Review article

Forensic application of the frontal and maxillary sinuses: A literature review

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ABSTRACT

This study aimed to point out the contribution of the frontal and maxillary sinuses for Forensic Sciences, specifically in Forensic Dentistry. For this, a review was performed with 30 articles comprised in the period 2003–2014, about the application of the frontal and maxillary sinuses for human identification and sex determination, using the search words: Frontal Sinus, Maxillary Sinus, Human Identification, and Sex Differences. It was observed that the frontal and maxillary sinuses are useful for human identification. In relation to sex determination, there is no agreement about the applicability of the frontal sinus, although authors suggest that further studies should be performed to verify if it can be employed as an auxiliary method; but regarding the analysis of the maxillary sinus, this has shown satisfactory results. Thus, is possible conclude that the frontal and maxillary sinuses provide important information to the forensic context in cases involving human identification and, in the case of the maxillary sinus, allow the sex determination.

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Contents

1. Introduction

The identification is a systematic and organized process, which primary function is to establish the identity. For this purpose, various methods have been applied [1,2]. In the Forensic Sciences, different methods have been developed for human identification based on comparisons between *ante* and *post mortem* data [1,3].

The fingerprint is an accurate identifying method, widely applied; however, in some cases, the collection becomes difficult or even impossible, such as in decomposed, fragmented or charred corpses [1,3–7]. Regarding DNA, although their techniques are accurate and propitiate reliable results, the method is time consuming and requires laboratory infrastructure, besides being impossible if the remains are badly degraded or exposed to environmental conditions [2,6–8].

In cases where these traditional methods are unfeasible, there is the study of anthropometric characteristics, as a secondary method in human identification, and, this method is reliable and essential to guide the identification procedure [8,9] and still gains importance when combined with Forensic Dentistry [1,3,5,7,8,10,11], can avail of information able to set the identity [7,8,12–14] from comparative analysis of anatomical variations [1,6,13,15].

An example of this analysis is the identification using the frontal and maxillary sinuses. The frontal sinus has become quite solidly in the literature as a safe method [1,4,8,12,16] for comparative radiographic studies to get the identification [1,2,4,8,12,14,16–22]. Regarding the use of the maxillary sinus, their characteristics

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Table 1
Papers about human identification and sex determination through the frontal and maxillary sinuses.

