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Rumor has it: A narrative review on the use of skeletal non-metric traits and variants for personal identification

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ABSTRACT

The human skeleton displays an immense array of traits and variant features that are elements of inter-individual variability. The general assumption is that they may represent individualizing markers for the personal identification of unidentified decedents, but very few works consider them as such. This review provides an overview on the possible use of non-metric traits and skeletal variants for personal identification. The paper discusses the issues related to unquantified comparisons, then it presents a statistical approach based on frequencies of these features for identifying unknown remains. Narrowing down an initial number of 1000 papers, the core of the review is represented by 10 papers that considered non-metric traits and skeletal variants as individualizing features, according to both qualitative and quantitative assessments. Despite visual examination remains the gold-standard, more sound methods are requested to quantify the strength of a match or a mismatch. This especially applies in the wake of juridical demands, hence also satisfying the desire of prosecutors and judges to rely on a "quantified" risk. To this purpose, non-metric traits and skeletal variants seem to be a suitable tool to provide quantified evidence, when related frequencies are known.

1. Introduction

Among the tasks which forensic scientists (e.g., pathologists, anthropologists, odontologists and radiologists) are appointed to, is personal identification of unknown human remains. According to the information available and the level of confidence, three types of identification are used. Tentative, when the possible identity is based on circumstantial evidence, such as personal belongings [1]. Presumptive, when evidence indicate an identity without exclusions, but they meet a lesser standard than positive [1,2]. Positive identification relies on a higher level of probability and on a set of features that is shared between Postmortem (PM) and Antemortem (AM) evidence. The experts should determine the uniqueness of the feature considered in the comparison [1,2], and more importantly, establish the probability that an individual present a set of traits [3]. The main weakness in forensic anthropological identification is the traditional subjective nature of the comparisons which has been criticized time after time, especially for the lack of quantitative evidence that would prove an identification [4].

Personal identification results from the comparison of the PM information from a cadaver or human remains and the AM data of a missing person that include different sources [2]- i.e., conventional radiographs, CT or MRI scans, medical records. Although local jurisdictions are entitled to determine how personal identity is established [5], attempts to standardize the procedures and suggest better practice have been made. Police agencies, such as Interpol, have traditionally divided identifiers into primary (DNA, Fingerprints, Odontology) and secondary (a mix of other personal descriptors as well as of personal belongings) [6]. Nevertheless, this rigid separation as far as biological markers are concerned has been discussed and reviewed [5,7], even in the most updated version of the guidelines [6]. Personal belongings and documents are not to be used in isolation for identification [6], whereas any biological element (from DNA to bone shape) can be adequate means of identification [5,6], so long as the method meets the criteria of admissibility in court. In other words, more and more the realm of

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identification through morphological comparison of teeth or bones is requested to meet methodological standards and provide the error of that specific method of identification [8].

When dealing with the personal identification of extensively decomposed or skeletonized remains, forensic anthropologists look for normal, pathological and surgical features of the skeleton that are unique to the individual and could be used in the comparisons [2]. The human skeleton displays an immense array of traits and variant features both in the cranial and postcranial structures. In general, they are referred to as non-metric (or discontinuous, discrete, or epigenetic) traits. They can be observed or not, and therefore scored as present or absent, and they can vary in location, numerousness, size and shape [9]. Genetic and epigenetic factors are believed to contribute to the origin of these features that usually result from deviations from the normal skeletal development and often remain silent and undetected during life [10–12]. Hauser and De Stefano [9] provided an exhaustive classification of the variants of the cranium and Mann et al. [13] produced an atlas that encompasses possibly all the non-metric traits and anatomical variants in the human skeleton. In biological anthropology, some variants, especially the cranial ones, have been considered to explore biological distance between populations and kinship between individuals [14]. Moreover, a sound knowledge of such variants may be useful for other purposes, such as the distinction between normal and pathological anatomy, as some variants may mimic pathology of the bone [11,15].

