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ORIGINAL ARTICLE

Relationship between sphenoid sinus volume and protrusion of internal carotid artery and optic nerve: a 3D segmentation study on maxillofacial CT-scans

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Abstract

Purpose Anatomy of sphenoid sinuses has acquired a growing importance with the diffusion of transsphenoidal surgical procedures. A common risk in these practices is the damage of internal carotid artery (ICA) and optic nerve (ON), which may protrude into the sphenoid air cavities. This study aims at analysing the relationships between sphenoid sinuses volume and protrusion of ICA and ON.

Methods 260 head CT-scans were retrospectively analysed (equally divided among males and females, age range 20–92 years). Volume was segmented through ITK-SNAP software. In addition, the subjects were classified into four groups: no protrusion of any structure (group 1), protrusion of ICA (group 2), protrusion of ON (group 3), protrusion of both ICA and ON (group 4). Possible statistically significant differences in prevalence of the four groups according to gender were assessed through Chi-squared test ($p < 0.05$). Differences in volume between the four groups were assessed through one-way ANOVA test ($p < 0.05$), separately for males and females.

Results Group 1 was the most frequent (40.0%), followed by group 4 (27.7%) and group 2 (18.5%), without any difference according to gender. For what concerns volume, cases of ICA and concomitant ICA + ON protrusion had significantly larger sinuses, whereas isolated ON protrusion did not modify sinus volume.

Conclusions Results show that protrusion of ICA is positively related with the volume of sphenoid sinuses, whereas the same relation was not verified for ON: surgeons should accurately consider possible ON protrusion in each case, as it may occur independently from sphenoid sinuses volume.

Keywords Sphenoid sinus · Internal carotid artery · Optic nerve · CT-scan · 3D segmentation

Introduction

Sphenoid sinuses are two pneumatised structures located in the body of the sphenoid bone: from an embryological point of view, they can be divided in an orbito-sphenoid (deriving from mesoderm) and a basis-post-sphenoid part (deriving from the neural crest) [1]. The right and left sinuses are divided by an intersphenoidal septum, highly variable among different individuals: therefore, size of the two sinuses may be extremely different [2]. In addition, there is a wide variability in sinuses pneumatisation, ranging from absent to extensive [3, 4].

Recently, sphenoid sinuses have gained a special importance with the diffusion of transsphenoidal surgical techniques: in these procedures, the sphenoid sinuses become the optimal surgical access for the treatment of several pathologies, including intrasellar and cranial base tumors [5, 6]. The transsphenoidal approach is more efficient and is associated with lower morbidity and mortality in comparison with the traditional transcranial one [7]. Therefore, the assessment of sphenoid sinuses morphology has acquired

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a growing importance in planning and managing surgical procedures [8].

The importance of anatomical research on sphenoid sinuses is even more evident when considering the close relationships of these air cavities with important surrounding structures, such as the internal carotid artery (ICA), the optic nerve (ON), the maxillary and the vidian nerves [8]. In case of extensive pneumatisation, the above-mentioned structures may protrude into the air spaces, sometimes without any bone separation [9]. In these conditions, they may be injured during transsphenoidal surgical procedures, with catastrophic consequences [9, 10].

CT-scan technology allows researchers to extract volume of anatomical structures through 3D segmentation procedures [11]. Volume of sphenoid sinuses has already been calculated by several articles [12–16]. However, no study has so far analysed the possible relation between the volume of sphenoid sinuses and protrusion of close anatomical structures into the air cavity.

This study aims at filling this gap, assessing the prevalence of protrusion of ICA and ON into the sphenoid sinuses and analysing the possible relationship with their volume.

Materials and methods

For the present study 260 patients (130 males and 130 females) aged between 20 and 92 years (mean: 49.0 ± 19.4 years and 52.2 ± 21.0 years in males and females, respectively) were retrospectively assessed from a hospital database of maxillofacial CT-scans. Requests for CT-scans were justified by screening of cranial fractures in trauma (57.3%), sinusitis (20.0%), neurological symptoms (12.7%). Patients affected by cranial deformation, traumatic injuries and sinusitis involving the sphenoid sinuses were excluded from the study.

