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COMPARATIVE STUDY

Classification of the maxillary sinus according to area of the medial antral wall: a comparison of two ethnic groups

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Abstract
Objectives This study is an anatomical study designed to benefit surgeons working in the region of the maxillary sinus. This paper investigates ethnic and gender variations in the shape of the maxillary sinus in dried crania from the Raymond Dart collection of human skeletons. The paper claims that an estimate of the area of the medial antral wall of the maxillary sinus is one of the best ethnic/gender group predictors.
Methodology Helical, multislice computed tomography was performed using 1mm coronal slices length, depth, width and volume measurements for each sinus were taken. Classification by shape and estimated area of medial wall was attempted.
Results Shape classification was found to be unsuccessful whilst medial wall classification into ethnic/gender groupings gave encouraging results.
Conclusion The area of the medial wall is related to ethnic/gender groups.

Keywords Functional endoscopic sinus surgery · Maxillary sinus · Shape classification · Computed tomography · Correspondence analysis

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Introduction

Morphological classification of the maxillary sinus according to its shape or other parameters is of interest to surgical disciplines such as otorhinolarngology and maxillofacial surgery. Surgeons operating endoscopically in this region would benefit from the knowledge of shape differences across ethnic or gender lines due to a limited visibility during the procedure. In other surgical areas such as cancer surgery, reconstructive surgery or sinus lift procedures for dental implants, knowing the shape and size of the maxillary sinus in different ethnic or gender groups is beneficial. From an anatomical perspective, if a classification of the maxillary sinus according to ethnicity or gender is possible, then this variation should be highly relevant to surgery where a good understanding of the anatomy is of paramount importance to a successful surgical outcome. This is especially relevant in very small sinuses because access can be difficult.

The maxillary sinus is the most pneumatized of the paranasal sinuses and therefore the largest in size. They are pyramidal cavities extending into the bodies of the maxilla [1]. The maxillary sinus lies within the maxilla which is shaped like a quadrilateral pyramid [2]. Numerous authors concur that the sinus itself is shaped like a pyramid. The base of the pyramid is the medial wall of the sinus and forms part of the lateral nasal wall. The apex points towards the body of the zygomatic bone [3] and sometimes extends into the zygomatic process of the maxilla [1]. The floor of the sinus is comprised of the alveolar and palatine process of the maxilla. The roof of the maxillary sinus forms most of the orbital floor [2].

The shape of the antrum may or may not vary between individuals according to ethnic group or gender. This research will investigate ethnic and gender variations in the shape of the maxillary sinus in dried crania from the Raymond Dart Collection of Human Skeletons at the University of the Witwatersrand in South Africa.

Background

In a concurrent and recently published article Fernandes CL [4] demonstrates a significant difference between the volumes of European and Zulu maxillary sinuses and between male and female sinuses using the above mentioned crania. With a significant ethnic and gender variation in volumes it was theorized that there may be an ethnic or gender variation in the shape of the maxillary sinus in these groups. This research attempts to classify the maxillary sinus according to its shape as similarly described by Anagnostopoulou

who classified the sinus according to 4 basic solid shapes. The classification performed by Anagnostopoulou et al. is based on the fact that the sinus is pyramidal in shape and the apex is more or less rounded depending on the extension into the zygoma. The volume of a solid can be determined by the formula: *basearea x height x shape* where, possible shape coefficients are given in Table I.

In this research we re-investigate the classification of the maxillary sinus according to shape and then we show that simply using the area of the base of the maxillary sinus gives a better ethnic and gender predictor. In fact, with the aid of a neural network we will show that the area of the base is possibly the best ethnic/gender predictor possible.

Table I Geometric shape coefficients

Cone or pyramid	0.3333
Hyperboloid	0.39582
Paraboloid	0.5000
Semi-ellipsoid	0.6667

Table II Boundaries between shape coefficients

Conical		Shape ≤ 0.39
Hyperboloid	0.39 <	Shape ≤ 0.46
Paraboloid	0.46 <	Shape ≤ 0.53
Semi-ellipsoid	0.53 <	Shape

Table III Ethnic/Gender versus shape counts

	con	hyp	par	Ell
zulu male	4	8	14	0
zulu female	3	4	17	4
euro male	0	8	14	4
euro female	5	9	12	0