These features are indeed elements of variability among individuals, and the general assumption is that that they could be used as additional individualizing markers for the personal identification of unidentified skeletal remains [16]. The recent position statement of the Forensic Anthropology Society of Europe [5] includes the skeletal variants among the features that should be considered as anthropological identifiers. Nonetheless, there is a lack of consistent reports on this topic, because very few studies investigated the potential of these variable features for personal identification. By surveying the literature about personal identification in forensic anthropology, the authors grasped that there are two main drawbacks that have scarcely been addressed:

1) There is a dearth of attempts at quantifying the likeness of an identification, as the comparisons are mostly based on unquantified agreement between AM and PM information [17]. More and more, the judicial systems require evidence that are not only based on the expert's opinion, but that can also be quantified to ensure the strength of an identification. This issue is not the main focus of this work, but it is preliminary to the following point.

2) If, on one hand, the anthropological research demonstrated great enthusiasm about the use of paranasal sinuses for identification purposes [18–25], on the other hand, other skeletal structures were limitedly considered [1]. For example, when the AM record lacks images of the conventional osteological identity markers (such as frontal sinuses), what other variable trait of the skeleton can be taken into account to identify the remains? Trabecular pattern is a possibility to take into account [26–28], although caution was suggested [29]. Therefore, are traditional morphological bone variants and non-metric traits suitable tools to perform a quantification of the possible match?

Within the forensic field, unidentified bodies are a burning issue: the right to identity is an essential human right defended by international humanitarian law and failure to uphold this right has serious repercussions spanning the criminal, civil, administrative fields, and even psychophysical well-being of the living relatives [3,30,31]. The academic institution where the authors work is heavily involved in the identification of unidentified bodies and human remains [32,33]. Indeed, anthropologists and odontologists are well familiar with the issues of personal identification, quantification of the evidentiary values and related proving "beyond a reasonable doubt", as judges and prosecutors often require these factors when presenting evidence in court. In 25 years of forensic activity of the laboratory, the contribution of anthropological parameters proved to be fundamental in solving the case, especially in badly preserved remains where primary identifiers were unavailable. More recently, in a timespan of 5 years, the resolution of at least ten cases was aided by the use of variant features of the skeleton (which were not strictly related to conventional anthropological identifiers, i.e., frontal sinuses) that contributed to the screening process of suspected identities and even in positive identification. For example, in a case report where the identification could not be performed using the primary identifiers because of the advanced decay or the lack of dental or fingerprint data, a co-author of this paper investigated the individualizing potential of variants within the trabecular bone, such as areas of idiopathic osteosclerosis [34]. By superimposing a PM image of the proximal femur onto an AM image, the authors found a perfect correspondence and therefore suggested the possible application of such variants in the identification process.

In light of the recent endorsement for the potential role of skeletal variants in personal identification [5], this narrative review investigates and discusses the above-mentioned issues related to non-metric traits and bone variants and their role in the process, focusing on the features that have not been extensively explored for this purpose yet. The review takes into account the papers that suggested an identifying potential of non-metric traits as defined by Hauser and De Stefano [9] and of skeletal variants not strictly classified by the literature. The aim of this work is not to present a method to identify unknown remains based on skeletal non-metric traits and variants, but to consolidate the reliability of such features as valuable personal identifiers when conventional identity markers cannot be considered. Furthermore, this work presents the statistical approaches that have been adopted to tackle the issue of subjective comparisons, in order to strengthen the evidentiary value provided in favor or against a personal identification.

2. Materials and methods

The literature was investigated via Pubmed, Google scholar and Scopus. The following keywords were input: "forensic personal identification" "personal identification", "non-metric traits", "non metric traits", "nonmetric traits", "skeletal variants" or "anatomical variants". The research was also performed using Bolean operators (and, or). Initially, 1,000 articles were collected, but most of them were ruled out to include only the works that discussed the issues in personal identification, specifically those related to the use of non-metric traits and bone variants for such a purpose. The references of each paper were checked to find works that were left out from the initial search. In addition, chapters of textbooks concerning personal identification in forensic anthropology were included. The consistency of the works with the scope of the review was evaluated by two authors. Finally, 25 works among scientific papers and book chapters that concern the issues 1 and 2 (see Introduction) fell within the scope of the study. Ten papers that investigated and/or endorsed the use of variant skeletal features for personal identification (Table 1) represent the core of this review.