Authors	Year	Article Type	Examined Cases	Modality Used	Anatomical Region	Analyzed Implication	Results	Conclusions
Taniguchi et al. [17]	2003	Research	24	Radiograph	Frontal sinus	Human identification	Comparison of the ante and postmortem films ($n=24$) gave an identical result in about 75%.	Frontal sinus radiographic patterns are useful for human identification.
Christensen [26]	2005	Research	808	Radiograph	Frontal sinus	Human identification	Results show that Euclidean distances between outlines of different individuals are significantly larger than those between replicates of the same individual, and typicalities show that the probability of finding two different individuals with Euclidean distances less that that between a particular case's replicate is very small.	The differences between the frontal sinuses are significant and measurable between individuals.
Camargo et al. [28]	2007	Research	100	Radiograph	Frontal sinus	Sex determination	The mean values of the frontal sinus were greater in males and the left area was larger than the right area, based on Student's t-test at the 5% level of significance. The mathematical model based on logistic regression analysis gave a concordance index for gender of 79.7% in the cases studied.	The frontal sinus analysis may be useful in sex determination.
Iordan and Ulmeanu [29]	2008	Review	_	Radiograph	Frontal sinus	Human identification	Paranasal sinuses can be explored by different methods, but the most accessible and easy to perform is conventional radiological imaging.	Radiographs can be evaluated to establish the individuality are frontal sinus.
Falguera [4]	2008	Research	90	Radiograph	Frontal sinus	Human identification	The method based on Image-Foresting Transform has shown itself efficient in frontal sinus segmentation from radiograph images. Techniques for extracting frontal sinus geometrical and shape-based descriptors were investigated and implemented as well.	Individuality, accuracy and usability of the frontal sinus for human identification.
Soriano et al. [1]	2008	Review	_	Radiograph	Frontal sinus	Human identification	It was observed that many are the possibilities of radiographic techniques that can be used in order to identify anatomical characteristics, especially of paranasal sinuses and its variants, or even artificial elements present in the analyzed bodies, such as dental restorations, endodontic treatments, implants and fixed or removable prostheses.	The frontal sinuses provide important contributions to the establishment of identity, as meeting the requirements of uniqueness, permanence and immutability.
Silva et al. [18]	2008	Case Report	1	Radiograph	Frontal sinus	Human identification	At work, it was possible to positively establish the identity of the skeletonized body as belonging to the missing victim.	Radiographs allow visualization of the frontal sinus morphology and the establishment of positive identity.
Silva et al. [19]	2009	Case Report	1	Radiograph	Frontal sinus	Human identification	A positive identification of a body by means of corresponding images X-rays before and postmortem.	The frontal sinus radiographs of comparison is a reliable method because of the uniqueness of the sinus in humans.
Tang et al. [20]	2009	Research	165	Radiograph	Frontal sinus	Human identification	The unilateral frontal sinus scalloped with one arcade has few parameters applied to personal identification, and shows the poorer discrimination power.	The frontal sinus can be applied to personal identification.
Silva et al. [8]	2009	Case Report	1	Radiograph	Frontal sinus	Human identification	Associating data anthropological research to those obtained by the frontal sinus analysis was possible to set the positive identification of the body examined.	With the frontal sinus analysis is possible to reach the positive identification.
Carvalho et al. [12]	2009	Review	_	Radiograph and computed tomography	Frontal sinus	Human identification	The analysis of ante-mortem and post-mortem radiographic and tomographic images has become an essential tool for human identification in forensic dentistry, particularly with the refinement of techniques resulting from developments in the field of the radiology itself as well as the incorporation of information technology resources to the technique.	The observation of the frontal sinus pattern is already a good established technique for personal identification.
Musse et al. [23]	2009	Research	328	Radiograph	Maxillary sinus	Human identification and sex determination	The average values were higher in males than in females.	The morphology and measurements of maxillary sinuses can be used for sex determination and human identification.
Besana and Rogers [16]	2010	Research	116	Radiograph	Frontal sinus	Human identification	The research finds that most sinus traits are dependent upon one another and thus cannot be used in probability	Only superimposition pattern matching is an effective method of

Table 1 (*continued*)