Table IV Boundaries between shape coefficients

small		wall area	≤ 471
medium	471 <	wall area	≤ 562
large	562 <	wall area	≤ 700
extra large	700 <	wall area	

Table V Ethnic/Gender versus wall area counts

	small	medium	large	extralarge
zulu male	13	4	7	2
zulu female	9	8	8	3
euro male	0	1	8	17
euro female	5	13	4	4

Table VI Neural network classification convention

	< 0.5	> 0.5
ethnicity	european	Zulu
gender	male	Female

Material and methods

In order to classify the maxillary sinus, 53 dried adult crania obtained from the Raymond Dart Collection of Human Skeletons (University of Witwatersrand) were selected according to the following criteria: 13 male and 13 female crania from persons of European descent and 13 male and 14 female crania from persons of Zulu descent.

The sinuses of the 53 dried crania (106 sinuses) were scanned in the coronal plane in a Toshiba Asteion Multislicer helical CT machine using the Brainlab protocol. Four crania were scanned simultaneously using a purpose built apparatus. 1mm slices were obtained at the following machine settings: 120kv, 200ma and reconstruction detail set to large.

Raw data was transferred from the scanner to a Vitrea 2 workstation. This data was also transferred to a Dell Pentium 4 laptop to allow viewing by Osiris Dicom format. A CD was made of the raw data. A magnetic optical disc of the raw data was also made directly from the CT scanner. Analysis of the data and volumetric calculations were made by tracing the outline of the maxillary sinus for each 1mm slice and totalling the number of slices for each sinus. A volumetric calculation for each sinus was done by the program on the CT machine once all the tracings for each sinus were complete. In addition, the greatest antero-posterior length, the greatest vertical height and the greatest width were measured for each sinus.

Classification by shape

As mentioned in the introduction we start our search for an ethnic and gender predictor by repeating the shape analysis of Anagnostopoulou et al. [3]. For each sinus a shape coefficient was calculated according to the formula:-

$$\text{Shape} = \frac{\text{measured volume}}{\text{estimated volume}} = \frac{\text{volume}}{\text{length x height x width}}$$

Each sinus was then assigned a shape type according to Table II which represents the boundaries between the shape descriptors of Table I. Once all the sinuses in the Raymond Dart dry crania collection have been classified a table of counts of ethnic/gender versus shape can be drawn up for the data. The result is shown in Table III.

From Table III, the shape coefficient does not provide an ethnic/gender group indicator. Most sinuses are classified as parabolic irrespective of their ethnic/gender groupings. To confirm that shape is not a good grouping predictor we performed a correspondence analysis as outlined in

Greenacre [5]. We coded the routine using the modelling language Mathematica and the result is shown in Fig. 1.

Consideration of Fig. 1 reveals that shape is indeed not a good predictor of ethnic/gender groupings. We have all ethnic/gender groups clustered about the parabolic shape with european males and zulu females slightly elliptical whilst european females and zulu males are slightly hyperbolic.

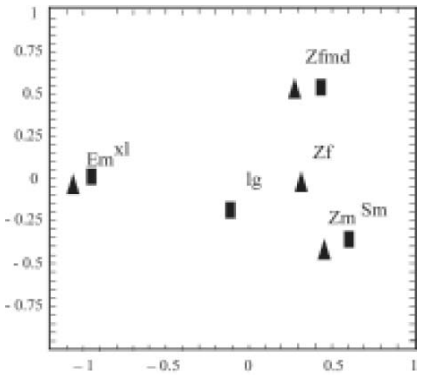

Fig. 1 Correspondence analysis (Ethnic/Gender versus shape)

Vertical axis: Gender
Horizontal axis: Shape Co-efficient
Legend
Zm = Zulu Male
Zf = Zulu Female
Em = European Male
Ef = European Female
ell = Ellipsoid
par = Paraboloid
hyp = Hyperboloid
con = Conical
Comment: Fig. 1 shows that differentiation between gender and ethnicity is poor using shape analysis as most sinuses are paraboloid in shape as demonstrated by the clustering which is also demonstrated in Table 3.

