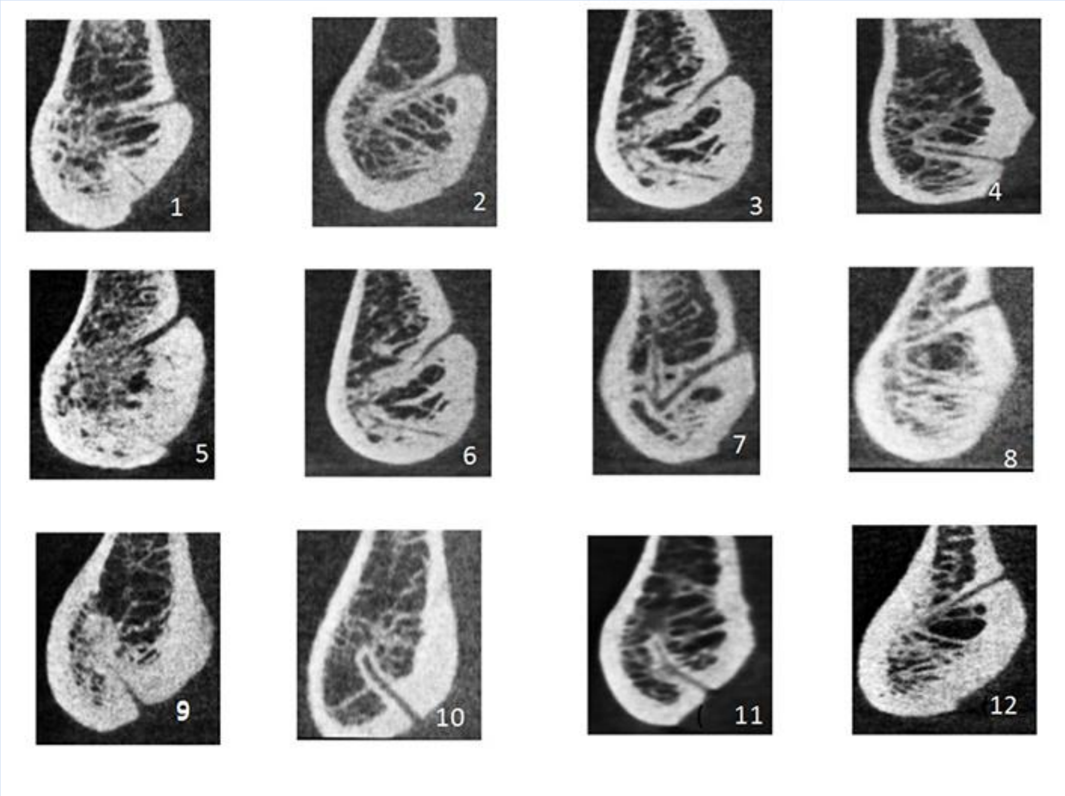

Fig.1: Observational chart with 12 views of 11 different mandibles, with only 2 cross-sectional views on the plate deriving from one and the same mandibular midline.

Image analysis part of the simulated AP/PM matching

In this part, the dataset of one mandible scanned with the system 3D Accuitomo CBCT (J.Morita, Kyoto, Japan) was selected as the PM case and the datasets of 10 mandibles scanned with the system Promax 3D (Finland) were selected as the AM cases. The mandible scanned with the system 3D Accuitomo CBCT was also included within the complement of ten mandibles scanned with the system Promax 3D (Finland). Registration was carried out between the post-mortem dataset and each of the ten ante-mortem datasets using software tools (MIMICS v16.0 and 3-matic v8.0, Materialise, Leuven, Belgium).

The procedure to match the AM and PM datasets used MIMICS software As a first step a bone mask was created using a global threshold value. The region of interest (ROI) was selected by cropping this mask around the midline symphyseal structures. From this ROI, a surface rendered 3D model was calculated and saved as an STL file.

