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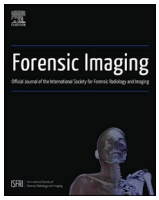

Cranial surgical approaches in the 21st Century Identified Skeletal Collection

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ABSTRACT

In Forensic Anthropology, identification is comparing information from a person whose fate and whereabouts are unknown with data from a person who is present but whose identity is unknown. The rarer and more distinctive the characteristics observed during the anthropological investigation, the greater the probability of reaching an identification. Taking this into account, cranial surgeries can be considered good individualization factors. The cases of skulls with lesions compatible with surgical procedures from the 21st Century Identified Skeletal Collection are presented, and their identification potential is discussed. This collection comprises 302 adult individuals, of which four females (aged 55 to 94 years) and four males (aged 67 to 92 years) present cranial lesions of surgical origin. The results of the macroscopic and imaging analyses (conventional x-rays and CTs) are presented, along with a detailed description and location of each lesion. In five cases there is clear evidence of bone remodelling. This research, which combines anthropological analysis with imaging and neurosurgical insights, demonstrates the importance of correctly interpreting these lesions, illustrating how important is a complete and interdisciplinary analysis for forensic expertise.

Introduction

The forensic anthropologist's work should begin upstream of the laboratory analysis. From the beginning, in a criminal investigation, alongside other experts, such as forensic archaeologists and police forces, the forensic anthropologist can participate in the location, excavation and recovery of human remains and contribute to understanding their context. The skills of these experts include, among others, taphonomic and trauma analyses, which contribute to reconstituting the scene, understanding the postmortem processes, and making a paramount contribution in determining the mechanism, the cause and the circumstances of death. Notwithstanding, of course, that identification, both of the living and the dead, is one of the main objectives of Forensic Anthropology expertise.

The identification process is necessarily comparative. That is, to identify is to compare the information of a person whose fate and whereabouts are unknown with the data of a person who is present, but whose identity is unknown [1–5]. In forensic anthropology expertise there are two major phases for identification: the reconstructive and the comparative. The first, where the characteristics of the unidentified person (body without identity) are inferred through a scientifically based analysis, and the second, where these data are compared with those of the missing person (identity without body). The first step in the reconstructive phase is to assess the biological profile (generic identity factors: sex, population affinities, age, and stature) which, by itself, does not allow an identification, only exclusions. Then, in the second step of the reconstructive phase, the individualizing factors are sought. With the most common Forensic Anthropology casework being decedents in various degrees of skeletonization, the individualizing characteristics of interest are skeletal variants of anatomical or pathological aetiology that

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constitute unique and exclusive conditions for each individual. These include the frontal sinuses, trabecular bone patterns, anatomical variants, developmental anomalies, pathological changes due to disease or antemortem trauma, and medical interventions [1,3,4,6].

The work of forensic anthropologists is not limited to forensic expertise, it must also involve multidisciplinary scientific research, encompassing a continuous search for new and better diagnostic methods. In addition to the study of real forensic cases already solved, forensic anthropologists often resort to identified osteological collections to develop new methods, test/validate the existing ones, and establish their accuracy [7]. In fact, the importance of this type of osteological collection has been internationally recognized for a long time [7–10].

The 21st Century Identified Skeletal Collection, housed in the Laboratory of Forensic Anthropology, Department of Life Sciences, University of Coimbra, embraces this long tradition of the assemblage of identified human skeletons for use in research and teaching, with the advantage of being a recent collection, whose individuals died, mostly, in the 21st century [9]. One of the benefits of resorting to recent collections for research in Forensic Anthropology is the availability of cases with current medical treatments. Thus, the experts can train in the identification of lesion patterns, both in bone and teeth, implants/prostheses, and surgical procedures of various types. Some information is known about the individuals of the 21st Century Identified Skeletal Collection, including the name (not available for all investigations due to it being sensitive information), age-at-death, sex, date of death, and year of exhumation. For some individuals, other information is known, such as cause of death, antemortem traumas, and pathologies, but these are limited to a minority. However, none of these individuals will be analysed within the scope of the present investigation.