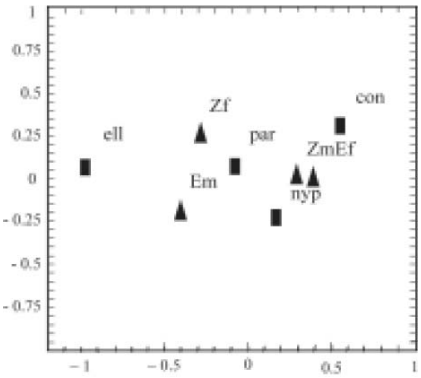

Fig. 2 Correspondence analysis (Ethnic/Gender versus wall area)

Vertical axis: Gender
Horizontal axis: Wall area (ie medial wall area of Maxillary sinus)
Legend
Zm = Zulu Male, Zf = Zulu Female
Em = European Male, Ef = European Female
xl = Extra Large, lg = Large, md = Medium
sm = Small
Comment: Fig. 2 shows good differentiation between ethnic and gender groups when comparing the medial wall area of the maxillary sinus. Note Clustering of em at xl point on graph and zm at the em point on graph showing that European Male sinuses have large medial wall areas and Zulu Male sinuses have small medial wall areas.

Classification by medial antral wall area

Surgeons operating endoscopically in this region have reported that it is more difficult to operate on Zulu sinuses compared to European sinuses due to the fact that the uncinate process is more laterally and inferiorly situated and it is therefore more difficult to locate the maxillary ostium which lies behind the posteroinferior attachment of the uncinate process.

Thus we decided to consider the area of the medial antral wall of the sinus to see if we could get a better ethnic/gender predictor. For each sinus a medial wall area was calculated according to the formula:

$$\text{wall area} = \frac{\text{measured volume}}{\text{width}}$$

Each sinus was then assigned a medial wall area type according to Table IV

The numbers in Table IV, which are in units of mm seem rather arbitrary. They were chosen to partition the data set into four groups of equal size. Once all the sinuses in the Raymond Dart dry crania collection were classified according to the area of the medial antral wall, a table of counts of ethnic/gender versus medial antral wall area can be drawn up for the data. The result is shown in Table V.

Table V looks more promising as an ethnic/gender predictor. It seems as if zulu males are on the small side and european males are on the large side. To confirm that the medial wall area is a good grouping predictor we run a correspondence analysis on the data in Table V to get the classification diagram shown in Fig. 2.

The correspondence analysis that produced Fig. 2 shows that zulu males can be classified as having small medial antral wall area, european males have extra large medial wall area, european females have medium medial wall area and zulu females have large medial wall area.

The remaining question is: Does the medial antral wall area offer the best prediction of ethnic/gender groupings?

Neural network classification

We felt it appropriate to use artificial neural network techniques in this research primarily because of their ability to recognize patterns and classify data. In biological systems, as in neural networks, learning and classification occurs through training by example.

Ethnic classification

It is a simple matter to estimate how effective the medial antral wall area is in predicting ethnicity alone. Using our data to estimate the total medial antral wall area of the two maxillary sinuses for each skull it was found

The neural net ethnic/gender prediction formulae are of the form

$$ethnicity = \frac{1}{1+2.72^{-0.38+\frac{4.12}{1+2.72^{4.28-1.60L-2.6H-4.81V+0.2W}}-\frac{3.58}{1+2.72^{-3.1+1.2L+2.2H+3.5V+0.6W}}}}$$

$$gender = \frac{1}{1+2.72^{-0.5+\frac{2.0}{1+2.72^{4.28-1.60L-2.6H-4.81V+0.2W}}-\frac{1.06}{1+2.72^{-3.1+1.2L+2.2H+3.5V+0.6W}}}}$$

where the letters L, H, W and V refer to the quantities length, height, width and volume that were measured for each maxillary sinus of each skull in the 53 skull collection. Note that the values of the constants in the above formulae (or weights as they are called in the Neural Net literature) may change from training run to training run. This is due to the fact that there is some randomness built into the Neural Net back propergation training algorithm. One must also remember that the above prediction formulae deliver predictions on a scale of 0 to 1. To obtain an ethnic/gender Table VI.

that the number ± 1200mm separates the two ethnic groups in such a fashion that 70% of the skulls are correctly ethnically classified according to the formula:

Ethnicity = ((zulu…total area<1200
(european…total area>1200

This formula gives incorrect ethnic classification for the remaining 30% of the samples.

