Accuracy of Sphenoidal Sinus Morphometry in Forensic Identification Using Cone Beam Computed Tomography

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Abstract

Bony identification is the foundation of forensic investigation when the corpses are beyond recognition.The present study was performed to identify the accuracy and reliability of the sphenoidal sinus (SS) morphometry in forensic identification by using CBCT imaging . Using ITK-snap software, a set of 112 cone beam computed tomography (CBCT) images for both genders were retrospectively analyzed. The age ranges between 20-50 years old. The height, width, breadth and volume of sphenoidal sinuses were measured.

SS lateral-lateral (width), antero-posterior (breadth) and volume were significantly greater in males than in females. SS volume was the best discriminant parameters that could be used to differentiate males from females with Wilk's Lamda = 0.890 and an overall accuracy of 63.4%. By using multivariate analysis, 67.9% of SS dimensions of females and 60.7% of SS dimensions of males were sexed correctly.

CBCT imaging can provide valuable information of SS and could be used for sexing with moderate accuracy when other methods are inconclusive.

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Introduction

At the middle of the skull, the sphenoidal sinus (SS) is located, making it the most inaccessible part of the face. It is encased directly below the Sella Turcica in the sphenoid body. The sphenoid 's body is cubic in shape and is usually divided to shape cavities by one or more narrow septa. It makes the sinus asymmetrical and differs in size and form because of the form and irregularity of the septum.[1] Moreover, the relations of the SS with the adjacent structures are close when the sinus is well pneumatized. When this happens, the surrounding vessels and nerves are seen in the sinus cavity as irregularities or ridges.[2]

Owing to the unique position and the anatomical relationship in its internal walls, it is important to understand the internal anatomy of the SS. With the advancement of imaging technology, the paranasal sinuses are now assessed with computed tomography replacing previous means like plain radiography and cadaveric studies.[3,4] In contrast to other, larger open- source programs, ITK-SNAP is an image analyzing tool designed to explore three-dimensional images, focusing on image segmentation while keeping in essential features at a minimum. It grants a semi-automatic segmentation using a level-set method making the segmented structures appear more homogenous, thus making it an accurate easy tool to use.[5] In addition, the use of CBCT has become more prevalent in many countries and in everyday dental practice as their use in implant placement, endodontic and orthodontics has been more demanding leading to CBCTs being more readily accessible.[6-8] This results in an increased database of CBCTs which makes it widely achievable to retrieve CT images of missing people where it could be used for identification purposes.[9]

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In cases of natural disasters and catastrophic events such as chemical & nuclear bomb explosions and crime inspections, body identification is the foundation of forensic investigation when the corpses are beyond recognition. The purpose of this study is to provide linear and volumetric SS data analysis by segmentation on a sample of 112 CBCT images in order to verify sexual dimorphism using publicly accessible volume measurement tools.

Materials and methods

A total of CBCT images of consented subjects (56 males and 56 females) with an age range from 20-50 years were retrieved from the archive of Oral & Maxillofacial Radiology Department of our institute . Using simple convenient sampling method with the use of G Power software 3.1.9.3 for sample size estimation of independent samples (assuming medium effect size (d) =0.5, **α**-error probability = 0.05 and 1-β probability = 0.95).[10] The minimum sample size will be 56 subjects for each group. Ethical approval from the research and ethics committee was obtained under the number: (REC-20-01-25-01-S).

Inclusion Criteria:

This cross sectional retrospective study included CBCT scans of sphenoidal sinus where individual factors of gender, age and indication for scanning had been recorded. The subjects' age group was limited to early and middle adults with ages range 20-50 years since sphenoidal sinus volume reach maximum during third decade of life [11] and sinus pathology like fungal infection is more commonly detected in elderly patients (over 50 years old).[12,13]

Exclusion Criteria:

Any subjects with a history of maxillofacial pathologies, congenital or developmental anomalies, septal deviations, sphenoidal sinusitis, and previous surgeries or facial trauma were excluded.