To ensure a good starting position with the 3-matic software a global registration was necessary using two 3D models. This was achieved by performing a manual registration where the focus was on the visible overlap of the midline symphyseal structures (Figs. 2 and 3). A global registration was subsequently carried out; this procedure automatically moves one mandible with respect to the other trying to minimize the distance error between the two models. After the registration procedure, a part comparison analysis was performed in order to assess the differences between two mandibles. This was a point-based method where the deviations are calculated between the two models to allow AM and PM matching.

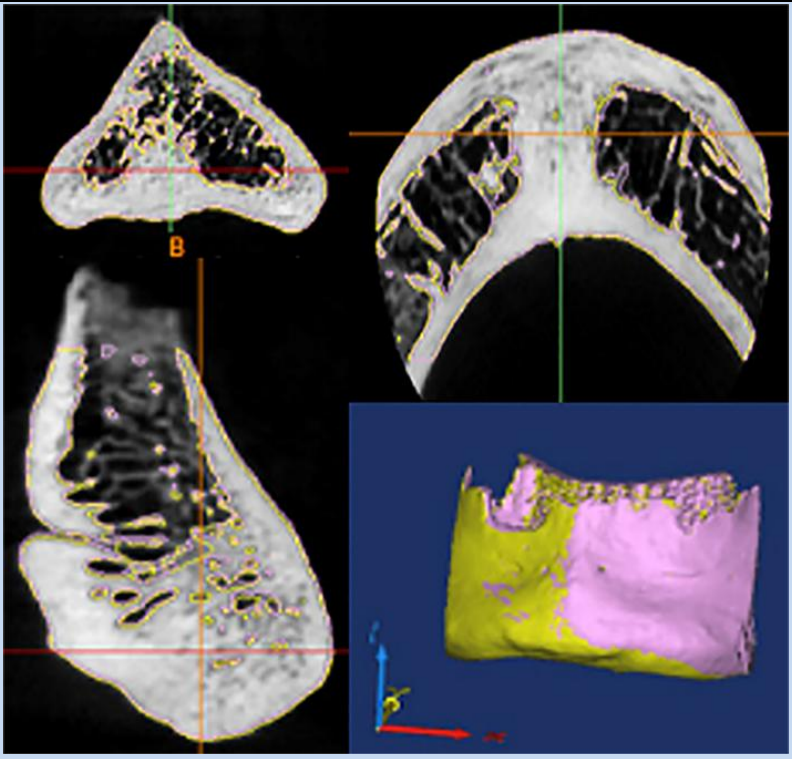

Fig. 2: Manual registration for the same mandible with two different machine showing perfect overlap where 3D model shows a yellow color represent the post mortem case and the pink representing the ante mortem case.

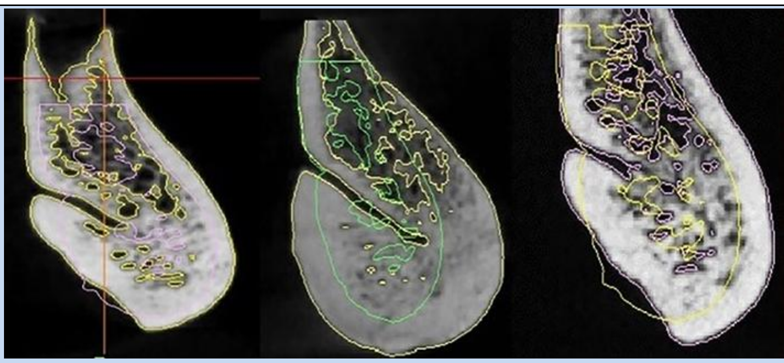

Fig. 3: Cross-sectional views of different ante mortem mandibles. The contour around the bone shows the mask inside the ROI. The second contour is from the post mortem case which is manually registered at the level of the lingual canals. It is clearly seen that there is no perfect overlap.