Authors	Year	Article Type	Examined Cases	Modality Used	Anatomical Region	Analyzed Implication	Results	Conclusions
							combinations. When looking at traits that are independent, this research finds that metric methods are too fraught with potential errors to be useful. Discrete trait combinations do not have a high enough discriminating power to be useful.	identifying an individual using the frontal sinuses.
Uthman et al. [30]	2011	Research	88	Computed tomography	Maxillary sinus	Sex determination	Maxillary sinus height was the best discriminant parameter that could be used to study sexual dimorphism with an overall accuracy of 71.6%. Using multivariate analysis, 74.4% of male sinuses and 73.3% of female sinuses were sexed correctly. The overall percentage for sexing maxillary sinuses correctly was 73.9%.	This computed tomography can provide valuable measurements for the maxillary sinuses and can be used for sex determination.
Musse et al. [24]	2011	Case Report	1	Radiograph	Maxillary sinus	Human identification	There were not tuneless points between the presented documentation and the points susceptible to comparison. All of the dental conditions comparable were coincident. The high specificity of the observed conditions and add of the coincidences verified during the exam indicated that the analyzed skeleton was of the missing assumption.	The morphology of the maxillary sinus is important standard of comparison in forensic identification.
Bolzan and Tucun-duva [14]	2012	Research	40	Radiograph	Frontal and maxillary sinuses	Human identification	In the maxillary sinus was observed in 29 normal jaw skulls (72.5%). Because of the higher within the details of clarity front on radiographs, compared to the other sinuses, their characteristics could be more detailed.	Radiographs are effective for viewing the maxillary and frontal sinuses, enabling identification of an individual.
Amin and Hassan [31]	2012	Research	96	Computed tomography	Maxillary sinus	Sex determination	The study concluded that the correct predictive accuracy was 70.8% in males and 62.5% in females.	The measurements of maxillary sinus by computed tomography is a useful resource in sex determination.
Patil et al. [6]	2012	Research	100	Radiograph	Frontal sinus	Human identification	The comparative identification by superimposition of the frontal sinus was 100% positive. The size, shape, unilateral or bilateral presence, absence, and septa were observed to be unique in each case; neither had the measurements changed over a period of time.	The frontal sinus is unique to each individual.
Pinto et al. [25]	2012	Review	_	Radiograph	Maxillary sinus	Human identification	Noted the importance of alerting dentists on recording and appropriate archiving of data and information about their patients.	The methods of human identification through measurements and formats of the maxillary sinuses show up reliable.
Ruder et al. [39]	2012	Research	125	Computed tomography	Frontal and maxillary sinuses	Human identification	For all readers, sensitivity was 83.7%, specificity was 100.0%, negative predictive value (NPV) was 95.4%, positive predictive value (PPV) was 100.0%, and accuracy was 96.3%. For radiologists, sensitivity was 97.8%, NPV was 99.4%, and accuracy was 99.5%. For non-radiologists, average sensitivity was 69.6%, negative predictive value (NPV) was 91.7%, and accuracy was 93.0%. Radiologists achieved a significantly higher sensitivity ($p < 0.01$) than non-radiologists.	Visual comparison of ante mortem and post mortem computed tomography of the head is a robust and reliable method for identifying unknown decedents.
Goyal et al. [32]	2013	Research	100	Radiograph	Frontal sinus	Sex determination	Multivariate logistic regression equations allowed correct sex identification in 60% of cases only.	The frontal sinuses may have limited application as the sole predictor of sex.
Vidya et al. [33]	2013	Research	30	Computed tomography	Maxillary sinus	Sex determination	The preliminary analysis of data discriminative by CT method has been tabulated. The volume of the maxillary sinuses of both sides was significantly greater in males compared to female skulls. The p value of left width and right sided volume of maxillary sinuses 0.015 and 0.021 respectively were considered statistically significant.	Computed tomography measurements of the maxillary sinuses can be useful to support the determination of sex.
Jasim and Al-Taei [34]	2013	Research	120	Computed tomography	Maxillary sinus	Sex determination	The statistical analyses of maxillary sinus measurements for dentate and edentulous groups showed that the volume and dimensions of maxillary sinuses in both groups were larger in	The study showed that the measures and volumes of the maxillary sinuses are larger in men than in women.

Table 1 (*continued*)

