Post-mortem cross-sectional slicing of the frontal sinuses and comparison with AM anatomical imagens – A case report

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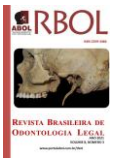

Forensic dentistry

POSTMORTEM CROSS-SECTIONAL SLICING OF THE FRONTAL SINUSES AND COMPARISON WITH ANTEMORTEM ANATOMICAL IMAGENS – A TECHNICAL DESCRIPTION.

Secção transversal postmortem dos seios frontais e comparação com imagens antemortem – descrição de técnica.

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ABSTRACT
The anatomical features of the frontal sinuses (FS) are known as highly distinctive and potentially useful for human identification. Assessing these structures with advanced postmortem (PM) imaging, however, is not always feasible in medicolegal units worldwide. This study proposes and validates the anatomical assessment of the FS via cross-sectional slicing of the frontal bone to reproduce images comparable to antemortem (AM) axial views. The bodies of two unknown sisters with advanced decay (decomposition stage III.1) were referred for human identification. The AM data provided for comparative analysis consisted of multi-slice computed tomography (CT) and magnetic resonance images of the skull. In the lack of primary alternatives for human identification, PM assessment of the FS was considered. Justified by the mortuary facilities there were not equipped with CT devices, sequential cross-sectional slicing of the frontal bone was performed. With the skulls in supine position, the technique followed Griesinger's anteroposterior plane using an oscillating saw blade at 90^0. Multiple slices (n = 20) of the frontal bone were obtained in craniocaudal direction up to the superior limit of the orbits. The outline of the FS, as well the number of lobes and position of the intersinus septum were visible and compatible with the AM data, enabling positive identification. External validation of the proposed technique was accomplished by reproducing it to successfully identify a male victim in a medicolegal institute 2,000 KM far from the original site.

KEYWORDS
Anatomy; Forensic dentistry; Forensic medicine; Frontal sinus; Human identification.

INTRODUCTION

The analyses of friction ridges, dental features, genetic profiles and even batch numbers from medical appliances are often referred to as the primary means for human identification in mass disasters[1-3]. From the perspective of human identification, mass disasters consist of unexpected events that exceed the normal logistics of forensic units[4]. To enhance technical procedures and reports, the primary means for human identification are also used in single cases or in other circumstances that do not necessarily figure as mass disasters[5]. Striving for the less expensive and fastest reliable responses in human identification, some jurisdictions follow a sequence from friction ridge analysis (usually using fingerprints) to dental analysis (comparative with clinical dental records), and to genetic analysis (mostly from DNA)[6].

The scientific literature has reported situations of major complexity for human identification, such as cases that involve charred, skeletonized, and mutilated bodies[7]. All these situations hamper the analysis of friction ridges from soft tissue[8]. However, there are cases with even more distinctive complexity, because not only friction ridges are missing, but also dental features – e.g. in case of patients with no history of dental treatment or clinical records[9]. Genetics may sound as the final undisputable option, but limitations exist even for this technological approach. Cases that involve twin- or sibling-victims may be challenging, especially if cadaveric alterations are advanced and parental genetic samples are limited[10]. Experts' anthropological analyses on the human body may reveal alternative sources and potential solutions for such complex situations[11].

Forensic cases from the scientific literature reported the use of frontal sinuses for human identification[12-15]. It is estimated that the inherent anatomy of these structures may be highly distinctive based on their outline (shape) and volume (size)[16,17]. More specifically, Prossinger (2008)[18] affirms that the *"morphology, volumes, outlines, and cross-sectional areas"* of the frontal sinuses have a higher variation compared to all the other paranasal sinuses. The antemortem (AM) evidence of frontal sinuses usually provided for human identification consist of bi- (2D)[19] or three-dimensional (3D) images of the skull[20]. Examples include posteroanterior radiographs[19] and computed tomography images[20], respectively. While on one hand these anatomical resources are mostly auxiliary in human identification, on the other hand they may be decisive to distinguish between victims in complex and uncommon cases.

An existing gap that hampers a direct translation from theory to practice, however, remains on the facilities required to produce PM imaging that may be expensive for medicolegal institutes in developing countries. This issue was raised before in the scientific literature[21] to corroborate the need for the development of alternative tools for those practicing without state-of-the-art devices. Accordingly, the present study aimed to propose a necroscopic technique for the

assessment of the frontal sinuses via multiple and sequential cross-sectional slicing of the frontal bone. This technique attempts the production of PM images that are comparable to axial CT scans of the frontal sinuses. External validation is presented along this study to test and confirm the application of the proposed technique in a different medicolegal institute and forensic routine.