RESULTS

Observational part

In the first observation test using 100 PowerPoint slides each depicting 12 different cross-sectional views of the symphyseal region and midline of randomly selected mandible three observers achieved 100% success in achieving correct identification of the matching pairs, while 2 observers achieved a success rate of 92%. In the second observation test the average of matching was 95%. Intra and inter-observer agreement was good (95% agreement on average). Results of the matched pairs for identification is shown in Fig.4 for all 5 observers. Inter- and intra-observer agreement was 99% and 96.1% respectively.

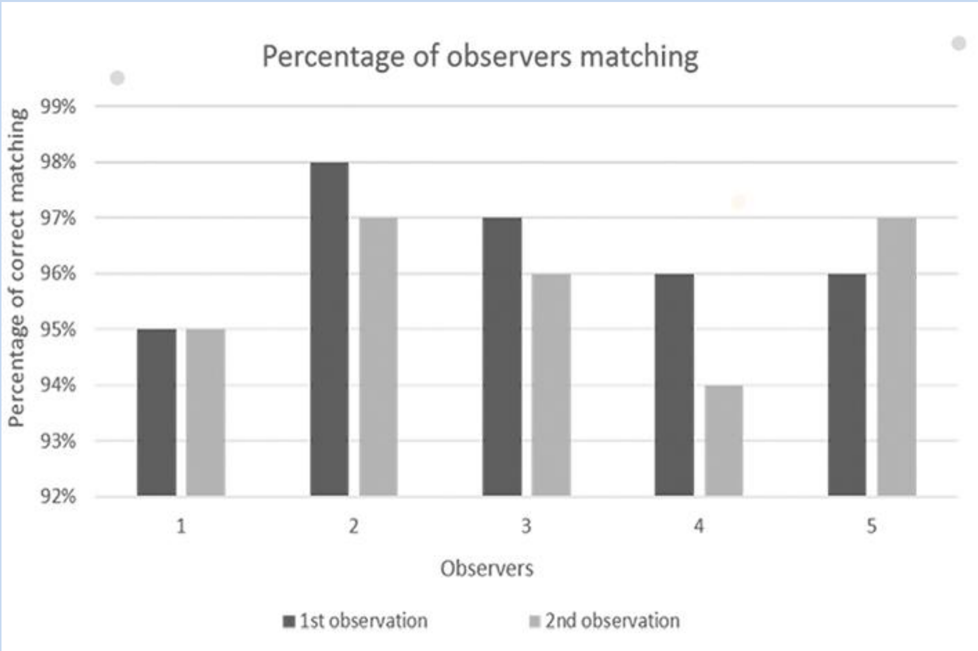

Fig. 4: Results of the observation of the matched mandibles of the 100 in vivo cases of the mandible.

