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SYSTEMATIC REVIEW

Frontal sinuses as tools for human identification: a systematic review of imaging methods

[1]Julia Gabriela Dietrichkeit Pereira, [1]Juliane Bustamante Sá Santos, [1]Silmara Pereira de Sousa, [2,3]Ademir Franco and [4]Ricardo Henrique Alves Silva

[1]Department of Pathology and Legal Medicine, Ribeirão Preto Medical School, USP-University of São Paulo, Ribeirão Preto, Brazil; [2]Division of Forensic Dentistry, Faculty of São Leopoldo Mandic, Campinas, Brazil; [3]Department of Therapeutic Dentistry, Institute of Dentistry, Sechenov University, Moscow, Russia; [4]Department of Stomatology, Public Health and Forensic Odontology, School of Dentistry of Ribeirão Preto, USP-University of São Paulo, Ribeirão Preto, Brazil

The frontal sinuses are potential evidences for human identification because of the inherent distinctiveness of their morphology. Over the last decades, several techniques emerged to enable the visualization and analysis of the frontal sinuses via bi- and three-dimensional imaging. This systematic review aimed to compile different methodological approaches found in the scientific literature to contribute to human identification. Three examiners revisited the scientific literature in order to find imaging techniques for the visualization of the frontal sinuses applied to human identification. The standard search strings built-up from a PICO question identified 404 unique articles in the following databases Medline/Pubmed, Web of Science, Scopus, Lilacs and Scielo. Based on eligibility criteria applied during title, abstract and full-text reading, the sample reduced to 19 articles. The articles were published between 1987 and 2019 by research groups from 10 different countries. Computed tomography was used in 37% of the techniques, while the remaining (63%) techniques used skull radiographs. The techniques were highly heterogeneous and varied between metric analysis, direct image superimposition and morphology code-based systems. The authors considered their techniques useful for human identification and reported accuracy rates from 13 to 100%. Most of the studies revealed low risk of bias. More advantages were related with the techniques based on direct image superimpositions and three-dimensional visualization. Forensic experts must be aware of the use of frontal sinuses for human identification, especially when three-dimensional images are available as ante-mortem and post-mortem evidences for superimposition and comparison.
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Introduction

Human identification is a complex, systematic and standardized procedure in the scope of civil and criminal law that aims to recover the individual information of a victim.[1] Personal features known for their distinctive aspect are assessed for human identification. Ideally, primary means are considered, namely fingerprint, dental and genetic analyses.[2] The lack of available primary evidence, however, justifies the assessment of secondary sources of identifying information, such as anthropological features and imaging of maxillofacial morphology.[3]

The frontal sinuses (FS) became popular for human identification because of their distinctive outline among persons. Individual aspects may influence on FS morphology, especially stress, masticatory function and hormonal changes.[4] From an anatomical perspective,

Correspondence to: Dr Ricardo Henrique Alves Silva, E-mail: ricardohenrique@usp.br

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the FS consists of bilateral cavities in the frontal bone that are only visible through radiographs around the age of four. In the early adulthood, nearly the age of 20, the frontal sinuses reach the final morphological aspect.[5–7]

Zuckerkandl, in 1895, highlighted the asymmetric and distinctive morphology of the FS.[8] Even in monozygotic twins, the FS might be different because after final maturation, additional pneumatization may occur throughout life.[3,9] The reliability of *ante-mortem / post-mortem* morphological comparisons of the FS is confirmed in the forensic field with previous cases of human identification.[5] The first technique for the assessment of FS was described by Schuller (1921), and emerged as the initial application of radiographs for human identification using FS morphological evidence.[10] Six years later, Culbert and Law (1927) reported the first identification case founded on FS analysis.[11] Over the last 100 years, several techniques were developed, increasing the armamentarium of forensic experts and bringing performances that are more realistic to the forensic practice – in particular, with the rise of three-dimensional imaging.

Based on the exposed, this systematic literature review revisited the existing techniques and compiled methodological information to point out to the scientific community the advantages and limitations of FS morphological assessment for human identification using bi- or three-dimensional imaging of the maxillofacial region.