This article will focus on the analysis of cranial surgical lesions. Head injuries of various aetiologies (e.g., infectious, circulatory, traumatic, oncological) may be at the origin of surgical procedures that require the opening of the skull. Since every surgery is unique, its potential for identification requires further research. In any scenario, to make an appropriate diagnosis, the anthropologist must know the characteristics of this type of intervention. This becomes a pressing issue, considering that the discovery of skulls with this type of evidence is not rare, either in archaeological or forensic contexts. Cranial surgery (irrespective of its motivations, beliefs, or treatments) is not a modern procedure but rather has a long history that dates back to the distant past. In fact, references to cranial surgery are abundant in archaeological literature. For example, in the Portuguese context, considering the current national territory, the first case of probable trepanation was identified in the Moita do Sebastião shell midden (Muge shell midden complex, on the Tagus River), dating back to the Mesolithic period [14]. Already in the Late Neolithic, several cases were identified in different regions of the territory, and many of these cases were associated with blunt trauma [15,16]. Outside of Portugal, there are records of these procedures in different regions and at different times, namely in classical antiquity. The history of these interventions on the skull is outside the scope of this paper, for a more comprehensive knowledge of the history of cranial surgery the reader can consult (among others) [11,17–24].

The present research article aims to explore the eight cases of skulls with lesions compatible with surgical procedures from the 21st Century Identified Skeletal Collection and discuss its potential for identification in Forensic Anthropology casework.

Sample and methods

The creation of the 21st Century Identified Skeletal Collection began in 2009 and, currently, comprises 302 individuals of Portuguese nationality, who died between 1982 and 2012, and were exhumed between 1999 and 2016 [9,12]. Female individuals comprise more than half of the collection (162; 53.64%), with ages ranging from 28 to 101 years old (mean: 81.22 y.o.; S.D.: 12.85). There are 140 males (46.36%) aged between 25 and 96 years old (mean: 73.29 y.o.; S.D.: 15.60). It is important to highlight that this collection consists mostly of elderly individuals (87.75% are older than 60 years old), which mimics the current demographic profile of the Portuguese population deaths. Research in this collection has a positive legal appraisal from the Ethics Committee of the Faculty of Medicine of the University of Coimbra (CE_026.2016). It is also noteworthy, that due to the Portuguese data protection law, the medical data of these individuals cannot be accessed for the purposes of this investigation, thus no comparison between ante and postmortem data was made in this study [13]. These type of analyses are still relevant to better understand cranial lesions from an anthropological perspective, contributing a documented corpus of surgical descriptions of the lesions on dry bone. This allows for a more targeted, efficient and faster search for medical records in forensic cases.

The skulls of the 302 individuals, including those fragmented and/or poorly preserved, were analysed macroscopically (a magnifying glass was used whenever needed) to scrutinize for lesions compatible with surgical procedures: evidence of cuts, with or without remodelling, were searched on all cranial surfaces. Cutting marks compatible with an autopsy procedure were excluded from this study. Subsequently, the postcranial skeleton of the selected individuals was macroscopically analysed, and the respective skulls were subjected to imaging analysis. For the conventional radiology approach, a Philips Digital Diagnost equipment was used and orthogonal projections were made in the anteroposterior and lateral planes. In computed tomography, the volumetric acquisition was performed, with reconstruction in the axial plane and subsequent additional 2D and 3D multiplanar reformatting in Siemens Somatom Go All equipment. The skulls under study were positioned at the isocenter. In the CT exposure parameters, the Care Dose 4D systems (perform automatic tube-current modulation in the angular and longitudinal directions [mA]) were used, with 100KV, a minimum collimation of 0.6 mm, a rotation time of 0.8s, and a pitch of 0.5. Regarding the reconstruction, reformatting, and visualization parameters, we established an effective slice thickness of 1.0 mm in all planes (axial, coronal, and sagittal); the Field of View (FOV) limited to the area of interest; with an Hr60 kernel; a window with a level of 400 UH and a width of 4000 HU, thus allowing for proper differentiation of the studied bone tissue. A second reconstruction was performed with an effective thickness of 0.6mm, with 50% overlap, and an Hr36 kernel, aiming to carry out a 3D volume rendering.

Metric analyses of the lesions were made both macroscopic and through CTs.

The observations obtained by the two methodological approaches were compared and complemented. After this, a comparison was made between standard neurosurgical procedures and findings in the skulls in order to be able to list the most probable causes for the observed procedures. The macroscopic analysis was carried out by four of the authors, three anthropologists and an imaging specialist with training in biological anthropology. The image capture and processing was carried out by one of the authors who is a specialist in imaging with training in biological anthropology. The interpretation of the images was done jointly by all authors. The neurosurgical analysis was carried out by two of the authors who are neurosurgeons.