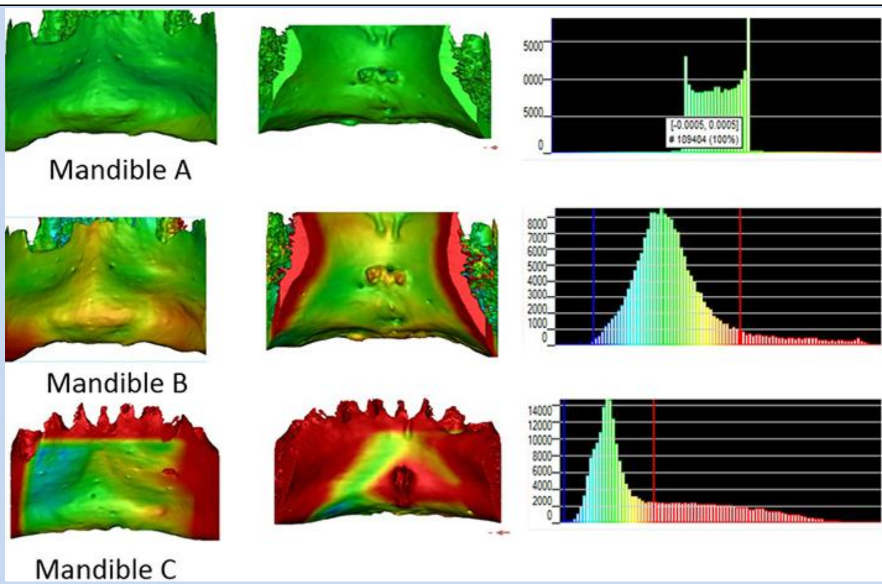

Fig. 5: Mandible A: The 3D color coded model after part comparison analysis showing values located around 0mm deviation, which is represented by the green color.The histogram ranges from -0.0005mm to 0.0005mm and the sliders fixed at -0.0005mm and 0.0005 mm.Mandible B and C: 3D models showing the minimum and maximum deviation between different mandibles and the histogram range is going from the minimum and maximum deviation found in the part analysis however the threshold sliders for defining the color code are fixed at -2.00mm to 2.00mm.

Image analysis part

The registered post-mortem mandible CBCT dataset showed 100% overlap and fit at the midline symphyseal area with the ante-mortem images of the same mandible obtained on the other CBCT machine; the error distance after global registration was 0.0 mm.

Following global registration the registered images of two different mandibles never showed a perfect fit: there was always an error distance after global registration. The error distance between the registered different mandibles ranged from 0.13 mm to 0.18 mm

The part comparison analysis for the registered mandibles showed mean values from 0.14±1.34 mm to 0.53±2.13 mm; however the part comparison for the same registered mandible from two different machines showed 0 mm. In Table 1, the mean error distance after global registration is shown together with the mean deviation obtained with a point-base part comparison. The simulated AM and PM data deriving from the same mandible, showed a zero deviation, indicating a perfect overlap or 100% matching data. The median value and standard deviation values are also presented. From the part comparison, it is possible to create a colour-coded 3D model where the blue colour represents a negative value and the red colour represents the maximum value.

Table 1: Measurement of mean error distance from the global registration and part comparison analysis of the mandible representing the post mortem case with the other 10 mandibles representing ante mortem.

Registered mandible	Error distance in mm	Median in mm	Mean in mm	SD in mm
PM 1 with AM 1	0.00	0.00	0.00	0.00
PM 1 with AM 2	0.18	0.15	1.09	2.31
PM 1 with AM 3	0.17	0.15	0.01	0.7
PM 1 with AM 4	0.17	0.14	0.56	1.34
PM 1 with AM 5	0.13	0.43	0.99	1.73
PM 1 with AM 6	0.17	0.53	1.84	2.75
PM 1 with AM 7	0.17	0.45	1.99	3.1
PM 1 with AM 8	0.18	0.44	1.36	2.27
PM 1 with AM 9	0.17	0.31	1.31	2.33
PM 1 with AM 10	0.17	0.53	1.26	2.13

PM: Post mortem; AM: Ante mortem

For Mandible A (Fig.5) a colour-coded 3D model is presented together with the histogram of the deviations from the identical AM and PM mandible. The 3D colour coded model, depicting the buccal and lingual sides of the mandible, together with the histogram following part comparison analysis of the same mandible scanned with two different machines, demonstrates a single green colour code; the green colour code represents a 100% match.

For Mandible B (Fig.5) a colour-coded 3D model is presented compiled from both AM and PM data. The 3D colour coded model, depicting the buccal and lingual sides of the mandible, together with a histogram following part comparison analysis of the two different mandibles demonstrated a minimal amount of error distance and showed a wide area of matching green colour. There were limited unmatched area coloured red. The histogram ranges from -2.71 mm to 3.03 mm .

For Mandible C In (Fig.5) a colour-coded 3D model is presented compiled from both AM and PM data. The 3D colour coded model, depicting the buccal and lingual sides of the mandible, together with a histogram following part comparison analysis of two different mandibles with maximal amount of error distance demonstrated a wide area of unmatched colour. There were wide areas of red colour and limited areas of green color. The histogram ranges from -2.24 mm to 14.11mm.