The antero-posterior (AP) and lateral-lateral (LL) dimensions of the sinus were measured using the widest point found from the transverse section, the same procedure was carried out for the superior-inferior (SI) dimensions but from the coronal section using the image annotation mode feature of the CBCT software. (Figure 1) The DICOM files of the CBCT images were uploaded onto the ITK-SNAP software. The SS was identified using the active contour segmentation mode of the software, followed by the segmentation of the images, and the adjustment of the threshold mode. The volumetric measurement of the whole SS (in mm^3) was processed using the semi-automatic segmentation feature. Since the SS is connected to the nasal cavity, the volumetric segmentation has to be precisely chosen.

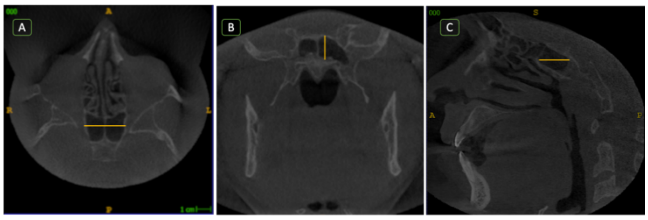

Figure 1. a-c. Linear measurement of the sphenoidal sinus,
a: Longest horizontal distance of the sphenoidal sinus (axial view). b: Longest inferio-superior distance of the sphenoidal sinus (coronal view). c: Longest antero-posterior distance of the sphenoidal sinus (sagittal view)

The analyses were conducted by a maxillofacial radiologist (AU) with more than 25 years of experience and certified in the program ITK-SNAP 3.0® (Cognitica, Philadelphia, PA, USA) and had detailed knowledge of the paranasal sinus's tomographic anatomy. The 3D model reconstruction was carried out with the semi-automatic segmentation feature of the program. The anterior, posterior, lateral, superior and inferior walls of the sphenoidal sinus were the boundaries for choosing the region of interest to be segmented. With the Snake ROI tool, the area of interest was delimited (Fig. 2).

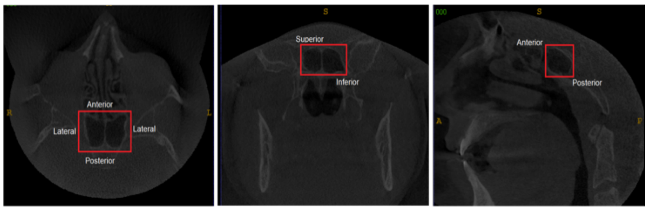

Figure 2. Selection of ROI and limits represented in the sphenoidal sinus.

In the software's 3D pane, the segmentation of the sinus image was reconstructed. The volume was determined by the software itself in cubic millimeters (mm^3). (Fig. 3).

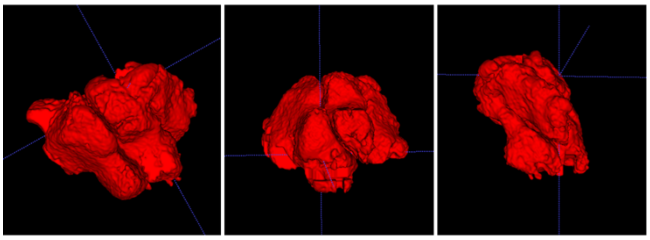

Figure 3. Volumetric images of the 3D reconstruction of the sphenoidal sinus by software. 3D reconstruction of the sphenoidal sinus in different planes.

Intra-examiner and inter-examiner reliability were done by measuring the above-mentioned dimensions of 15 CBCT images which were then repeated after ten days to determine the percentage error. Reliability analysis for measuring internal consistency using paired t-test and Cronbach alpha were done to compare the inter-examiner results and intra-examiner results. Quantitative variables were expressed as mean ± SD. The difference between females and males were tested using independent sample t-test. Furthermore, one-way ANOVA test was done to study the effect of aging on the SS dimensions and to compare the results. In addition, Pearson's correlation coefficient was also used to estimate the strength of association between the studied variables. Finally, discriminant analysis (A type multiregression analysis) was conducted to predict the gender value based on the studied variables. This analysis was done for each predictor alone and another discriminant analysis was done for all significant predictors in one model after exclusion the parameters of non-significant results. Measurements were considered statistically significant if $p < 0.05$ using IBM SPSS ® (Ver. 23, Chicago, IL, USA).

Results

I. Inter- and intra-examiner reliability

In order to ensure that the measurements of the SS volume were carried out in a reliable and consistent manner, inter-examiner and intra-examiner reliability tests were carried out using paired t-values and Cronbach's alpha. Table (1) showed the inert and intra- examiner internal consistencies of the measured parameter.