MATERIAL AND METHODS

The cadaveric specimen

This study was carried out in a medicolegal institute of Central Brazil, in 2019. In this institute the protocol for human identification includes a sequential assessment of the fingerprints, dental features, and genetic profiles – according to the recommendation in international standards[1]. Alternatively, case-specific adaptations are accepted depending on the reliability of the presented evidence. The timely development of the present technique came from the official request of the Judiciary towards the identification of an unknown body found in a remote scrub area. The body was referred to the State medicolegal institute for investigations on the cause of death and human identification.

The medicolegal autopsy was performed by a forensic pathologist with 19 years of experience in practice. Under macroscopic examination, it was possible to observe the external genitalia of a male. Decomposition with advanced decay[22] was observed. The facial soft tissues (and traits) of the victim were not preserved, as well as the fingertips. The body was reduced to skeletal remains after physicochemical cleaning of the putrefied tissues. The analysis of the skeleton revealed led to an estimated age of 40 years (based on skull sutures and lumbar vertebrae). Additionally, healed fracture lines on the parietal bones extending up to the right squamous suture were detected. Despite the evidence of previously healed trauma, the cause of death was inconclusive given the lack of directly related traces. According to experts in forensic entomology, the body was found within an estimated interval of one month after death.

AM data collection

Police investigations in recent archives (6 weeks back in time) found records of a male reported missing by his sister. According to the reports, the man was run over by a car in 2014 and suffered from seizures since then. When requested for medical records that could help the identification process, the alleged sister provided a posteroanterior radiograph of the skull and set of 15 printed multi-slice computed tomography scans of the skull (Figure 1). There were no digital copies. The images dated back to 2014, when the victim was treated in a hospital, after the accident. History of dental treatment was null and dental data unavailable. Personal smile photographs of the alleged victim were not provided. The evidentiary value of the AM radiograph and CT scans was considered appropriate for a PM assessment of the frontal sinuses aiming an anatomical comparative analysis for human identification.

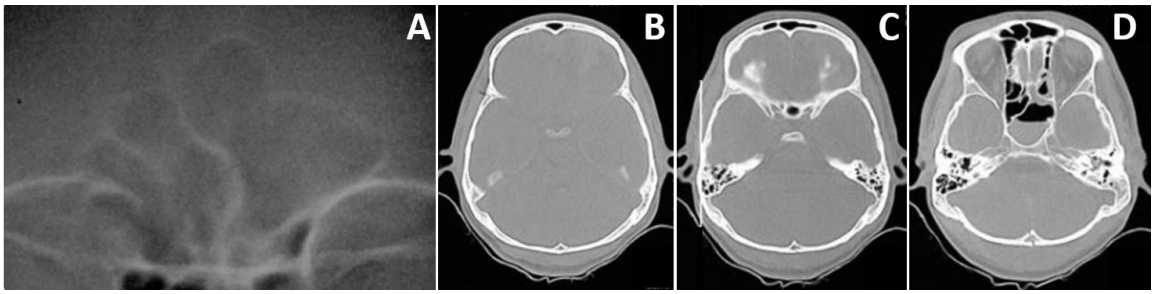

Figure 1 – Antemortem data of the case originally used to illustrate the sequential cross-sectional slicing technique. A posteroanterior radiograph of the skull showing the frontal sinuses was provided (A), as well as a set of 15 printed multi-slice computed tomography scans with axial views of the frontal sinuses (three samples provided in B, C and D).

PM data collection

The PM data collection attempted a reproduction of the data obtained AM. However, the lack of PMCT equipment led to a manual sequential cross-sectional slicing of the skull. On an autopsy table and using a head positioner, the skull was placed in anatomic (supine) position. Forensic pathologist and autopsy technician proceeded with the sequential slicing using an oscillating autopsy saw version HB 740 (KUGEL medical GmbH & Co. KG™, Regensburg, Germany) with a HB 50 round blade 50 mm mounted (KUGEL medical GmbH & Co. KG™, Regensburg, Germany). The blade was positioned 90^0 to the floor, following Griesinger's anteroposterior plane to open the cranial cavity.