To facilitate the reading flow of this paper, here follows a brief explanation of some of the most common nomenclature in skull surgery: Craniotomy (the piece of bone that is removed from the skull during the procedure is put back in place after the surgery is complete) is distinguished from craniectomy (where the bony flap of the skull is not replaced immediately, allowing the brain to swell, thus reducing intracranial pressure) and from trepanation (the opening of one or more holes in the skull). For trepanning, a trephine is used (a surgical instrument with a cylindrical blade). Burr holes are small holes in the skull that can be used to relieve pressure to avoid compressing the brain tissue. It is also important to mention that trepanning is also known as trepanation, trephination, trephining or making a burr hole. In Bioarchaeology, the

term trepanation is generally used to describe any surgical procedure to the skull, regardless of the object used, the type of procedure and whether it occurred ante or postmortem.

Results

Four female (aged 55 to 94 years) and four male individuals (aged 67 to 92 years), who died between 1998 and 2010, present cranial lesions compatible with surgical procedures (please refer supplementary material). Table 1 presents the sex, age-at-death and year of death of the individuals, as well as the location of the lesions and whether or not they have signs of remodelling. The post-cranial skeletons were also analysed macroscopically and no lesions compatible with tumours or metastases, perimortem trauma, prostheses and/or other medical devices were found. A detailed description of the skull of each individual is presented next. In the supplementary material, photographs and CT-scan images in different planes can be consulted.

Individual CEI/XXI_88, female, 80 years old, year of death: 2001

Macroscopically, it is possible to observe a hole measuring about 42x51mm in the left portion of the occipital bone, with rounded edges and no porous lesions on the bone surfaces, i.e., completely remodelled. The lesion encompasses the occipito-mastoid junction to the midline and from the superior nuchal line next to the foramen magnum. CT analysis shows a left occipital craniectomy with a corticalized bony ridge. From what was observed through both approaches, there is no doubt that this woman survived the surgical procedure and lived for some years.

From a neurosurgery standpoint, it is most likely that this was an emergency surgery, which would justify the non-replacement of the bone plate removed during the craniotomy. The extension of the craniectomy suggests an approach to the cerebellar hemisphere or the treatment of extra-axial pathology of the left posterior hemifossa (such as a tumour, or a haemorrhage, among others). It is much less likely to be a cerebellopontine angle approach. There are no changes in the rest of the skull and skeleton that could give indications about the injury/pathology that motivated the intervention.

Individual CEI/XXI_99, female, 55 years old, year of death: 2001

In the skull of this individual are present two circular metallic devices (approximately 12mm in diameter), five orifices of different sizes with round borders (the largest measuring 13x13mm and the smaller measuring 12x18mm) and regions of bone depression, arranged in a circular fashion (with about 72x62mm) in the area of the left parietal and occipital bones. CT analysis corroborates these findings, a left parieto-occipital craniotomy with rounded margins and corticalization. Moreover, the bone was replaced by resorting to CranioFix®, still displaying two devices. There is no doubt that the edges of the lesion show bone remodelling, indicating an antemortem lesion.

Compared to the neurosurgical practice, the most likely cause for this procedure is a tumour, perhaps a meningioma. However, the hypothesis of a vascular lesion cannot be excluded. Once again, the analysis of the post-cranial skeleton did not contribute to a possible diagnosis. It should also be noted that this surgical technique continues to be employed in Portugal to this day.

Individual CEI/XXI_156, male, 67 years old, year of death: 1998

The skull of this individual shows a hole in the right posterior region of the frontal bone. This orifice is round (approximately 12 mm in diameter) and has a regular margin. In the macroscopic analysis, doubt arose as to whether or not it has (some) signs of bone remodelling. The frontal bone, especially in its medial region, shows porosity with signs of remodelling, a lesion compatible with cribra cranii. On the other hand, the CT scan shows a right frontal trephine without signs of remodelling, which means that if there was a survival period, it was short.

This surgical technique can be used to place a drainage tube to decrease intracranial pressure, e.g. acute cerebrospinal fluid pathology, due to hydrocephalus or intraventricular haemorrhages. It is a technique frequently used in emergency cases, although it can also be employed when treating tumours. Analysis of the post-cranial skeleton showed no bone pathology or trauma that could contribute to elucidating the need for this neurosurgical intervention.