II. Gender difference among studied variables

1. Gender differences among the studied variables

The males showed significantly higher AP (28.46±5.58 mm), LL (34.96±7.81mm), and volume (11354.57±4500.07 mm^3) values when compared to females (25.60±5.33 mm, 31.59±5.36 mm, and 8781.41±2682.68 mm^3 respectively) as shown in Table (2). Moreover, a non- significant statistical difference between females and males regarding age, septa, and SI was observed.

Reliability test	t value	Cronbach's alpha
Inter examiner	0.07	0.99
Intra examiner	0.13	0.97

Table 1. Examiners reliability tests.

Variable	Females (n=56)		Males (n=56)		t value	P value
	Mean ±SD	Range	Mean ± SD	Range		
Age	35.63±8.38	20-50	35.59±8.26	21-50	0.023	0.982
Septa	2.00±0.97	1-5	2.04±0.99	1-5	0.193	0.848
AP	25.60±5.33	14.07-39.48	28.46±5.58	14.25-38.97	2.76	0.007*
SI	23.80±3.89	14.17-32.17	24.93±4.26	14.21-33.97	1.46	0.146
LL	31.59±5.36	21.40-47.42	34.96±7.81	13.71-54.65	2.66	0.009*
Volume	8781.41±2682.68	2475-13410	11354.57±4500.07	3143-22500	3.68	0.0004*

Table 2. Gender differences among the studied variables.
AP: antero- posterior, LL: Lateral- lateral, SI: supero-inferior.
*Significantly different at p <0.05.

Variable	Age groups						F Value	P value
	Group 1 (20-29 years)		Group 2 (30-39 years)		Group 3 (40-50years)			
	Mean± SD	Range	Mean± SD	Range	Mean± SD	Range		
Septa	1.94± 0.79	1-3	2.16±1.09	1-5	1.86±0.95	1-4	1.004	0.370
AP	28.44± 5.18	18.47-38.97	26.18±6.19	14.25-39.48	26.90±4.87	14.07-34.02	1.640	0.199
SI	25.42± 4.15	14.17-33.81	23.93±3.92	14.79-33.97	23.90±4.27	14.21-29.47	1.591	0.208
LL	33.42± 5.19	24.04-47.42	32.22±6.93	13.71-49.67	34.93±8.24	20.48-57.65	1.453	0.238
Volume	11017.33 ±4201.65	4181-21100	9515.00± 3986.31	2475-22500	9941.14± 3907.72	3778-15420	1.503	0.227

Table 3. Measured variables according to various age groups.
AP: antero- posterior, ML: Lateral- lateral, SI: supero-inferior.
*Significantly different at p<0.05.

2. Measured variables according to various age groups

As shown in Table (3), there was no significant statistical differences among all age groups, which indicates that there is a baseline characteristic that was achieved regarding age categories. So, the age categories are not considered as confounder.

3. Correlation between different variables in female and male groups

The results of correlation were shown in Table 4 for females and Table 5 for males.
Regarding females, there was a significant positive correlation among all measurements done as shown in Table (4). The correlation between SI with volume was the strongest (r=

0.666, P<0.01), followed by AP with volume (r= 0.661, P<0.01), then LL with volume (r=0.631, P<0.01).

Females	Age	Septa	AP	SI	LL	Volume
age	1	-0.002	-0.097	0-.015	0.009	-0.080
septa	-0.002	1	-0.019	0-.253	0.177	-0.129
AP	-0.097	-0.019	1	0.548**	0.435**	0.661**
SI	-0.015	-0.253	0.548**	1	0.388**	0.666**
LL	0.009	0.177	0.435**	0.388**	1	0.631**
Volume	-0.080	-0.129	0.661**	0.666**	0.631**	1
Males						
age	1	-0.005	-0.102	-0.149	0.097	-0.127
septa	-0.005	1	0.273*	0.402**	0.377**	0.460**
AP	-0.102	0.273*	1	0.682**	0.616**	0.840**
SI	-0.149	0.402**	0.682**	1	0.430**	0.756**
LL	0.097	0.377**	0.616**	0.430**	1	0.651**
Volume	-0.127	0.460**	0.840**	0.756**	0.651**	1

Table 4. Correlation between different studied variables in female group.
The correlation between AP with volume was the strongest (r= 0.840, P<0.01), followed by SI with volume (r= 0.756, P<0.01), then AP with SI (r=0.682, P<0.01).