All CT-scans were anonymized. The study was performed according to local laws and guidelines by Helsinki Declaration.

CT-scans were performed through a second generation dual-source scanner, Somatom Definition Flash (Siemens, Forchheim, Germany), with the following parameters of acquisition: kV: 120, mAs: 320, collimation: 40 × 0.6 mm, tube rotation: 1 s; reconstruction thickness: 3 mm; reconstruction filters: H21s smooth for soft tissues and H60 sharp for bone.

Three-dimensional semi-automatic segmentation of sphenoid sinuses was performed through ITK-SNAP open source software [11] according to a protocol already described in a previous publication [12]. In detail, a "seed" was located in each sphenoid sinus, which automatically increased in size, permeating the entire air space within the limits of the mucosa and the bone walls (Fig. 1). The entire procedure of segmentation of air spaces was found repeatable [17]. Volume of both sphenoid sinuses was automatically calculated through VAM® software (Vectra Analysis Module, version 2.8.3, Canfield Scientific®, Inc.).

Morphology of sphenoid sinuses was analysed in each CT-scan, with special attention to possible protrusion of ICA and/or ON: protrusion into the air space was defined whenever a part of the ICA or ON section produced an indentation of the sphenoid sinuses, in the transverse and coronal views, respectively (Fig. 2).

The entire sample was divided into four groups according to ICA and/or **ON** protrusion into the sphenoid sinuses: no protrusion of any structure (group 1), protrusion of ICA (group 2), protrusion of ON (group 3), protrusion of both ICA and ON (group 4). Percentages of cases included in each group were calculated, together with the average volume of sphenoid sinuses, divided between males and females.

Age distribution between genders was tested by an independent Student's *t* test, ($p < 0.05$). Possible statistically significant differences in the prevalence of the four groups between males and females were assessed through Chi-squared test ($p < 0.05$). Differences in volume between the four groups were assessed through one-way ANOVA test ($p < 0.05$), separately for males and females. Post-hoc tests were performed through Tukey HSD test ($p < 0.05$). All the statistical analyses were performed through SPSS® software.

Results

No statistically significant age difference was observed according to gender (Student's *t* test, $p > 0.05$).

Overall results are exposed in Table 1. In both genders, the most represented group was the first one (no protrusion of any structure, 40.0% on the entire group), followed by group 4 (protrusion of both ICA and ON, 27.7%), and group 2 (protrusion of ICA alone, 18.5%). The isolated protrusion of ON is the rarest (13.8%). All cases of ICA and ON protrusion were bilateral. No statistically significant differences were found in the distribution of groups between males and females (Chi square: 1.58; *p* 0.664).

For what concerns volume, a statistically significant difference was found among groups, both in males (F 20.21; $p < 0.0001$) and in females (F 21.82; $p < 0.0001$). Results of Tukey HSD test are exposed in Table 2, and were similar in both genders: statistically significant differences in volume were found between group 1 (no protrusion), and groups 2 (ICA protrusion) and 4 (ICA and ON protrusion), between group 2 (ICA protrusion) and group 3 (ON protrusion), and between group 3 (ON protrusion) and group 4 (ICA and ON protrusion). In detail, in all cases where a protrusion of ICA (alone or combined with ON) was found, the volume of