2.1. Matching antemortem (AM) and postmortem (PM) data: Unquantified comparisons

Traditionally, anthropological identifications are carried out based on visual comparisons of skeletal features without quantifying the likeness that AM and PM information belong to the same person [17]. The focal dilemma in personal identification is the lack of consensus on how many traits are needed to establish a positive identification. In countries where medico legal authorities and forensic anthropological experts are closely related, the two figures work together to evaluate the reliability of the identification to then be submitted as evidence in court [32]. In 2011, Ciaffi et al. [35] exhaustively illustrated the impasse where forensic medicine has not managed to define yet the sufficient number of features to ascertain the identity of unknown remains. This issue endures nowadays: up to date, the forensic anthropological community has not agreed upon a threshold for establishing the confidence of an identification [17]. Yet, no guidelines are available for

Table 1
Summary of the studies that propose the use of non-metric traits and variants of the skeleton based on qualitative and quantitative approaches for personal identification.

Study	Qualitative	Quantitative	Skeletal region/ features	Type of study
Chandra Sekharan [43,44]	X		Ectocranial sutures	X-ray
Stephan et al. [41]	X		Thoracic cage	X-ray
Weiss et al. [36]	X		Sternum	Computed Tomography (CT)
Watamaniuk and Rogers [42]		X	Vertebral margin	X-ray
Komar and Lathrop [47]		X	Pathological and traumatic features	Direct assessment
Cappella et al. [49]		X	Pathological and traumatic features	Direct assessment
Palamenghi et al. [50]		X	Cranial non-metric traits	Direct assessment
Verna et al. [51]*		X	Sternum	Computed Tomography (CT)
Macaluso and Lucena [16] *		X	Sternum	X-ray

*studies that presented frequencies of skeletal variants without testing the possible use in personal identification.

practitioners, although the unspoken rule is "the more, the better" [36,37]. Some authors addressed this issue, although different minimum numbers were suggested. Fischman [38] maintains that one to four features should be concordant, and no discrepancy should be observed. Mann [26] suggests that four corresponding points should be recognized for a positive identification. Ross et al. [1] states that several points of concordance of the features observed are needed to yield higher probabilities of a correct identification according to the skeletal portion. Based on their study sample, there should be at least two consistent features for lateral cranial radiographs. More than one trait is needed for cervical vertebrae and femoral head and neck, whereas at least four traits are required for thoracic and lumbar vertebrae. Weiss et al.[36] designed a method for the automated comparison of PM and AM data based on 10 morphological and 10 morphometric features of the sternum from 44 PM CT scans. Using MATLAB, the potential identities were automatically checked based on the number of matching features between AM and PM images. 65.1% of the cases were positively identified. For a small percentage (11.6%), several possibilities of identification were recorded. In 23.3% of the cases, a false positive identification was assigned. The authors reported that at least 8 matching features were needed to identify: most successful identities were based on 10 or 11 features, whereas a lower number of matching features were needed for a few cases. Only one case was identified with just eight features. Other authors give vague solutions, stating that identifications could not be based inevitably on minimum numbers [35] or that several traits have to be concordant [39]. However, this does not provide a quantification of the difference between two or more skeletons [35,40]. Moreover, the accuracy of a match cannot be determined exclusively by the number of concordant points between AM and PM records, as this may be related to the reader's confidence to ascertain the match [40]. The reliance on the observer's experience was anticipated by Stephan et al [41]: the authors investigated the potential of normal skeletal features of the thoracic cage and compared 1460 AM and 12 PM radiographs from male individuals among the U.S. military personnel from World War II and Korean war. The PM material was produced by the examiners by performing a postero-anterior radiograph of some skeletal remains (i.e., clavicles, C3 to T4 vertebrae) from 12 subjects. Nine PM individuals had their corresponding AM radiographs, whereas three subjects did not present a corresponding AM image. In simultaneous tests (where the examiners were presented with all AM radiographs), trained examiners were always able to identify the correct match, whereas in sequential tests (where the examiners were presented the AM material one-at-a-time) only one false negative was generated. Two mistakes (one false positive and one false negative) were made by trained observers when assessing highly eroded bones. Untrained examiners yielded lower accuracy rates on both simultaneous and sequential trials. With this study, the authors confirmed the value of chest radiographs in the identification process, even when dealing with low preservation of the remains or low AM image quality. The take-home message of the paper is two-fold. The authors maintain that the availability of the entire the group where to look for the individual -or "Identification Universe" as defined in Watamaniuk and Rogers [42]- may be indispensable to perform an identification with the highest possible accuracy. Moreover, they emphasized the role of trained examiners in the identification process as untrained observers performed poorly, reducing the performance of the method. Chandra Sekharan [43,44] maintains that cranial sutures possess such a unique and varied configuration (in the form of spikes, denticulations, indentations, and other irregularities) that they can be used as individualistic features when comparing the skull pattern with AM radiographs: only the ectocranial pattern presents such individualistic features and should be taken into account. As stated by the author, the possible comparison with AM data is hampered by the partial or complete obliteration of the sutures which increases with age progression.