To see if this was the best ethnic classification possible using our data, the authors commissioned computer science honours student, Richard Pierce-Jones, to build a neural network using our data as a training set for the neural network. After training by the back-propagation method the best neural network could also only predict the ethnic groupings of 70% of the skulls. However it performed a little better with the incorrect classifications in that it misclassified 15% of the skulls and labeled as unclassifiable the remaining 15%.

Unfortunately, gender classification was unsuccessful and the best neural networks could only produce correct gender classifications 50% of the time, which is no better than guessing. These results are all reported in Table VI [6].

Ethnic/Gender classification

Given an arbitrary skull, if one were to make an ethnic/gender classification by simply guessing, one could expect to be correct 25% of the time. It is a simple matter to show that for this collection of data the medial antral wall area estimate gives a 48% success rate when used to predict ethnic/gender groupings. This is almost as twice as good as guessing. To see if the medial antral wall area provides the best possible ethnic/gender predictor one needs to consider a family of all possible predictors using the given data. We decided to repeat the experiment and build, train a neural network to see if better ethnic/gender predictors could be found. Our neural net for predicting ethnic/gender groupings achieved a 48% success rate showing that the much simpler wall area formula provides a good rule of thumb for ethnic/gender predictions.

Discussion and Conclusion

The question as to whether there are ethnic and gender anatomical differences in the maxillary sinuses of dry crania is interesting. As the maxillary sinus is of anatomical interest, the subject of research, a site of disease and frequently operated on, it has been of value to investigate its shape and attempt a morphological classification.

This research shows that, despite a significant difference along gender and ethnic lines in volume, there is very little difference in the shape of the maxillary sinus. The sinus appears to preserve a parabolic-hyperbolic shape despite quite marked variations in volume. The sinus appears to maintain its integrity of shape throughout the range we analyzed.

The variation in volume found by Fernandes CL [4] indicates that there should be a corresponding variation in anatomy or in shape.

The ethnic classification using medial wall area to predict ethnicity produced an acceptable result of 70%. This successful ability to predict ethnic group has implications for maxillofacial surgery, dental implant surgery, plastic and reconstructive surgery. It would also have relevance to archaeologists, anatomists and forensic pathologists or criminologists where it would be of value to predict the ethnic group of a cranium of unknown origin from the area of the medial wall of the maxillary sinus.

The best predictor of ethnicity and gender given an unknown skull is also the area of the medial wall of the maxillary sinus. For endoscopic sinus surgeons, this is of significance because the medial wall of the maxillary sinus forms the major part of the lower portion of the lateral nasal wall. As all the crania were of similar size, the portion of the lateral nasal wall taken up by the medial wall of the maxillary antrum was greatest in European males and least in Zulu males. This means a corresponding difference in anatomy and differences with ease of access into the middle meatus and ostia of the middle meatus during endoscopic sinus surgery.

Access through the inferior meatus to the maxillary sinus for sinus washout procedures or for inferior intranasal antrostomy will be more restricted in Zulu males than in European males. There is a corresponding difference in female anatomy. The structures of the pterygo-maxillary fissure will have easier access posteriorly with a smaller sinus. This means that surgeons can access the sphenopalatine artery in cases of epistaxis more readily and the vidian nerve is more accessible in the Zulu patient than in the European patient. With a smaller sinus, as in the Zulu, the middle meatus will be more inferior and lateral making access to the meatus more oblique and thus more difficult. The uncinate attachment will be more inferior, lateral and oblique with a smaller sinus and access to the maxillary ostium will be more difficult in the Zulu. The orbital wall will be more exposed to the surgical damage. External access through the canine fossa can also be more difficult. A small sinus would be more laterally placed and inadvertent entry into the nasal cavity may occur more medially.

This research concludes that morphometric ethnic classification of the maxillary sinus according to its shape is most successful when taking the area of the medial wall into account, resulting in a 70% predictive ability. Gender classification is not possible in this way. Classification of the sinus according to its overall shape, using a shape coefficient demonstrated that shape is not a good ethnic or gender predictor. Anatomical differences in the antrum are therefore related to different sizes of the medial wall of the maxillary sinus in the European crania. Therefore an ethnic anatomical difference does exist in the maxillary sinus. Surgeons operating in this field should be aware of these ethnic differences in order to avoid some of the surgical complications.

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Special approval

Ethical approval for the study was given by the Ethics committee of the faculty of medicine of the University of Natal in 2002.

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