



## Original communication

## Human identification through frontal sinus 3D superimposition: Pilot study with Cone Beam Computer Tomography



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## ABSTRACT

As a unique anatomical feature of the human body, the frontal sinus morphology has been used for identification of unknown bodies with many techniques, mostly using 2D postero-anterior X-rays. With the increase of the use of Cone-Beam Computer Tomography (CBCT), the availability of this exam as antemortem records should be considered. The purpose of this study is to establish a new technique for frontal sinus identification through direct superimposition of 3D volumetric models obtained from CBCT exam, by testing two distinct situations. First, a reproducibility test, where two observers independently rendered models of frontal sinus from a sample 20 CBCT exams and identified them on each other's list. In the second situation, one observer tested the protocol and established on different exams of three individual. Using the open source DICOM viewer InVesalius<sup>®</sup> for rendering, Mesh Lab<sup>®</sup>, for positioning the models and CloudCompare for volumetric comparison, both observers matched cases with 100% accuracy and the level of coincidence in a identification situation. The uniqueness of the frontal sinus topography is remarkable and through the described technique, can be used in forensic as an identification method whenever both the sinus structure and antemortem computer tomography is available.

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## 1. Introduction

Individual variation in biological structures forms the premise for human identification. Since maxillofacial radiography has become more routine for clinical purposes, there now exist various forms of antemortem records available for forensic comparisons.<sup>1</sup> Even though the philosophical idea of uniqueness in humans is controversial,<sup>2</sup> an anatomical match is unlikely and therefore reliable for human identification.<sup>3–6</sup>

INTERPOL considered the identification by the analysis of teeth as one of their primary methods through a comparative radiographic human identification,<sup>7</sup> along with DNA and Fingerprint comparison. Due to intensive preventive dental care, nowadays it is

not unusual to have patients with few or total absence of dental restorations, thus impairing the identification through traditional forensic odontology methods, which increases the importance of individual anatomical features for identification.<sup>1,8,9</sup> Recently, the use of Computed Tomography (CT) added volumetric records to patient files, but when concerning teeth superimposition, additional difficulties are encountered due to possible distortion and artifacts caused by metallic restorations.<sup>10</sup>

Many anthropology studies are performed with radiographs of the human skull,<sup>11</sup> and the structure of the frontal sinus is well reported to be a reliable evidence, if necessary, for comparative identification of unknown bodies.<sup>1,3–5,12,13</sup> It is completely formed by the age of 20 years old<sup>4,5,14,15</sup> and its individual formation is even observed in monozygotic twins,<sup>14</sup> with low rates of bilateral absences encountered in the population.<sup>13–15</sup> These findings stimulated the development of many identification methods through frontal sinus comparison, using conventional radiographs and computed tomography imaging, even though some researchers claim a lack of standards for visual outline comparison.<sup>3</sup>

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Identifying a person through the frontal sinus morphology is a task that requires a certain level of expertise and careful analysis.<sup>1,13,16</sup> Antemortem (AM) and postmortem (PM) radiographs can present minor variations in head-position that may alter the radiographic images, thus adding difficulty to the process of comparison.<sup>5,14,16</sup>

Most of the developed scientific methods studied the outline of the sinus in anterior-posterior (PA) radiographs, as it enables a complete view of the frontal sinus' bony structure. Through manual superimposition of exams, graphical reproduction of the sinus<sup>13,14</sup> or computer-assisted approaches,<sup>12,15,16</sup> many techniques simply superimpose the contour of a sinus in order to achieve a satisfactory match and qualitative analysis. The introduction of linear<sup>13</sup> and angular<sup>14</sup> measures provides additional information, thus increasing the quality of the sinus comparison and enhancing the forensic as reported by Ribero (2000).<sup>13</sup> Other techniques assessed the variability of the human frontal sinus outline through a quantitative analysis of the similarity.<sup>17</sup> Yet all radiograph-based analyses are dependent on images of the same size and angulation to be possible.

In the last decades, Computed Tomography (CT) gained importance in the forensic field, specially through the studies of groups such as the Virtopsy.<sup>18–20</sup> Both Spiral CT and Cone-Beam Computed Tomography (CBCT) can also be used in methods such as forensic radiology and Frontal Sinus analysis,<sup>21,22</sup> and, due to the difficulty of reproduction of an AM radiographic exposure in radiology, CT images may provide accuracy since the head orientation is not as critical as in conventional radiographs, including for linear or morphology studies.<sup>23–26</sup> Furthermore, its use for many dental diagnosis criteria is increasing its availability as an AM record.<sup>27</sup>

For a three-dimensional (3D) analysis, Kim et al. (2013)<sup>4</sup> proposed a series of classifications for frontal sinus 3D digital models, reconstructed from Multidetector computed tomography of 119 cadavers. The study suggested a metric analysis whereby volume, width, depth and height are recorded, in association with non-metric, qualitative classification and according to the presence of the sinus and its shape in frontal, upper, lateral and cross-sectional views.