DISCUSSION

The mandible is one of the strongest bone in human face and the best preserved after death. It can be of assistance for purposes of personal identification. The present study evaluated the anatomical variability of the mandibular neurovascular canals in the midline symphyseal region and sought to establish whether this feature could act as a forensic fingerprint.

This study showed the differences in shape and direction of the lingual canals on CBCT images (Fig.6). Observers were able to identify the matched mandibles according to the specific anatomy of these lingual canals (shape, direction, and angulations).

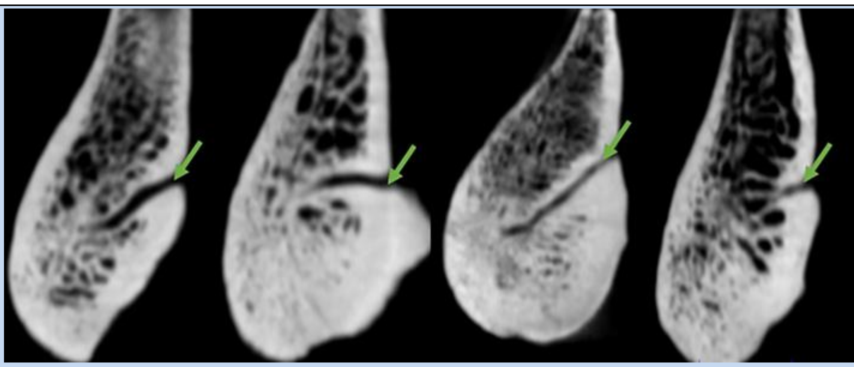

Fig. 6: Cross sectional view of different mandibles showing multiple shapes and directions of the lingual canals.

The observation study on the dry in-vitro mandibles showed a high agreement between the observers to distinguish the matched mandibles presented on the PowerPoint slides depicting cross-sectional images at the midline area containing the lingual canals. One observer achieved a success rate of 100% to match mandibles correctly. The other observers had difficulties in matching one of the mandibles. It was noticed that the same mandible was always wrongly classified and thus difficult to match. The reason for this might be the fact that this mandible showed less distinct and developed canal structures.

The high level of agreement noted between the observers to identify the lingual canals in each mandible was important; it “flagged up” the potential of the lingual canals as an aid to identification by comparison of ante-mortem and post-mortem CBCT data. Liang et al.,[25] described the anterior region of the mandible and its lingual side and showed that there was a difference in number of the lingual foramina.

The existence of the midline lingual foramina with neurovascular bundles was confirmed by a comparative study of histological findings and high-resolution magnetic resonance imaging.[26] The observation study on the patient CBCT data demonstrated that two views of the same mandible could be matched by careful consideration to the lingual canals. A success rate of 96 % was achieved.

The registration of the mandible representing the ante-mortem case with the identical mandible scanned with another CBCT system representing the post-mortem case showed a perfect fit and overlap in the midline neurovascular canals. The mean error distance obtained with global registration was 0mm implying a perfect (100%) fit between AM and PM data of the same mandible.

The registration of different mandibles representing ante-mortem cases and post-mortem cases did not demonstrate an overlap of 100%. The distance error ranged from 0.13 mm to 0.18 mm.

It can be concluded that every mandible has a specific anatomical structure at the midline including the lingual foramen and the neurovascular bundles. Against this background it is proposed that the symphyseal region with its neurovascular canals can be used for differentiation and identification of human mandibles. Further studies using larger samples should be considered.

CONCLUSIONS

There is variability demonstrated within the morphology of the human mandibular midline neurovascular canals. This could be a useful aid in cases of human identification.

There is a distinct contrast between the almost perfect success rate achieved in matching corresponding ante-mortem and post-mortem data compared with the significant deviations noted in the success rate to match different ante-mortem and post-mortem data.

Against this background the mandibular midline neurovascular canals could be of assistance in forensic dentistry in the same way that fingerprints are recognised as being a unique identifying feature.

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