Methods and materials

Search strategy and data sources

Each of the following steps were performed by three independent examiners. Study search was performed without restriction of the year of publication. Only studies in English, Spanish and Portuguese were selected. Pubmed, Web of Science, Scopus, Lilacs and Scielo were searched as sources of related studies. Combinations of Medical Subject Headings (MeSH) and Descriptors in Health Sciences (DeCS) were performed using the Boolean operators AND and OR to build-up search strings. The terms consisted of "human identification" and "frontal sinus" (in each of the three languages) which were chosen, with the aim of finding studies that developed new techniques and methodologies that could help the reader to find useful means for the process of human identification when the use of the frontal sinus is necessary.

Eligibility criteria

The inclusion criteria followed PICO elements, namely studies that investigated human FS (P) through bi- or three-dimensional images of the skull (I) for the visualization of morphological traits (C) for human identification (O). The exclusion criteria consisted of duplicates, abstracts from proceedings of conferences, literature reviews, studies on age estimation or sexual dimorphism, and studies that applied but not necessarily developed a technique. Only observational (cross-sectional, case-control and cohort) studies and technical notes were considered as eligible study designs.

Study selection

Duplicates were automatically excluded via Mendeley Desktop (Elsevier, Amsterdam, The Netherlands) software. The remaining studies underwent a manual double-check to search for additional duplicates. The identification of studies after the removal of duplicates started from an initial analysis of titles. Studies that did not fit to the eligibility criteria because of title description were excluded. Abstract reading was performed next. Again, exclusions were performed based on eligibility. Studies that did not have abstract were kept for the next step. In the final exclusion phase, full-text reading was accomplished. Studies excluded during this phase were registered in a separate spreadsheet. A summary of the eligible studies selected for qualitative analysis was designed in a flowchart according to PRISMA guidelines.[12] Disagreements between reviewers during the selection process were solved by considering the majority of opinions (two reviewers against one).

Data extraction

Authorship, year of publication, journal of publication and main country of author affiliation were the initial data extracted from each eligible study. Sample size and its distribution per sex and age were registered, followed by the type of image analysis, image device, number of examiners and image assessment were investigated within the second phase of data extraction. Finally, the main outcomes and conclusion of the manuscript were extracted.

Methodological quality

The methodological quality of the selected eligible studies was assessed by means of *Joanna Briggs Institute Critical Appraisal Tools (JBI Tool*). According to the tool, each study had to fulfil eight questions to quantify the methodological quality into a score. Positive answers could decrease the risk of bias, while negative answers increased the risk. Scores up to 49% of positive answers suggested "high risk of bias". Positive answers between 50 and 69% had "moderate risk of bias", while studies that scored >70% had "low risk of bias".

Results

The initial search resulted in 403 studies over the five electronic databases. One study was added later by expert opinion, (totalling $n = 404$). Nineteen studies resulted after study selection following eligibility criteria (Figure 1). The studies were published between 1987[13] and 2019,[14,15] and had as main affiliation institutions