Individual CEI/XXI_176, male, 71 years old, year of death: 2007

In this case, the individual exhibits a hole (88x79mm) in the right side of the skull that affects several bones (frontal, sphenoid, right parietal and temporal). Inside this hole and joined by a small metallic device (there is another similar device, but it is not fixed to the skull) is the bone fragment (72x59mm) that was cut. The metallic devices (about 19mm in length) are attached to the bone by small screws. The edges of the skull lesion are sharp, with no signs of bone remodelling. These edges are irregular, and in three zones (one in the parietal, another in the lower part of the temporal, and another in the frontal region immediately above the frontosphenoid suture) where the cut has a different rounded shape, namely burr holes. It is evident, to the naked eye, that the removed bone portion is smaller than the cut margin, which is confirmed by its measurements. Moreover, the antero-inferior portion of the bone flap has an irregular form.

Concerning the postcranial skeleton, besides the general degenerative lesions compatible with an age-at-death of 71 years old, it should be mentioned an old fracture on the right ulna, identifiable by the visible remodelled bone callus, in the proximal third of the diaphysis. Therefore, this lesion is not contemporary to the skull intervention.

The imaging analyses show a right fronto-parieto-temporal craniotomy started from at least two burr holes (one frontal and one parietal). The remaining bone flap has been fixed with microplates and screws. The lesion shows no signs of bone remodelling.

From a neurosurgical point of view, it is an atypical format craniotomy, with a craniectomy component, which suggests unplanned surgery, potentially for the treatment of traumatic pathology (intra- or extra-cerebral haemorrhage) or, eventually, spontaneous cerebral haemorrhage or decompensated neoplastic pathology. The fact that the antero-inferior limit of the bone flap is irregular means that it was not performed with a craniotome, which may indicate the presence of some previous anomaly, more likely of a traumatic nature. There is also severe

Table 1
Summary description of individuals.

No.	Sex	Age-at-death	Year of death	Signs of remodelling	Location of lesions
CEI/XXI_88	Female	80	2001	Yes	Occipital
CEI/XXI_99	Female	55	2001	Yes	Left parietal and occipital
CEI/XXI_156	Male	67	1998	No	Frontal
CEI/XXI_176	Male	71	2007	No	Right parietal and temporal, frontal, sphenoid
CEI/XXI_230	Male	92	2008	Yes	Frontal
CEI/XXI_231	Female	92	2009	Yes	Frontal, sphenoid (?)
CEI/XXI_251	Female	94	2010	Yes	Frontal
CEI/XXI_259	Male	81	2010	No	Frontal, right parietal

bilateral sclerosis in the inner ears (cochlea, vestibule, semicircular canals), a fact that does not seem to be associated with the surgery. The type of fixation device found in this skull is still used in surgeries performed in Portugal today.

Individual CEI/XXI_230, male, 92 years old, year of death: 2008

Two small holes were observed in the frontal bone of this individual (12x2mm and 11x5mm) with clear signs of bone remodelling since the borders are rounded and smooth. There are no signs of porous lesions. From the analysis of the radiological projections, only the profile image shows a change in continuity of the frontal sinuses. However, in the CT images of the axial plane, the absence of bone continuity at the level of the frontal sinuses, right lateral and left lateral is evident. On sagittal plane images, it can be observed bone discontinuity with evidence of bone remodelling process, rounded edges with increased bone density. These findings are more evident in the sagittal planes of the left maxillary sinus. From a surgical point of view, the observed lesion may have been originated by a frontal sinus drainage procedure.

Individual CEI/XXI_231, female, 92 years old, year of death: 2009

In this case, the skull presents a lesion on the right frontal with a sulcus and, approximately, rounded shape (with an area of 53x65mm) and three small depressions, without continuity. Laterally, following the sulcus, a small cavity (4x21mm) exists in the region of the right frontosphenoid suture. Anteriorly, the sulcus converges with another orifice (28x21mm), with rounded edges, which extends to the upper rim of the right orbit. The smooth and rounded edges and the absence of porosities are indicative of an old lesion, which suggests survival after the intervention. Imaging results are consistent with macroscopic observations. It is a right frontal craniectomy, with a right supra-orbital bone defect, which includes the upper edge of the orbit. There is bony fusion over most of the limits of the original craniotomy. The edges of the defect are remodelled, suggestive of an antemortem lesion. Changes are observed in the medial portion of the roof of the orbit related to craniectomy.