Authors	Year	Article Type	Examined Cases	Modality Used	Anatomical Region	Analyzed Implication	Results	Conclusions
							males than females and they tend to decrease with the older age, in addition it is found that there was no significant differences in measurements of maxillary sinuses between dentate and edentulous groups, but the exception was in height measurements which were significantly higher in edentulous than dentate group for both genders.	
Mathur et al. [2]	2013	Research	40	Radiograph	Frontal sinus	Sex determination	A highly significant difference was observed in both width and height of frontal sinus between males and females.	The frontal sinus can be used as an auxiliary method in sex prediction.
Navdeep et al. [35]	2013	Research	50	Radiograph	Frontal sinus	Sex determination	No statistically significant difference was found between mean area of frontal sinus between males and females.	The frontal sinus analysis is not reliable to assist sex discrimination.
Masri et al. [36]	2013	Research	144	Computed tomography	Maxillary sinus	Sex determination	The maxillary sinus increased in sizes and volume from birth to 30 years of age. Females demonstrated to have significantly larger maxillary sinus width ($p=0.02$), height ($p=0.04$) and depth ($p<0.01$) than males in 0–6 years age category. The male's maxillary sinus width and height were significantly larger than females in 7–12 ($p<0.01$) and 21–30 ($p=0.02$) years age categories. Moreover, maxillary sinus depth were found to be larger in males than females in 21–30 years age category ($p<0.01$). Males also exhibited larger maxillary sinus volume than females in 7–12 ($p<0.01$) and 21–30 ($p<0.01$) years age categories.	The measures and volumes of the maxillary sinuses show sexual dimorphism.
Belaldavar et al. [22]	2014	Research	300	Radiograph	Frontal sinus	Human identification and sex determination	One hundred and forty seven males and 142 females show presence of frontal sinus with seven individuals showing unilateral/bilateral absence of frontal sinuses. The mean values of the frontal sinus height, width and area are greater in males. Right frontal sinus is larger than the left sinus in both the sex. The mathematical model based on logistic regression analysis gives an average concordance index for sex determination of 64.6%.	The frontal sinus offers average accuracy in determining sex, but high precision in human identification.
Sidhu et al. [9]	2014	Research	50	Radiograph	Maxillary sinus	Sex determination	The mean area and perimeter of maxillary sinus in males was 1.7261 cm^2 and 5.2885 cm whereas, the mean area and perimeter in females was 1.3424 cm^2 and 4.3901 cm. In-group centroids if someone's discriminant function (DF) score is close to 0.838 then the subject are supposed to be male. Whereas, those having DF score closer to −0.838 are supposed to be females. DF analysis showed that, 76% of the original grouped cases were correctly classified. Hence, the overall sensitivity and specificity was found to be 80% and 72%.	The analysis of area and perimeter of the maxillary sinus can help in determining sex.
Ekizoglu et al. [37]	2014	Research	140	Computed tomography	Maxillary sinus	Sex determination	The size of the maxillary sinus is significantly small in female gender ($p<0.001$). When discrimination analysis was performed, the accuracy rate was detected as 80% for women and 74.3% for men with an overall rate of 77.15%.	The morphometric analysis of the maxillary sinuses are useful for sex determination.
Jehan [38]	2014	Research	191	Computed tomography	Maxillary sinus	Sex determination	A statistically significant difference with $p<0.0001$ was observed in the bizygomatic distance with mean $\pm$ SD of 9.55 $\pm$ 0.41 cm for male and 9.262 $\pm$ 0.52 for female. The strongest correlated variable with bizygomatic distance was the intermaxillary distance ($r=0.3037$) in male & AP diameter of sinus ($r=0.5980$) in female.	The dimensions of the maxillary sinus are useful for sex determination.

provide important insights that enable the forensic identification [9,23–25].

This literature review aimed to evaluate the contribution of the analysis of the frontal and maxillary sinuses for Forensic Sciences in human identification and sex determination.

2. Material and methods

This review studied articles comprised between 2003 and 2014, involving the last decade of published works, about the application of the frontal and maxillary sinuses for human identification and sex determination, from the Forensic point of view.

The keywords used, by DeCS (Descriptors in Health Sciences), were Frontal Sinus, Maxillary Sinus, Human Identification, Sex Differences. The databases Pubmed and Scielo were used in this research.

The inclusion criteria were papers that used maxillary and/or frontal sinuses in human identification and sex determination purposes. The selected papers were published in English or Portuguese and the article types were theses available on the internet databases including literature reviews, case reports and research papers.

3. Results

47 articles were found. and the analysis of each one showed that 30 articles were specifically about human identification or sex determination by the frontal and maxillary sinuses; 9 articles do not had relation with the specifically theme (sex determination or human identification), but were related in references and were used in other parts of this paper (as introduction and discussion); about the remaining 8 articles, 2 articles were excluded because of the publication language that was Chinese, and the 6 others reported technical aspects of the procedures or could not be correlated with the Forensic Dentistry context and it were excluded. Table 1 providing information such as author, year of publication, type of publication (case report, original research article, review, etc.), power (number of cases being examined), modality used (x-rays, CT, other), the anatomical region examined (frontal or maxillary sinus or both), analyzed implication and conclusion.