To set the initial slice, the AM posteroanterior radiograph of the skull was used as reference – so the upper limit of the frontal sinuses could be estimated. From the upper limit, multiple slices (n = 20) of the frontal bone were obtained in craniocaudal direction, towards the superior limit of the orbits. Millimetric markings on the frontal bone guided the slicing process. After each slice, photographs were taken from the superior view of the frontal sinuses to simulate a CT axial view for further AM/PM comparison (Figure 2). Since the AM data lacked information about the image acquisition protocol, the PM sequential cross-sectional slice thickness was set arbitrarily at 3mm. From each photograph, the anatomical limits (outline) of the frontal sinuses, the number of lobes, the position of the intersinus septum, and the existing intrasinus septa were assessed.

External validation

An external validation was planned through the application and reproducibility of the technique in an external medicolegal institute located 2.000 Km far from the original center. The target institute is located in the Brazilian Amazon region and was chosen because of the lack of 3D PM imaging, such as CT, for human identification in their forensic routine. In practice, the technique was presented to the target validation experts, so they could be trained and prepared for future suitable cases.

Figure 2 – Sequential cross-sectional slices (1-16) of the frontal bone revealing the frontal sinuses in craniocaudal direction. The technique was performed after reducing the decomposed body with advanced decay to skeletal remains. Sequential cross-sectional slicing performed to simulate a comparable scenario with the antemortem multi-slice computed tomography scans in axial view.

In 2020, eligible cases occurred for external validation. Two sisters were found dead in their house. Poisoning was suspected. Medicolegal investigations registered cadaveric decomposition with active decay[22]. Initially, ridgeology was attempted via fingerprint analysis, but the comparisons were not feasible given soft tissue destruction. Dental records were not available (both from dental offices and personal smile photographs). The police unit was informed that the sisters did not have living parents or descendants, except a niece that provided genetic material for comparisons. DNA tests confirmed the association between the victims and their alleged niece, but the individualization of the sisters was not possible. Medical images of the sisters were provided by the niece and consisted of hardcopies of computed tomography scans and magnetic resonance imaging of the skull. A summary of the victims and the rationale that justified the sequential cross-sectional slicing technique are presented in Table 1.

Table 1 – Cadaveric characteristics of the victims and AM data provided for identification.

Victim	Body status	Fingerprint	Odontology	Genetics	AM data
A	Decomposition (active decay)	Not feasible (destruction)	Not feasible Edentulous No AM records	Feasible (niece sampled) Parental association: + Individualization: -	Multis-slice CT scans of the skull (axial view), 2015
B	Decomposition (active decay)	Not feasible (destruction)	Not feasible Identifiers detected No AM records	Feasible (niece sampled) Parental association: + Individualization: -	MRI skull (axial view), 2018

+: feasible; -: not feasible; AM: antemortem; CT: computed tomography; MRI: magnetic resonance imaging.

For comparative purposes, posteroanterior radiographs of the sisters were obtained (to enable positional referencing) (Figure 3) and the sequential cross-sectional slicing technique was applied, following the approach proposed in this study.

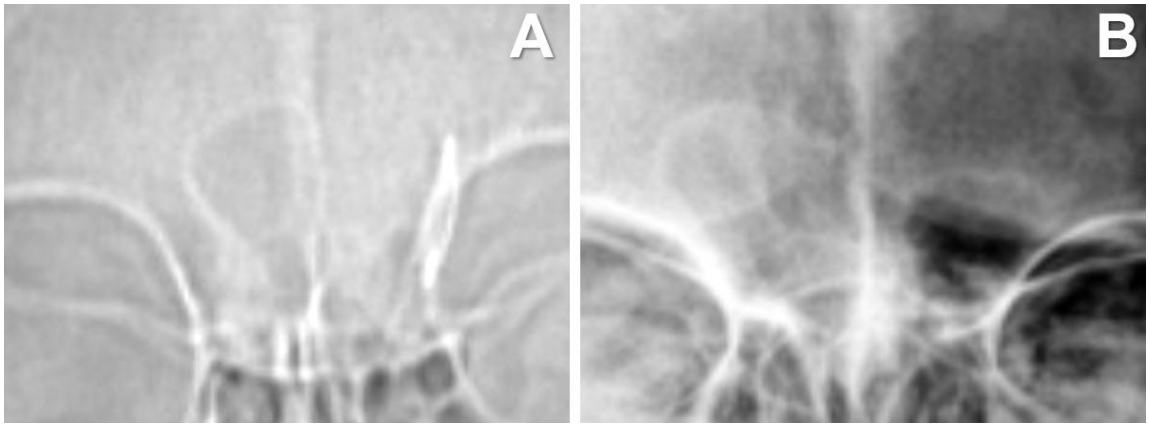

Figure 3 – Postmortem anteroposterior radiographs of the skulls of the two females victims taken to enable an overview of the anatomical features of the frontal sinuses and to guide the orientation of the sequential cross-sectional slicing.