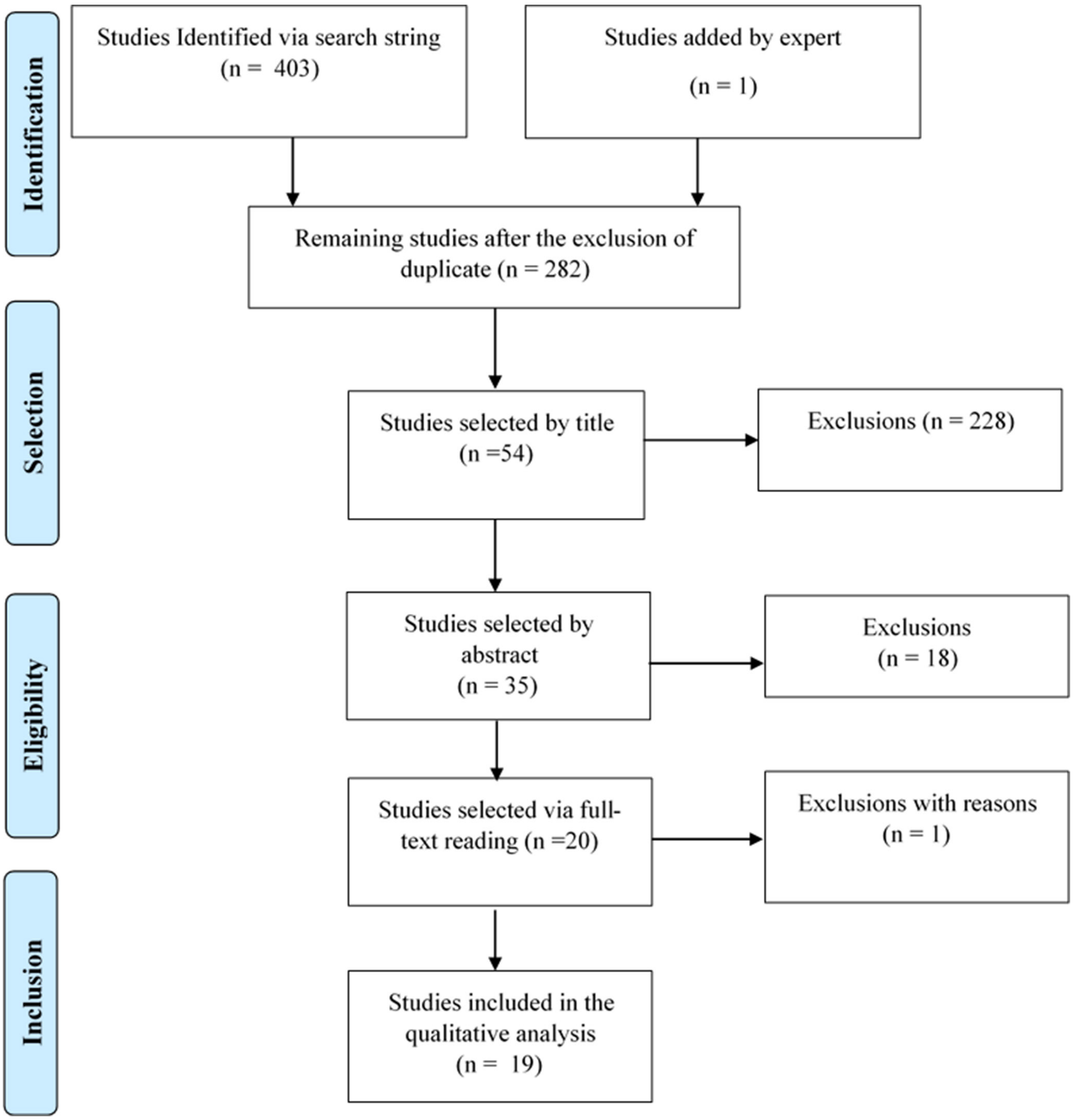

Figure 1 Flowchart depicting the study selection process from identification to inclusion in the qualitative analysis.

in Brazil,[16–18] Canada,[19–21] Korea,[22] United States,[23,24] Finland,[25] India,[15,26] Italy,[14,27,28] Japan,[13,29] Switzerland[30] and Turkey[31] (Supplementary Table 1, available online as supplemental material).

Sample size varied between 1 and 500 subjects aged from 15 to 99 years. Image exams included radiographs (mostly anteroposterior) and computed tomography. The number of examiners varied from one to three. FS analysis consisted of metric assessments and qualitative morphological assessment (Table 1).

The most relevant results as well as considerations on the conclusion were extracted by the examiners of this study (Supplementary Table 2, available online as supplemental material).

The methodological quality assessment score varied between 3[27] and 8[13–16,20,21,24,26] points. Most of the limitations consisted of proper description of sample eligibility criteria (Supplementary Table 3, available online as supplemental material).

More detailed information from each article was made available as online supplemental material in Supplementary Tables 1–3.

Discussion

When it comes to the identification of individuals through the FS, several methods will emerge in the scientific literature. Comparing each one of them and