Regarding males, there was significant positive correlation among all measurements done, a shown in Table (4).

It was noticed that correlation between studied variables is stronger in males than in females.

5. Discriminant analysis using studied variables to discriminate between genders

The equation obtained from the discriminate model to calculate D will help in the prediction of gender by substituting the values of the studied variable (s) in the equation. The resulting value of D was compared with a reference value (obtained also from the model by averaging the 2 functional centroids). A value of calculated D greater than reference D indicates male gender, while a value less than the reference value indicates female gender. The model calculated for the studied parameters was statistically significant regarding AP, LL, and volume only while it was non-significant for age, septa, and SI. Among the significant radiological measurements included, volume was the best discriminator, followed by AP, then LL (Tables 5). Adding the three significant radiological measurements to the regression model resulted in the highest overall classification accuracy for gender (Wilk's Lamda = 0.890, ovaerall accuracy = 64.3%). In addition, this combination showed that volume was the best discriminator, followed by LL, then AP (Tables 5).

Age			
D = -4.281 + 0.120 Age Wilk's Lambda = 1.00, P = 0.982 (NS)			
Percentage of accurately predicted group membership	**Female**	**Male**	**Overall**
	50%	46.4%	48.2 %
Functions at group centroids	- 0.002	0.002	NS
Septa			
D = -2.056 + 1.019 Septa Wilk's Lambda= 1.00, P = 0.848 (NS)			
Percentage of accurately predicted group membership	**Female**	**Male**	**Overall**
	73.2%	33.9%	53.6%
Functions at group centroids	-0.018	0.018	NS
AP			
D = -4.953 + 0.183 AP Wilk's Lambda= 0.935, P = 0.007 (S)			
Percentage of accurately predicted group membership	**Female**	**Male**	**Overall**
	62.5%	67.9%	65.2%
Functions at group centroids	-0.261	0.261	Classified male if D > 0.00
SI			
D = -5.972 + 0.245 SI Wilk's Lambda= 0.981, P = 0.146 (NS)			
Percentage of accurately predicted group membership	**Female**	**Male**	**Overall**
	50%	58.9%	54.5%
Functions at group centroids	-0.138	0.138	NS
LL			
D = -4.968 + 0.149 ML Wilk's Lambda= 0.940, P = 0.009 (S)			
Percentage of accurately predicted group membership	**Female**	**Male**	**Overall**
	69.6%	58.9%	64.3%
Functions at group centroids	-0.251	0.251	Classified male if D > 0.00
Volume			
D = -2.718 + 0.0003 Volume Wilk's Lambda= 0.891, P = 0.0004 (S)			
Percentage of accurately predicted group membership	**Female**	**Male**	**Overall**
	64.3%	62.5%	63.4%
Functions at group centroids	-0.347	0.347	Classified male if D > 0.00

Table 5. Discriminant analysis using studied variables to discriminate between genders.
AP: antero- posterior, LL: Lateral- lateral, SI: supero –inferior.

The equation obtained for calculating D was as follows: D = -3.076 - 0.004 AP + 0.020 ML + 0.0003 Volume, and this is useful in classifying an unknown gender (after substituting the selected measurements) into either male (if the discriminant score is >0.00) or female (if the discriminant score is <0.00). The confidence in male diagnosis is higher when the value of D is much higher than the reference value of 0.00, and the confidence in female diagnosis is higher when the value of calculated D is much lower (in the negative direction) than the reference value of 0.00 (Table 6).

	Standardized coefficients		
AP **LL** **Volume**	-0.023 0.137 0.924		
D = -3.076 - 0.004 AP + 0.020 ML + 0.0003 Volume Wilk's Lambda = 0.890, P = 0.005 (S)			
Percentage of accurately predicted group membership	**Female**	**Male**	**Overall**
	67.9%	60.7%	64.3%
Functions at group centroids	- 0.349	0.349	Classified male if D > 0.00

Table 6. Discriminant analysis using significant studied variables after exclusion the non-significant ones to discriminate between genders.
AP: antero- posterior, LL: Lateral- lateral, SI: supero –inferior.
D: discrimination score, NS: non-significant discrimination, S: significant discrimination at P < 0.05.