RESULTS

Data reconciliation: proposed technique

The sequential cross-sectional slices performed PM in the male victim that illustrated the proposed technique revealed anatomical features of the frontal bone and sinuses that were fully compatible with the anatomical features observed via multi-slice AMCT. In specific, the morphological outline of the sinuses, their anteroposterior and lateral expansion, the number of lobes and septa and the thickness of the adjacent cortical bone were included among the similarities found AM/PM (Figure 4). Particular findings of interest in this case were the “c-shaped” intersinus septum with a concavity to the left side and convexity to the right side; the singular unified cavity of the right frontal sinus; and the bilobular left sinus that started with a smaller area in cross-sectional view to a larges partially sectioned area (bilobular) as the slicing progressed towards the inferior limit of the bone. The similarities between sequential cross-sectional slices and the multi-slice computed tomography led to the

identification of the victim with a novel technical approach.

Data reconciliation: external validation

Victim A: The initial assessment of the frontal sinuses of victim A revealed an evident asymmetry between left and right sinuses (PM posteroanterior radiograph of the skull). Following Guerram's classification[23], the frontal sinuses of victim A ranged between hypoplastic and medium size. The lateral positioning of the frontal sinuses in relation to the frontal crest (inner surface of the frontal bone) was asymmetric with a predominance of the cavity towards the right side. Moreover, in the right limit of the frontal bone a small and round air cell was visible. All the described anatomical features detected AM were confirmed PM (Figure 5).

Victim B: Differently from victim A, the frontal sinuses of victim B were more balanced based on size between left and right cavities. Both sinuses extended over the medial border of the orbits and were classified as medium size.[23] In the cross-sectional (PM) and axial (AM) views, the sinuses were centralized in relation to the frontal crest. Again, the anatomical features were compatible between AM and PM data, enabling the individualization (distinguishing siblings) of the sisters and their respective identification (Figure 6).

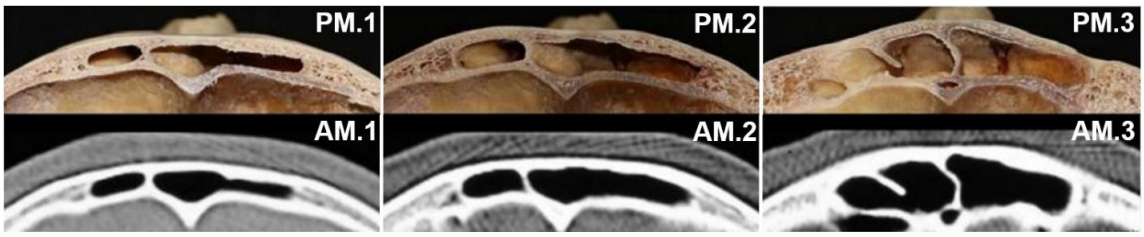

Figure 4 – Postmortem (PM) photographs of the sequential cross-sectional slicing of the frontal bone, showing the progressive increase (PM.1-PM.3) of frontal sinuses' cavities from the superior to inferior direction. Distinctive anatomical features are observed, namely the laterally expanded right cavity compared to the small and oval left cavity (PM.1 and PM.2). The "c-shaped" intersinus septum with a convexity towards the right side is evident, as well as the septum that partially divides the left frontal sinus in two lobes, while the right sinus consists of a single unified cavity (PM.3). The highlighted characteristics are found within the antemortem images (AM.1-AM.3).

DISCUSSION

Non-twin siblings share about 50% of their genes[24]. From a biological perspective, the genetic profile of siblings could be distinctive enough for individualization. In practice, however, case-specific circumstances could restrict comparative procedures between the siblings' DNA and databases or alleged parental sources. The present study proposed alternative anthropological solution for the assessment of the frontal sinuses after sequential cross-sectional slicing of the frontal bone. The technique was validated after practical application to distinguish two siblings for human identification. The technique proved to be useful when primary means[1] are unfeasible one-by-one because of case-specific circumstances.