4. Discussion

In human identification, there are cases of wide body degradation, such as charred, skeletonized or in advanced stages of decomposition [2,4–6,8,10,22,28,35] and, in these cases, the study of anthropometric characteristics and anatomical peculiarities get fundamental importance, which enables the identity [5,6,8,9,15].

The analysis of the frontal sinuses has become quite solidly in the literature as a secure method for comparative radiographic studies that promote human identification [1,2,4,8,12,14,16–22], due to the fact these sinuses are unique to each individual [26,27,29], even among monozygotic twins [2].

The uniqueness of frontal sinus is justified by the large inter-individual variation [1,4,6,8,12,14,22,27] as the size, shape, symmetry, outer edges, presence and number of septa [12]; therefore this analysis meets the requirements of uniqueness, permanence, immutability [1], providing technical and scientific information to be used in forensic identification [8]. Comparisons of data provided by the specifics of the frontal sinus were feasible in most cases, with the remaining usually prevented by positioning the influence of radiographic examination, as well as the quality of the radiographs [17].

In human identification the uniqueness of frontal sinus is advantageous, but to sex determination this large individual variation inhibit the use [21,22,32] and, despite studies on the morphological analysis of the frontal sinuses like an ineligible method for this purpose [21,27,35], other studies indicate its use as an auxiliary method [2,22,28,32] and there are authors who claim more research is needed regarding to obtain a conclusion [22].

When it comes to the maxillary sinuses, its high specificity makes reliable the method for this parameter of human identification [9,23–25]. However, in the literature there are few studies that used this method, when compared to work performed using the frontal sinuses.

In relation to sex determination, it appears as valid by the structural comparison of the maxillary sinuses [9,23,30,31,33,34,36–38] and data presented in the literature clearly show that the volume and dimensions of the maxillary sinuses shown to be significantly higher in males than in females [9,33,34,36,37], except in children until six years of age [36]. The analysis of the maxillary sinus act as a helper method in sex determination [9,31,33,34,37,38]. However, there is no wider literature that analyses sex determination and therefore it is suggested that further studies about this subject are conducted in order to facilitate this determination [9].

It is evident that in cases where no one has the possibility of applying traditional methods of identification, analysis of the frontal and maxillary sinuses is important. Possible disadvantages are the need for *ante mortem* materials available for the compare and the possibility of this material does not present good quality (for example, a panoramic radiograph showing the cut or distorted maxillary sinuses). About the drawbacks of the *post mortem* imaging techniques in forensic identification and sex determination, the compromised integrity of anatomical structures can hinder the technique, and it's necessary trying to copy the conditions in life, for comparison. But the advantage is precisely the possibility of positioning the anatomical structure as it would be in life. In addition, the comparison of images is a completely viable method.

So, in a total of 30 papers presented in this review, 17 related the frontal sinus, 11 maxillary sinus and only 2 about both sinuses. About the methods of analysis of these paranasal sinuses, in the studies of the frontal sinus, 94,12% were based on radiographic images and only 5.88% were based on radiograph and computed tomography. Although in the studies of the maxillary sinuses, 36.36% used radiographic images and 63.64% used computed tomography. Regarding the articles that studied both frontal and maxillary sinuses, one half cited radiographs and the other half cited computed tomography.

In order of the forensic context, the subject of this study, the frontal sinus was associated in 70.59% to human identification, 23.53% to sex determination and only 5.88% to both purposes; in the studies with maxillary sinus, 72.73% were about sex determination, while 18.18% were about human identification and, 9.09% to both. The articles that studied the both sinuses, frontal and maxillary, were used to evaluated human identification. In this literature review, it were noted the trend of recent studies that use the frontal sinus to sex determination, the same is observed for the maxillary sinus, the studies focus on sex determination, and the most promising contribution mainly by computed tomography.

5. Conclusions

According to the literature review, is possible conclude that frontal and maxillary sinuses are useful tools for human identification. There is no agreement about the use of frontal sinus to sex

determination. In relation to the maxillary sinus, the application to sex determination is satisfactory.

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