Table 1 Extraction of methodological information of the eligible studies

Authors	*Sample*	*n*	*F*	*M*	*Age*	*Image*	*Device*	*Examiners (n)*	*Method*
Yoshino et al[13]	Radiographs of skulls	35	14	21	Adults	Anteroposterior technique	OMC603 soft X-ray (OMICRON)	1	The area of the FS was analysed, as well as bilateral asymmetry and contour of the upper limit. Partial septa and presence of supraorbital air cells was analysed.
Reichs and Dorion[19]	CT	1	0	1	48	CBCT	Picker 1200 SX	2	Reichs-Dorion classification (seven aspects were analysed).
Ribeiro[23]	Radiographs	500	NS	NS	Adults	NS	NS	NS	Linear measurements (from A to H) to enable the metric analyses of FS height and width.
Taniguchi et al[29]	Deceased and the living's radiographs	353	57 (deceased) 76 (living)	152 (deceased) 87 (living)	18-91(deceased) 16–86 (living)	NS	NS	NS	Morphological classification of the sinus septa and FS
Cameriere et al[27]	Radiographs	98	41a	57a	17–98	NS	NS	NS	Coded morphology of the FS; calculation of FS area and are of the orbit, upper limit and the presence of partial septa and supra orbital air cells.
Christensen[24]	Skeleton collection – radiographs made for this study	230 × 2 - duplicated, with a new radiograph	NS	NS	NS	FS radiographs	HoLogic HFQ series 100 kHz high frequency machine	NS	FS Contour by overlapping paper. The traces were scanned, their coordinates were carted, and these values were noted. An elliptical Fourier analysis was performed to regenerate the contours of the sinus coordinates around the centre of the sinus contour. Euclidean distances (data space) between contour pairs were calculated.
Pfaeffli et al[30]	Skeleton collection – radiographs made for this study	75 × 2 - duplicated, with a new radiograph							
Tatlisumak et al[31]	Historical collection – radiographs made for another study	52					NS		
Falguera et al[16]	Clinical collection radiographs	146							
Cox et al[20]	Human skulls	Teorical case: 4/ practical case: 2	NS	NS	NS	Anteroposterior, lateral and oblique radiograph and CT	NS	NS	Comparison of ante mortem radiographs with post mortem CT.

(Continued)

Table 1 (Continued)

Authors	*Sample*	*n*	*F*	*M*	*Age*	*Image*	*Device*	*Examiners (n)*	*Method*
Besana and Rogers[21]	Hospital CTs	100	62	38	20–69	paranasal sinuses CTs	Siemens Emotion Tomography Machine	2	System FSS. *F* = FS presence or absence *S* = Interseptal or intrasected septum and *S* = Scalloping Measures: width, height, anteroposterior length, total width of the two breasts, the distance between the highest points of the two breasts and the distance of each breast to its maximum limit. Qualitative and then quantitative classification.
Kim et al[22]	Living individuals – pre-existing collection	90 images (29 individuals)	NS	NS	>20	Anteroposterior skull radiographs	NS	NS	Manual and semi-automatic FS segmentation (DIFT) and shape analysis for the polar logarithmic distribution of the remaining shape points in relation to the pixel
Beaini et al[17]	Archaeological collection	41	16	25	NS	Skull radiographs - standard Caldwell view (occipitofrontal)	NS	2	Frontal sinus drawing on an acetate sheet. The drawings were digitized and the length of the baseline and the measurement from the middle of the baseline to the contour were measured every 3 degrees, up to 177 degrees. This produced 59 radiographic measurements. The absolute value of the differences between the measures analysed was added to find the DT, which was used to calculate the OR.
Cossellu et al[28]	Clinical collection	48	26	22		anteroposterior sinus radiographs, caldwell projection			
Nikam et al[25]	Contemporary collection	9 × 2 - duplication to simulate a postmortem radiograph	NS	NS		Skull radiographs - standard Caldwell view			

(Continued)

Table 1 (Continued)

Authors	*Sample*	*n*	*F*	*M*	*Age*	*Image*	*Device*	*Examiners (n)*	*Method*
Verma et al[26]	Pre-existing collection	100 method - 16 pilot method	NS	NS	NS	Anteroposterior skull radiographs	NS	3	FS measurements and shape; analysed 23 characteristics. Breast design on vellum paper with subsequent overlapping for identification
Souza et al[18]	Deceased (Digital Korean Human Model Database)	119	59	60	21–72	CT	NS	NS	Non-metric evaluation (FS shape, contour of the upper border and the FS cross-section shape)+measures of the FS. These characteristics are represented by a 10-digit number
Gibelli et al[14]	Pre-existing collection	20 method - three pilot method	10	10	20–35	CT	NS	2	FS Volume and overlapping of the ante mortem and post mortem images. Through the comparison cloud and colour map, he considered it identified or not.
Mohan and Dharman[15]	Pre-existing collection	150	91	59	15–78	CT	i-CAT	2	FS dimensions in three directions; FS volume; total area. Only volume and measurements in the three directions were used in the actual method.
	Randomized individuals	100	NS	40	60	Anteroposterior skull radiographs	Planmeca totalling EC Panoramic X-ray and Cephalostat CM	2	Manual traces on parchment paper segmented the FS into predefined quadrants and variables on the right and left side-for metric analysis of shape, then there was overlap with traces to check if the contour was corresponding

(Continued)

Table 1 (Continued)