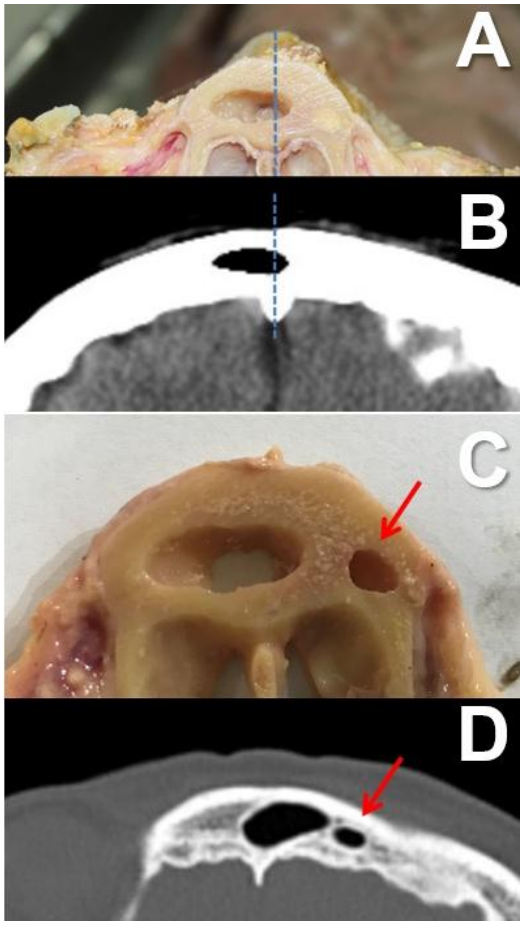

Figure 5 - Cross-sectional (A and C) and axial (B and D) views of the frontal sinuses of victim A (external validation).

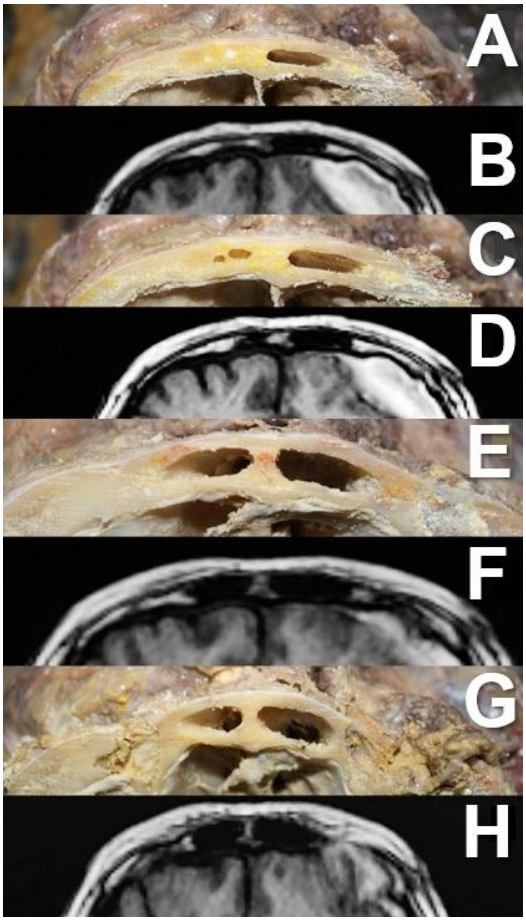

Figure 6 - Cross-sectional (A, C, E, G) and axial (B, D, G, H) views of the frontal sinuses of victim B (external validation).

Decomposition is a cadaveric alteration that affects the first line of identification means, namely the fingerprint analysis. Remarkable cases in the recent history of forensic sciences corroborated the fact that anthropological analyses may lead to human identification accelerating the reconciliation process in mass disasters. On August 25th 2021, the 261th victim of Brumadinho's (Brazil) water dam collapse was identified after 2 years and 7 months of investigations. The forensic taskforce in the mass disaster included protocols adapted from INTERPOL[1] that allowed human identification from anthropological examination. The frontal sinuses figure as sources of distinctive anatomical structures that may aid on identification, but advanced PM imaging units remain scarce for most developing countries.

Silva et al. (2019)[21] proposed a low-cost technique to the radiographic assessment of the frontal sinuses, in which they used an intraoral radiographic device installed in the mortuary and occlusal films to register the frontal sinuses. The authors claim that the technique is suitable for less developed centers and confirm the applicability of the technique with case reports. Similarly, the present study follows the same trend to produce and develop

tools that can best-fit forensic needs. However, it must be noted in this study, that the proposed technique is destructive and requires case-specific conditions that justify such alternative approach. Examples of conditional circumstances are: 1) bodies should be decomposed at least in stage 3 (decay, active or advanced)[22] with no recognizable facial traits; 2) human identification via all the primary means (ridgeology, odontology, genetics and batch numbers) was unfeasible; 3) experts are aware of the technique and were previously trained; 4) sequential cross-sectional slicing was preferably performed guided by a preliminary anteroposterior radiograph of the skull (whenever feasible); and 5) AM data has enough evidentiary value (quality and quantity) to justify the sequential cross-sectional slicing.