Discussion

The study of anthropometric characteristics is of fundamental importance when solving problems related to identification. One of the most important aspects of forensic anthropology is sex identification, in circumstances where the bones are significantly damaged due to natural diseases, chemical and nuclear bomb explosions.[14] Next to the pelvis, the skull is the most easily sexed portion of the skeleton, but the determination of the sex from the skull is not reliable until well after puberty. The craniofacial structures have the advantage of being composed largely of hard tissue, which is relatively indestructible.[15] When the skeleton exists completely, sex can be determined with 100% accuracy. This estimation rate is 98% in the existence of the pelvis and cranium, 95% with only the pelvis or the pelvis and long bones and 80–90% with only the long bones. However, in explosions, warfare and other mass disasters like aircraft crashes, identification and sex determination are not very easy.[14]

When all other ways fail to exist, paranasal sinuses have been found to be of benefit when acquiring sexual dimorphism. It has been found that both the maxillary and frontal sinuses remain intact and are damage resistant .[15,16] 483 paranasal sinus CT scans were analyzed by Akhlaghi et al., where the difference between males and females in the maximum height and width of the frontal sinus was significant .[16] Michel et al. studied the frontal sinus using CT scans and observed that the mean volume for the two sexes for the left and right sinuses was statistically significant.[15]

Kanthem et al. examined maxillary sinuses of 30 patients using CT scans to identify the sex of an individual using the height, length, width and volume of the maxillary sinus on the right and left side which was significantly different.[14] Uthman et al. concluded that the mean value of the total distance of right and left maxillary sinuses showed a statistically significant sex difference along with the height, length and width.[17]

However, in cases where both the maxillary and frontal sinuses are not preserved, congenitally missing or severely injured, it would impair their use in sex identification and make them less of an ideal candidate compared to the sphenoidal sinus which is deeply buried inside the cranial base in the sphenoidal bone. For the purposes of identification, it is considered very necessary as it has been stated that the sinus is highly shielded from any injury in cases of serious injuries or fire incidents.[9]

The internal records of Institute of Legal Medicine (Milan, Italy) stated that “regarding burned cases which have been recorded in the past 10 years demonstrate that the sphenoidal sinus is preserved perfectly in 9 out of 10 cases, in comparison to the frontal sinuses which has been preserved in only 1 out of 10 cases”. This further highlights the potential use of the sphenoidal sinus when other structures or human traces are no longer obtainable to identify the remains of humans. In addition, other laboratory internal records attained from forensic burials or even archeological sites showed that the sphenoidal bones were not only well preserved (in 60% of the cases) but also extremely recoverable in those cases where no other human remains were retrieved.[9]

Nowadays, CBCT has great role in dental procedures and evaluation of paranasal sinuses. CBCT machines are increasing being marketed and commonly used for a variety of purposes in oral implantology, dento-maxillofacial surgery, image guided surgical procedures, endodontics, periodontics and orthodontics. The equipment design is easier to use, image distortion is minimal, and the images are compatible with other planning and simulation software and it is cost effective and lesser radiation dose used when compared with conventional CT.[6]

The volume of data that is acquired during a CBCT scan is stored, reformatted, and realigned. Elimination of superimposition of the area under investigation with other neighboring structures is the major advantage of CBCT imaging compared to the 2D imaging. With multiplanar imaging, images can be recreated in different planes (flat or curved). Images can be displayed in axial, sagittal, coronal views, panoramic reconstruction, cross-sectional views, and 3D reconstructions.[18]

The sphenoid sinus offers fascinating knowledge about people; many researchers are researching it using either a corpse [19] or radiological images. [19-23] In addition, other studies have comprehensively analyzed MRI or computed tomography (CT) images.[24] We used CBCT images in this study to evaluate the volume, septal differences, and various axial lengths of the SS and compare the results between gender and adult age groups. The volume of the SS was analyzed in nine different age groups by Yonetsu et al. denoted that the volume increased until the third decade, then steadily decreased in the following decades.[11]