On a conclusive note, universal consensus could be difficult to reach, although not impossible. Since the availability of PM material and AM record to be compared differs from case to case and heavily depends on unpredictable variables related to the context, standards that encompass all cases that require personal identification are difficult to produce. However, we could aim to provide something similar to likelihood ratios in the future also for morphological identification, as described in the next section.

2.2. The strength of match: Moving from qualitative towards quantitative comparisons

Over time, the identification comparisons solely based on the qualitative and subjective observation of the skeletal features has been swinging between approval and criticism [45]. The recent position statement of Forensic Anthropology Society of Europe encouraged to include variable skeletal features in the personal identifiers list, although, at the same time, it pointed out that the shortage of statistical framework weakens the interpretation of anthropological evidence and that this issue seems to be partially unaddressed [5]. Although a visual approach is generally thought to be convenient (e.g., it is cost efficient), it seems that visual subjective comparisons cannot be considered reliable enough to provide an evidentiary value of the association [40]. Mainly, as already demonstrated by Stephan et al.[41], this approach depends on the experience of the practitioner [1,35,36,40,46]. As such, it often lacks a quantitative support, statistical basis, assessment of variability and its subjective nature can hardly be standardized, especially in the wake of juridical demands for more sound and verifiable methods [4,8,47].

In this perspective, morphological techniques have been improved to strengthen the severity of the observations, tested for reproducibility, error rates and other statistical analyses, in order to enhance their reliability and provide defendable evidence when experts are asked to testify in court [1,2]. Especially in the North America judicial landscape, admissibility of scientific evidence in court is regulated by sound criteria so that the employed methods must be testable and peer-reviewed and

possess known error rates [1,4,8,45]. As a result, anthropologists moved towards the quantification of the strength of a match, by using the variability of skeletal features and their frequencies within a population. Steadman et al. [46] laid the ground for a probabilistic approach to support possible identifications, when considering normal and pathological traits of the skeleton for the elaboration of the typical biological profile. Using Bayesian statistics, the likelihood ratios (LR) of all aspects of the profile, except for ancestry, were calculated. If independent, the LRs can be "multiplied via the product rule" to provide a probability that quantifies the strength of the identification. Christensen and Hatch [40] (page 15) provide the clearest explanation of the use of LR in a forensic context when AM and PM data are compared (other than DNA comparisons): "the likelihood ratios describe the probability of the antemortem and postmortem images sharing radiological features given that the identification is correct, divided by the probability of sharing the features if the identification is incorrect". The possibility to quantify the strength of a match when considering morphological features is a huge turning point for forensic anthropology. As such, experts are able to express the evidentiary value of their observations according to a sound statistic base, in a similar fashion to genetic analyses. Within this perspective, several works followed this innovative approach suggested by Steadman et al. [46] and started building a statistical framework around the possible use of the skeletal variants for identification purposes.