This study is a pilot test with the purpose to establish a detailed method, using only open-source software, to produce a color-map analysis that could aid human identification through a three-dimensional (3D) superimposition of frontal sinus surfaces exported from Cone Beam Computed Tomography (CBCT) exams.

## 2. Material and methods

A sequence of steps is necessary to correctly generate 3D surfaces from CBCT exams, align antemortem and postmortem models and finally access the level of coincidence between structures by a qualitative color-map approach.

The study was divided into two distinct phases: A randomized, blinded and two-observer reproducibility test with 20 CT exams, and a three-case pilot study, where the method was used for human identification through the comparison of frontal sinus 3D models obtained from different exams with an average one-year interval.

Before one can compare any 3D objects, there are some preparatory procedures that should be followed. Here we describe open-source software to perform:

1. Acquisition and reconstruction of tomography image files;
2. Selection of the region of interest from the Frontal Sinus space and generation of 3D surfaces;
3. Alignment of antemortem and postmortem surfaces;
4. Cloud comparison.

### 2.1. Sample selection and CT exams

The researchers were granted access to a private database of CBCT exams. The required authorizations were obtained and stored, and the use of the database was authorized to perform this pilot study by the ethics council of the University of São Paulo Dental School.

As a study based on database analysis, no patient was exposed to radiation for the purpose of this research. Therefore, there was no risk to any subject or researchers. A total of 23 exams were selected from the database with ages between 20 and 35 years. Selection occurred accordingly to an inclusion criteria where the quality of the exam, absence of surgical history in the maxillo-facial complex or fractures in the frontal sinus region were necessary features.

The selected clinical exams had a similar protocol of acquisition with two captures in a total field of view of 20 cm high and 16 cm wide and with a 120 kVp and 36.90 mAs set to a 40-second exposure. Images were reconstructed with a 0.4 voxel size, and both captures were merged together in the tomography's software so that each image file represented the full facial portion. Images were also exported in Digital Imaging Communication in Medicine (DICOM) files.

### 2.2. Surface creation

The CT images were imported into InVesalius<sup>®</sup>, an open-source DICOM viewer software (Technology and information center-Renato Archer - CTI, available for download at [http://www.cti.gov.br/invesalius/?page\\_id=8](http://www.cti.gov.br/invesalius/?page_id=8)). Its main purpose is the construction of 3D surfaces from CT regions of interest.

The surfaces were selected using the software's threshold brush tool, which segmented and created a region of interest (ROI) that should comprehend the air space within the frontal bone from its highest portions to the frontal-nasal suture (Fig. 1). For the sinus segmentation, the threshold interval was set between a minimum value of approximately –1000 and a maximum of –400 for optimal results.

After the selection of the desired ROI, a volume can be generated by pressing the “save surface” button and then exported as a Stereolithography (STL) file.

### 2.3. Alignment and visual comparison

The STL files were imported into the second open-source software: MeshLab (Visual Computing Lab- ISTI CNR, available for download at <http://meshlab.sourceforge.net>).

With this software, the alignment tool and its “point-based alignment” were used by selecting four possible points on each model<sup>28,29</sup>: the first at the most lateral point of the patient's right side; the second at the highest point of the right side; the third at the highest point of the left side; and the fourth at the most lateral point of the left side, adapted from Ribeiro's method.<sup>13</sup> This provides a rough alignment, and as both models are superimposed, the “process” tool should be used for fine superimposition. This feature is an ICP (iterated closed point) algorithm, which is capable of enhancing superimposition by finding corresponding points on both models to allow for a refined alignment reposition.

Once positioned, visual comparison of the coincidence of anatomical structures is possible (Fig. 2). The antemortem surface is always set as the reference as the postmortem model is repositioned on top of it. The postmortem surface must be frozen and exported as a new file, which will keep the achieved alignment.

### 2.4. Cloud comparison

In the CloudCompare software (Available at <http://www.danielgm.net/cc>), one must import mesh models that are already

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