The cadaveric alteration in common throughout the three victims that illustrated the present study was decomposition. This is a destructive, multifactorial, multilevel and progressive alteration of the human body[25] that potentially affects ridgeology. Fingerprint analysis is well-developed and fits amongst the preferred methods for identification in Brazil[26] – country in which the cases are described, but a next step towards dental identification was justified by the lack of soft tissue. Despite the history of dental extraction in victim A and the teeth and dental treatments of victim B, the dentists responsible for the siblings were not found, as well as the clinical records. The restricted access to relatives (only a niece available) also restricted the search for personal smile photographs. Consequently, DNA was used as final resource among the primary means for human identification. Once more, the case-specific characteristics of this case emerged to limit the potential of genetics tests, as parental association was possible with the niece, while victim individualization was not feasible – and this is the point where the invasive assessment of the frontal sinuses emerged and the last resort.

Ideally, the postmortem data should reproduce as close as possible the antemortem data.[19] In other words, if computed tomography scans of the skull are presented as medical antemortem data, the same imaging modality should be used postmortem[20]. Using different tools to register anatomical structures AM and PM does not necessarily transform the identification process in a comparison of apples and oranges, but discrepancies may result. In fact, discrepancies may result even from the use of the same imaging tools AM and PM, however, these are considered explainable discrepancies and can be justified based on image acquisition. In a previous study[27], authors demonstrated the impact of positive and negative angulation on frontal sinus images in posteroanterior radiographs of the skull. According to their study, angular variations up to 10^0 would be enough to impede any metric analysis of the frontal sinuses. Despite the consolidated usefulness of the metric analysis of the frontal sinuses in the clinical and forensic fields[28], this study relied on a qualitative assessment of sinus morphology to overcome the limitations of comparing two distinct image modalities – advanced imaging *vs.* photographs of the sequential cross-sectional slicing of the

frontal bone. The outcomes of the comparative analyses performed in this study confirm the similarities between antemortem and postmortem images of each of the three victims and reveal morphological features that were distinctive enough to enable the individualization and identification of siblings in an external validation phase.

CONCLUSION

The proposed technique presented in this study illustrates, with unusual casuistic, the value of frontal sinus morphology when primary means for human identification (i.e. ridgeology, odontology and genetics) are limited and advanced PM imaging is not available. The sequential cross-sectional slicing of the skull figured as an effective last resort to challenging human identification cases restricted by conditional circumstances. The technique must be performed by experts aware of human anatomy and following the five conditional circumstances discussed in this study.

RESUMO

As características anatômicas dos seios frontais (FS) são consideradas distintivas e potencialmente uteis para a identificação humana. A análise imaginológica postmortem (PM) destas estruturas, contudo, não sempre é viável. O presente trabalho tem como objetivo a apresentação e validação de uma proposta de análise anatômica dos seios frontais utilizando a secção do osso frontal a fim de se permitir comparações com imagens axiais antemortem (AM). A corpo de um indivíduo do sexo masculino, não identificado, e em avançado estado de decomposição (estágio III.1) foi encaminhado para identificação. Os dados AM providenciados para análise comparativa consistiram em imagens de tomografia computadorizada (CT) multi-slice e ressonância magnética do crânio. Na falta de alternativas primárias para identificação humana, a análise dos seios frontais (SF). Pelo fato de que o instituto médico-legal era desprovido de unidades de Imaginologia avançada, cortes sequenciais do seio frontal foram realizados. Com os crânios em posição supina, a técnica foi conduzida seguindo o plano anteroposterior de Griesinger's com uma serra oscilatória em 90^0. Secções múltiplas (n = 20) do osso frontal foram obtidas no sentido craniocaudal até o limite superior das orbitas. A anatomia dos SF, assim como o número de lobos e a posição do septo intersinual eram visíveis e compatíveis com os dados AM, viabilizando a identificação positiva. A validação externa da técnica proposta se deu durante a identificação de uma vítima do sexo masculino periciada em um instituto médico-legal 2.000Km distante do centro originalmente relatado no presente estudo.

PALAVRAS-CHAVE

Anatomia; Odontologia Legal; Medicina Legal; Seio frontal; Identificação humana.

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