Ross et al. [1] remind that the features used in positive identification need to be "statistically and reliably" proven unique to an individual. In this regard, about the uniqueness of the normal skeletal variation (i.e., morphological variants not yet classified by the literature), Watamaniuk and Rogers [42] assessed the variable morphology of the margins of thoracic vertebrae (from T6 to T12) on three groups of anteroposterior and lateral chest radiographs of male individuals aged 18–55 years (each group has 100 radiographs). 24 radiographs from Group 3 were used as unknowns to test the potential of each variant frequency as personal indicators. The frequencies established in Group 1 were used to calculate the strength of the identification by multiplying independent variants' frequencies. Individuals that showed the product of the frequencies lower than 1/100 (<0.01; where 100 is the "Identification Universe") were considered positive identifications. Products higher than or near 1/100 (>0.01) were considered tentative or possible matches, respectively. The authors state that rare combinations are the center of attention, as they occur in frequencies lower than the "Identification Universe", whereas more common combinations provide indications on possible identities. Since pathological features can be taken into account for identification [48] in addition to normal features, Komar and Lathrop [47] had already published a similar study within the abovementioned probabilistic framework but investigating on the reliability of traumatic and pathological conditions and signs of surgery as individualizing factors. The frequencies of these features were recorded by side in 482 documented individuals from two contemporary North American skeletal collections. The authors maintained that the distinctiveness of such features and of their combinations may be invalidated by their frequencies, which are more common in the populations at study than one would expect. Therefore, caution is suggested when the identification is made uniquely based on medical records. Following this, Cappella et al. [49] provided the frequencies of several pathological and traumatic conditions, and orthopedic and dental treatment, on 276 skeletons of a contemporary skeletal collection from Italy. They grouped their results into two main categories, namely relatively common and rare features. Given their common occurrence, the first ones (e.g., spondylosis/spondyloarthrosis and osteoarthrosis, with a frequency of 84% and 69%, respectively) may potentially represent indicators of identity when accurate and detailed antemortem data is available. More peculiar traits (i.e., antemortem fractures, amputations, neoplastic lesions, orthopedic and dental treatments, observed in less than 10% of the sample) could be considered valuable markers for a personal identification, especially if expressed in combination. However, when considering pathological features of the skeleton, it must be kept in mind that some pathological signs may not be observed in certain age groups: for example, young adults may not display any evidence of skeletal and dental degenerative changes, such as osteoarthrosis or dental work [36,49]. Within this avenue of research, Palamenghi et al. [50] investigated the frequencies of thirteen non-metric traits in a sample of 100 crania of 50 males and 50 females from a modern documented Italian skeletal collection. The frequencies of the traits were multiplied together to provide the probability of an individual to present a certain combination of cranial features, according to the worldwide population. The compound frequencies were grouped into 4 classes of probability (<1 billion; 1 out of 1 billion–1 out of 100 million; 1 out of 10 million–1 out of 1 million; $>$ 1 out of 1 million). Most of the compound frequencies were assigned to the 1 out of 10 million–1 out of 1 million probability interval, hence they proved not rare enough to be deemed individualizing. However, a small percentage of the sample presented compound frequencies with a probability <1 billion. The primary aim of the study was to present a new perspective on cranial non-metric traits, highlighting the potential of such variants in the process of personal identification. Other studies presented raw data on frequencies of variants of the thoracic cage in two European populations. Verna et al. [51] reported the frequencies of seven traits of the sternum (sternal cleft, sternal foramen, suprasternal bone, type of xyphoid end) and ribs (bifid ribs, lumbar ribs, absence of 12th rib, fusion between ribs) in 500 CT scans of individuals from southern France, aged between 15 and 60 years. Only the traits with a frequency lower than 10% (according to the literature) and that could be easily visualized on CT scans were evaluated. The results showed that the traits considered had frequencies lower than 5%, without any correlation with sex and age (except for the end of the xyphoid process, which was found associated with sex and age). Macaluso and Lucena [16] investigated and reported the prevalence of morphological variants in the sternum and ribs on 122 antero-posterior radiographic images of postmortem adult individuals from southern Spain. The traits considered are the same as in Verna et al. [51], with the addition of the sternoxiphoidal fusion. No significant differences for age, sex and side were observed, except for the complete sternoxiphoidal fusion, which was found more frequent in older individuals. Both studies concluded that the traits considered, having low frequencies, can represent potential indicators for personal identification, but the authors did not set up a pilot study to verify the possible use. Table 1 summarizes the works presented in the review. On a final note, a statistical approach involving frequencies would be essentially linked to the reference population from which the frequencies are inferred [40,50]. As world populations are now intermixed, population specific frequencies may be among the limitations to the approach as it entails that frequencies should be re-worked on a regular basis. This should be addressed when presenting evidence based on such an approach [40] and further work including wider population studies may help solve this issue.