Authors	*Sample*	*n*	*F*	*M*	*Age*	*Image*	*Device*	*Examiners (n)*	*Method*
	Patients undergoing orthodontic treatment (Nasal septum +FS)	149	75	74	20–45	Anteroposterior cephalograms	Kodak 8000C Digital Panoramic and Cephalometric system	1	FS was classified for presence and symmetry and other measures were taken. Nasal septum was classified according to the pattern of deviation. Measurements: Diameter of the FS at the widest points; The height of the sinus; Distance between the two.
	Images generated by CT scans	310	NS	NS	>20	CT	NS	NS	Automation of the FS recognition process in an image. 3 steps: 1) Segmentation of the FS automatically; 2) Extraction of measurements from the FS; 3) Recognition of the FS; 4) Agreement between manual and automated measurements.
	Living individuals – pre-existing collection	corresponding group: 60 images (two from each individual)	15	15	20–90	CT	somaton definition flash (second generation)	NS	FS segmentation; 3D overlap of two FS automatically
		unmatched group: 200 images	100	100	18–99 anos				
	Individuals from department of Medicine and Radiology - Dental School of Saveetha	96	31	65	20–45	Anteroposterior skull radiographs	Promax OPG X-ray	NS	FS shape analysis (area, lobe, symmetry) with nasal septum deviation analysis +classification of 9 possible FS patterns and five possible septum deviation patterns

CBCT, Cone bean computerized tomography; CT, Computorized tomography; DIFT, Semi-automatic segmentation; FS, Frontal sinus; NS, Not specified; RMS, Root mean square.
[a]Values exchanged by the author throughout the work on the results.

choosing for application in practice require time and efforts of forensic experts and radiologists. This systematic review compiles data from pre-existing literature, reports on a summary of scientific evidence and highlights convergent and divergent aspects across studies. The uniqueness of this study relies on the lack of a previous systematic literature review on the existing methods for FS analysis in the context of human identification. Moreover, the methods were not solely presented but depicted based on their advantages, disadvantages and limitations. With the increasing use of anatomic parameters for human identification, this systematic review arises with important inputs to support the forensic practice by showing pathways in the interface with radiology. Over the time, radiology has shown fundamental association with the forensic sciences. The possibility of studying the FS by means of imaging corroborates the association and triggers the present study with timely importance – in a scenario with a large spectrum of methods.

As expected, several methods were detected across the eligible studies. A prevalence methods based on 2D imaging was observed – contrasting with the remaining 3D methods (37%). More specifically, the 3D methods showed cone beam computed tomography (CBCT) as the predominant image modality.[14,17–19,22,28,31] CBCT is known for enabling a detailed visualization of anatomical features, especially dentomaxillofacial ones. By assessing FS more reliably through 3D imaging, authors have found that the classification of anatomical features and/or FS superimposition are feasible options for human identification, whether positive or not.[14,17] The methods based on 2D images were also considered useful because of the low cost and the more feasible access – especially in developing countries.

Most studies used metric methods. While metric analyses are more objective, given the quantitative outcomes, qualitative analyses are possibly more subjective since they might depend more on examiners' experience.[31] Some of the methods,[28,31] for instance, were found on the analysis using specific features of the sinuses, such as: presence or absence of FS, volume, height, width, depth, position of the septum, among others. Further on, with the use of measurements, codes were created for each frontal sinus (using metric and non-metric features) – varying from 8 to 21 digits.[19,22] The systematic search also showed a possibility of implementing the FS recognition by means of automatic segmentation and measurement (and subsequent identification).[18] Another method, proposed by Ribeiro,[23] came out interestingly prevalent (mainly detected in Brazilian studies). This method, founded on metric analyses, is depicted in the scientific literature as a low cost approach for simple applicability. According to the study, human identification may become especially feasible with the existence an image database.

Among the analysed articles, all proposed methods are capable of human identification based on the FS. Besana and Rogers,[21] however, suggested that metric analyses are more limited and should not be used for human identification purposes (the authors used metric and superimposition techniques and detected positive outcomes of below 30%). When the studies focused on image overlays, the positive outcomes for human identification increased.[17,21] When the analysis was through the coded-based methods, it was found that different skulls could have equal codes;[27] however, the error in positive identification would remain still low (according to the authors), ranging from 7×10^{-627} to 1.8%.[22] Another study showed that it is possible to acquire more than twenty thousand possible combinations of FS anatomic features – corroborating the approach for human identification.[13] In studies that applied measurements of the FS, the positive outcomes were mostly positive.[15,20,29,31] Among the 19 studies, 10.5% proposed an automated approach for human identification through the FS. Out of the studies with automated tools, an error rate of 5.82% was detected[16] – which was still close to non-automated analyses.