There are several possible causes for this surgical intervention, such as haemorrhages, tumours, frontal lobe pathology. This approach can also be used in larger or more complicated pituitary tumours.

Individual CEI/XXI_251, female, 94 years old, year of death: 2010

In this skull, two circular and symmetrical lesions can be seen in the frontal bone (on the left side with about 26x27mm and on the right with 26x26mm), next to the coronal suture. These lesions are sulci with rounded edges, on the exocranium, more demarked anteriorly than posteriorly, not reaching the endocranial surface. The macroscopic analysis leaves doubt as to whether the cut was complete with remodelling or if the cut was just superficial. There are no signs of porous lesions.

The imaging analysis shows two trephine-like orifices, located bilaterally and symmetrically in the frontal and parasagittal regions. The remodelling is visible around the contour of the bone sections. Osteosynthesis material is not present. It should also be noted that there are some signs of frontal internal hyperostosis.

Typically, this type of intervention allows for better access to the removal of hematomas, such as bilateral subdural hematomas. The observations indicate that this must have been a surgery performed a long time before the death of the individual, considering that the year of death was 2010, there was time for bone healing, and this technique has rarely been applied in Portugal since the end of the 20th century.

In the post-cranial skeleton, the following were also observed: partial hip prosthesis and osteosynthesis plate in the lower third of the diaphysis, both in the left femur. A poly-traumatic event could have caused a cerebral hematoma, therefore, given the pattern of injuries and the fact that they all healed, it cannot be excluded that the injuries to the femur and skull occurred in a single event.

Individual CEI/XXI_259, male, 81 years old, year of death: 2010

The skull of this individual shows two round holes with regular margins in the right side (both, approximately, 14 mm in diameter): one in the coronal suture, affecting the frontal and the right parietal, and the other in the right parietal, spaced 39 mm apart. These orifices are very similar to the one presented by Individual CEI/XXI_156, and, as in that case, there were doubts in the anthropological analysis as to whether or not it presents (some) signs of bone remodelling.

The CT scan images display two trephines located on the right side, one on the coronal suture and one on the parietal. These two burr holes do not show any signs of bone remodelling, which are indicative that the individual did not survive.

This intervention may have been performed with the intent of draining a subdural fluid collection, such as a chronic subdural hematoma, or due to a traumatic accident that occurred weeks before. It may also have been employed with the intent of draining an empyema (i.e., a collection of pus within a natural cavity). Like the case of individual CEI/XXI_156, presented before, the type of cutting instrument commonly utilized in these situations has been used in Portugal since the 1950s.

Discussion

The 21st Century Identified Skeletal Collection skulls were analysed and eight (2.7%) presented signs of cranial lesions compatible with a surgical origin. In these eight cases (4 females aged 55 to 94 years, and 4 males aged 67 to 92 years), five show clear evidence of healed bone, pointing to surgical intervention several years before death. The frontal bone was the most affected, having been intervened in 6 cases (75%). Despite only comprising eight skulls, the cases are very diverse: two cases of burr holes (CEI/XXI_156 and CEI/XXI_259); one case of frontal sinus drainage (CEI/XXI_230); a case of trephines with closure (CEI/XXI_251); one case of craniectomy (CEI/XXI_88); two cases of craniotomy (CEI/XXI_99 and CEI/XXI_176); and a more unusual case, with craniotomy and craniectomy (CEI/XXI_231). In two of the cases, metallic devices used to fix the bone were identified (CEI/XXI_99 and CEI/XXI_176). In none of the analysed cases was any evidence of a suture thread found.

In a Forensic Anthropology case, the assessment of lesions is extremely relevant. This analysis can help to understand the cause, mechanism and circumstances of death and even, in cases of investigation of crimes against humanity, make it possible to identify situations of torture. On the other hand, bone lesions that occurred during the individual's life, whether traumatic, infectious or of another aetiology, can be of added value in restoring identity to an unidentified person. Moreover, the location, type, extent, degree and remodelling of the lesions make each skeleton unique. Thus, one of the tasks of great relevance in anthropological expertise is to determine the chronology of the lesions/bone alterations. Nonetheless, this task is not simple, especially in dry bone, and at times it is not possible to definitively determine the chronology of the lesion. In these cases, complementary analyses are important. Imaging analyses have advantages over histological and chemical approaches, as there is no need to collect bone samples from the lesion area, thus maintaining the integrity of the bone piece. The interpretation of images obtained from dry bone is also not without challenges, hence the advantage of working in teams with members from different disciplines. The cases here described demonstrate the potential of a double methodological approach when analysing human osteological remains, which can be beneficial both for forensic cases and for past populations contexts.