In addition to the above-mentioned issues, another point for concern is whether the morphology of the present features correspond between the postmortem (PM) and antemortem (AM) data. Reasonably, in order to suggest and then confirm the identification, the traits observed should match both in presence and topography, shape and characteristics. The literature does not comment on this, being possibly taken for granted that the correspondence should be based both on presence and morphology. However, this work discussed the possibility of implementing the biological profile of an individual with the present bone variants up to the point of attempting positive identification through a statistical approach. The whole identification process pivots on the comparison and recognition of items of concordance between the PM evidence and the AM information (medical records, radiographs, CT and MRI scans). Just as with any other method, personal identification based on non-metric traits and anatomical variants is influenced by a great limitation, which is the availability of AM material that is consistent with the skeletal remains under study. The strength of a match is also

very dependent on the quality, orientation, and representation of the PM image in relation to the AM one [41]. However, AM records may not be within reach, because of inaccessible infrastructures [49], or they may not show the body portion of interest [36]. Moreover, AM material may not be available because the missing person could not access healthcare in their lifetime [5,46,49]. For example, in the study by Komar and Lathrop [47] the rates of pathological traits may suffer from a selection bias as the collections are from two states with uneven access to health care. These circumstances hold consequences especially in the current migration crisis, where thousands of people all over the world have perished in fleeing their home countries, becoming unidentified victims or missing, and the AM records are often inaccessible [31,52]. This, along with many other difficulties related to the personal identification of missing migrants, bottlenecks the identification and stalls the relatives' grief process. However, in a world where personal identification is extensively, if not only, performed by DNA comparison, forensic anthropologists are expanding the tools that may bolster and complete the identification activities, especially in contexts, such as that mentioned above, where DNA samples are hardly available [7,52,53].

3. Conclusions

Rumor indeed has it that non-metric traits and anatomical variants of the skeleton can be used as indicators of identity when adequate antemortem radiological information is available. As literature has mainly focused on variation of the frontal sinuses, other variants remained partially unexplored, so that there is a dearth of reports on their use for such a purpose. This review has pointed out the great potential that skeletal features differing between individuals could have in the personal identification process. Moreover, the work presented the statistical approach based on frequencies that is currently expanding and could be explored in addition to or in conjunction with the usual qualitative and morphological observations to bolster the results of the analyses. This paper thus highlighted the importance of recording and reporting frequencies of bone variants in different populations. These skeletal features potentially represent an effective mean for providing indications in the identification of human skeletal remains, by calculating compound probabilities from the product of frequencies, to quantify the strength of a match or a mismatch, hence also satisfying the desire of prosecutors and judges to rely on a "quantified" risk. Not being able to tag a quantified risk of error on an anthropological method has for the past decades penalized morphological identifiers with respect to conventional markers, such as DNA and fingerprint experts. In this perspective, both intra and inter-population studies on documented skeletal collections or CT scans databases should be expanded to monitor the variation of the frequencies of non-metric traits. On a "futuristic" side note, if future technologies allowed to automatically or semi-automatically classify CT or RX images based on the presence or absence of features and non-metric traits and file the set of variants that subjects display, this would be an enormous step forward towards a faster search of identity suspect.

4. Compliance with Ethical Standards

Funding: Not applicable.

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Informed consent: Not applicable.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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