Few studies reported the values of intra- and interobserver agreement, however, when these data were available they were always high,[20,28] reaching up to 0.999.[28] These analyses have great relevance and are encouraged in every single study because the methods must be reproducible for proper application in practice. Some studies did not report on identification rate,[14,18,19,23–26,28,30] however, they stated that the probability of having two individuals with the same anatomical features of the FS is very low.[14,19,24,25,28] This persistent lack of information and the methodological heterogeneity found made it impossible to carry out a meta-analysis in this systematic review. Because all studies were observational, the assessment of the risk of bias started from zero score and increased based on the established criteria. It can be seen that the studies scored from 3 to 8, with the sample selection criteria (inclusion) being the main negative aspect detected.

A core objective of this systematic review was to screen the advantages and limitations of the available methods for human identification using FS images. In order to sum-up and discuss table contents, the advantages and limitations may be understood in the levels: At a first level, the general advantages of methods founded on the radiographic assessment of the FS were: I) the possibility of performing non-invasive analyses (because of the inherent image set up); II) the possibility of re-analyzing cases because of the digital storage of medical files; III) the distinctiveness of the FS itself that could support comparatives analyses; IV) the overall good performance of the methods, which were positive; and V) the broad range of available evidences collected, such as quantitative (metrics of volume, surface and linear distances) and qualitative (visual differences from superimposition). The general limitations of the methods are the need for previous knowledge of radiology, the availability of FS images (AM set up), and the time-consuming procedure for image treatment and analysis on a virtual scenario. At a second level, specific advantages and limitations based on imaging modality exists: 2D images are low-cost, familiar to most experts and the methods usually require a shorter learning curve; on the other hand, 3D images (from CT) are more realistic, enable multiplanar navigation and three-dimensional visualization in detail. At a third level, the methods may be compared based on their application. Metric analysis are more objective, they might depend on specific examiner skills and reliability of the taken measurements. Non-metric analysis usually takes into account more anatomic information (*e.g.,* superimposition), but are more subjective and quite intuitive for reproducibility. When deciding for a method in practice, experts must remember that a large variety of options are available and that they can be chosen based on experts' previous knowledge and methods' performance, advantages and limitations known from the scientific literature.

This systematic literature showed that some methods had more advantages than others, especially the ones based on three-dimensional assessment and image superimposition. Information of this kind can help on the decision-making process in the forensic practice. Whenever available, and in case of need for human identification supported on FS anatomy, CT might be requested and 3D superimposition may be used for more detailed visualization and improved forensic reports. CT is already in use for the diagnosis and treatment planning of several clinical conditions. Additionally, the visualization of FS anatomy is feasible even when they are not the main region of interest during an examination of maxillofacial conditions (*e.g.,* facial trauma).[32] Evidently, the inclusion of the FS on CT scanning field of view (FOV) will depend on the clinical justification. The findings of the present systematic review can be easily translated to practice. Patients with alterations of the FS (pathological or not) may be studied by means of CT and have their FS volume, surface and metrics compared to health patient anatomy (by means of 3D superimposition or not) in a virtual software environment. For this reason, the methods presented in this study also emerge as options for clinicians dedicated to find solutions for the clinical practice. Interestingly, the CT data requested in the clinical practice will boost the source of AM data that can be used in the future for human identification.[33]

This study presents the limitation of selecting only observational research. Ideally, randomized clinical trials would enable higher evidence outcomes,[34] but in the forensic sciences (especially when it comes to image analysis and human identification), observational studies are more common. This issue hampers a more solid decision for a method in practice. On the other hand, this study encourages future studies with more standardized protocols and external validation - possibly with different examiners and samples. Additionally, a better description of the sample is a must, especially after the low scores of the eligible studies during the analysis of the risk of bias.

Conclusion

The eligible studies depicted heterogeneous protocols for FS analysis useful for human identification. Computed tomography and radiographs of the skull (several techniques for acquisition) were the image modalities of choice across studies. Metric (measurements) and non-metric (coding systems and superimpositions) analysis were used. Most of the studies revealed low risk of bias. However, sample description was a prevalent limitation. Forensic experts must be aware of the use of frontal sinuses for human identification, especially when three-dimensional images are available as evidences for superimposition and comparison.

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