In a medico-legal context, the identification of a body is of paramount importance for ethical, juridical and civil motives and is performed through a comparison between biological data obtained from the

cadaveric remains and antemortem data collected from potential victims [25–27]. As previously mentioned, forensic anthropologists rely on skeletal variants of anatomical or pathological aetiology as individualizing factors. It is common knowledge that antemortem trauma and medical intervention signs observed on skeletal remains can provide significant information about the identity of a non-identified individual. Obviously, the more unusual the lesion, the bigger the potential for identification, as it is easier for it to be remembered by family and friends, or if it has visible sequelae, such as cosmetic damage or mobility difficulties (i.e. someone with a limp). The cases analysed in this investigation are among those that are most easily remembered by the relatives of the victims (namely, the cases CEI/XXI_230 and CEI/XXI_231 which are located in the facial region). The literature of Forensic Anthropology is poor in the description of these cases. For example, in the study of 276 individuals of the Italian CAL Milano Cemetery Skeletal Collection, Capella and colleagues [28] found no cases of cranial surgery.

As it is, this work strives to reinforce the range of knowledge available in the field of expertise of the forensic anthropologist, seeing that recognizing lesions resulting from surgical interventions is imperative to a holistic and concise trauma assessment. For example, the work by Amadasi and collaborators [29] explores two case studies where gun-shot trauma interacts with burr holes present in the skulls, demonstrating biomechanical alteration of the formation of fracture lines in the area where the surgical interventions were evident. Hence, avoiding misinterpretation of lesions (attributing a violent aetiology to surgical evidence, or vice versa, for example) and understanding how these findings may affect typical human anatomy allows for a more reliable assessment of cases and, consequently, improves the identification processes.

Despite the impossibility of obtaining antemortem data from the eight individuals analysed in the present study— making it impossible to compare with postmortem findings obtained through the anthropological macroscopic analysis and imaging combined with neurosurgical interpretation —this type of research remains essential in the field of Forensic Anthropology. Indeed, this study allows a better understanding of the lesions observed in dry bone, thus supporting the forensic anthropologist's ability to better evaluate evidence during a forensic examination. Furthermore, the imaging analysis proved to be particularly relevant in cases where macroscopic analysis could not determine whether bone remodelling was present.

The results of this research show the potential of the combined application of different disciplines. For what can be observed in these skulls through this combined analysis, skeletal findings have the potential to provide useful postmortem information that can be compared with antemortem witness statements and clinical imaging.

Conclusion

The combined use of macroscopic anthropological analysis, neurosurgical diagnoses, and conventional radiology and computerized axial tomography performed for each of the eight skulls of 21st Century Identified Skeletal Collection with signs of cranial surgery led to a more comprehensive knowledge of the cranial lesions and their origins. In fact, the present research illustrates the value of an interdisciplinary approach (between specialists in the areas of Anthropology, Imaging, and Neurosurgery) in assessing lesions in skeletal remains and to increase and exponentiate its identification potential, absolutely necessary to comply with ethical and legal requirements, whether in routine forensic cases, mass disasters or crimes against humanity.

Ethics approval

Positive legal decision from the Ethics Committee of the Faculty of Medicine of the University of Coimbra, Portugal (CE_026.2016).

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The 21st Century Identified Skeletal Collection is available for research.

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Code availability

Not applicable.

CRediT authorship contribution statement

Maria Teresa Ferreira: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Catarina Coelho:** Conceptualization, Formal analysis, Writing – review & editing. **Rosa Ramos Gaspar:** Formal analysis, Methodology, Writing – review & editing. **Daniela P. de Matos:** Formal analysis, Methodology, Writing – review & editing. **Ricardo Pereira:** Formal analysis, Methodology, Writing – review & editing. **Eugénia Cunha:** Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Inês Oliveira-Santos:** Conceptualization, Investigation, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors state that they do not have any conflict of interest to declare.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fri.2024.200616.

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