This result is in line with our findings, where the volume of SS has changed between age groups, particularly between the first and third age groups but without reaching statistically significant differences. Cohen et al. measured SS among individuals between the ages of 25 and above, then further divided the sample size into those above and below the age of 65. Individuals under the age of 65 had a slightly greater SS volume.[4] Jat et al. stated that the SS shows continuous growth from the age of 10 until the age of 22. [25] Due to significant variation in SS measurements before age 20, and to prevent bias, the present study was conducted on subjects above 20 years old, since the SS tends to stabilize at this age. Using regression statistical model, SS volume in the present study was the best discriminator between males and females with Wilk's lambda =0.890 and an overall accuracy of 64.3%. Gibelli et al. found that females had smaller SS volumes relative to males and that the volume differed significantly with the form of SS. In the Gibelli et al study, the SS volumes of women measured were close to those measured in the present study (8381 vs 8781mm^3). [3] Oliveira et al. examined 25 men and 25 women with 3D reconstruction and computer graphics applications via CT of Brazilian sample. They noted that males had greater SS volumes than females. [26] Similarly, Ramos et al, recently measured the SS volume using ITK-snap software that was used in the current study and found a statistically significant higher SS volume of males compared to females and was very similar to that found in the current study, especially for males (11304 vs 11354 mm^3).[27]

In addition, Cohen et al. concluded that males on all sides of the SS had substantially greater volumes than females.[4] These results were in accordance to our findings where SS volumes of males were substantially greater than those of females ($p<0.001$). On contrary, two studies, did not notice any substantial difference between males and females in volumetric measurements.[11,26] This could be due to the various measurement methods used, they used helical CT scans instead of CBCTs, and the sample collected of different ethnicity could be another factor. As our sample was made for Arab ethnicity. The SS volume was 11354 ± 4500 mm^3 for males and 8781 ± 2682 mm^3 for females. Ozer et al. [9] also found a high standard deviation value of (± 4245 mm3) in the total SS volume measurement, which is greater than what we observed (± 3907). Some literature has provided few studies concerning size of sphenoid sinuses, and the present results can be compared with the existing data from other geographic context; the comparison highlights a relevant ethnic difference (Table 7).

Study	Population	SS total volume Males (mm^3)	SS total volume females (mm^3)
Gibelli et al. (3)	Italian	9886	8381
Coehn et al. (4)	Israeli	4740	3550
Selcuk et al. (29)	Turkish	7030	6000
Ramos et al (25)	Brazil	11304	10000
Present study	Emirati	11354	8781

Table 7. Comparison of volumes of sphenoid sinuses in different populations: all values are expressed in mm^3.

Kim et al. support the existence of racial differences and explain the higher volume of sphenoid sinuses in Asian by the larger skulls in comparison with the rest of the body.[28] Regarding the presence and absence of SS septa, Ozer et al. found that 3.4% of their studied sample presented with no septa at all.[9] In the present study, the least number of septa found was 1 with the highest frequency rate of (41%) and the maximum number of septa observed was 5 with the lowest frequency rate (2%). This variation in the number of septa could be attributable to the different radiographic measurement techniques adopted by other studies.

The lack of knowledge about other craniofacial dimensions (such as head diameter and facial types, etc.) that may have an impact on sphenoidal sinus morphometry is a drawback of the present research. Therefore, to study the effect of these parameters on the sphenoid sinus, further studies are needed with bigger sample size and wider age range.

Conclusions

Sphenoidal sinus measurements are valuable in studying sexual dimorphism in forensic investigations. Sphenoidal sinus dimensions tend to stabilize after the second decade of life and the CBCT images can provide reliable measurement of these dimensions. This study also concluded that forensic anthropologists may be able to distinguish unrecognizable bodies and skeletal remains based on gender using the volume of the sphenoidal sinus when other methods are infeasible.

List of Abbreviations:

ANOVA: Analysis of Variance
AP: Anteroposterior
CBCT: Cone Beam Computed Tomography
D: Cohen's D
DICOM: Digital Imaging and Communications in Medicine
ITK-SNAP: a software application used to segment structures in 3D medical images
LL: Lateral-Lateral
MRI: Magnetic Resonance imaging
ROI: Region of Interest
SI: Superio-inferior
SS: Sphenoidal sinus
UDHS: University of Sharjah Dental Hospital.

Declaration of Interest

The authors report no conflict of interest.

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