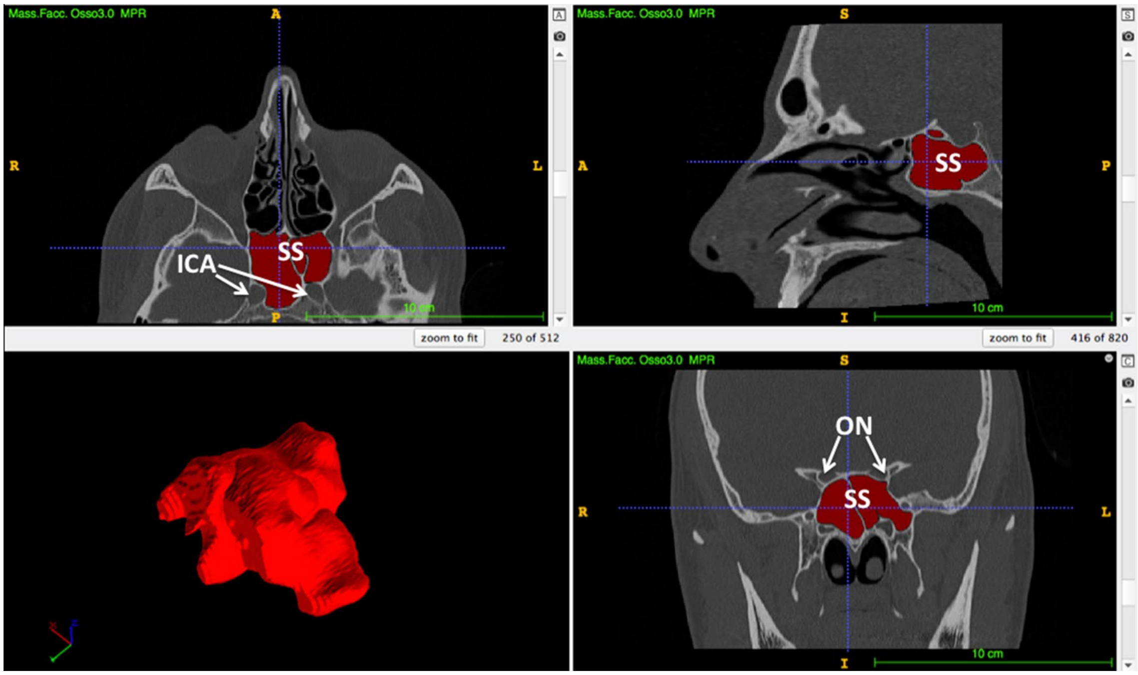

Fig. 1 segmentation of sphenoid sinuses through ITK-SNAP software, visualized in different views; in the lower left box, the segmented 3D model: *SS* sphenoid sinuses; *ICA* internal carotid artery; *ON* optic nerve

sphenoid sinuses was significantly higher than in the other groups. No differences of volume were found between subjects without protrusions and those with isolated ON protrusion, as well as between subjects with ICA protrusion and with contemporary protrusion of ICA and ON ($p > 0.05$).

Discussion

Sphenoid sinuses were once considered as difficult structures to approach because of their deep anatomical localization and the high variability in shape and size; the latter factor justifies the complexity of reciprocal relationships between sphenoid sinuses and surrounding neurovascular structures, first of all ICA and ON [18]. The progressive diffusion of transsphenoidal approach and modern imaging techniques has increased the importance of these air cavities in surgery; now they represent the basilar route for approaching lesions of pituitary gland as well as tumors involving the anterior cranial base, the parasellar region, clivus, petroclival region and cavernous sinus [18]. For these reasons anatomical studies focusing on sphenoid sinuses are acquiring a growing importance as they are crucial for a correct planning of surgical intervention and for preventing possible iatrogenic injuries [8].

The present study provided data concerning the volume of sphenoid sinuses in different profiles of ICA and ON protrusion: for what concerns volumetric measurements, results are well in line with those reported in a previous article of our research team [12] and with general ranges reported by the literature [19].

On the other hands, prevalence of ICA and ON protrusions is higher than those reported by literature: ICA protrusion usually ranges between 3.9 and 41.0%, whereas ON protrusions is between 2.8 and 35.6% [20, 21]. The same percentages in the present study were respectively 46.2% and 41.5%. These differences may find several explanations: first of all, there is no homogeneity in assessing protrusion of the above-mentioned structures. For example, some authors define protrusion as an indentation of sphenoid air cavities with more than 50% of the diameter of a neural or vascular structure [22]; instead other authors do not give a specified definition for protrusion [23]. In the present study, we decided to include all subjects where ICA or ON produced an indentation of the sphenoid sinuses with any part of their circumference to collect all cases which may represent an issue during transsphenoidal procedures.

Another explanation for discordant prevalence of ICA and ON protrusion reported by the literature is the ethnic variability which seems to affect sphenoid sinuses, both in size and morphology [12, 18] this conclusion strengthens the importance of population data to collect respective rates in specific geographical contexts, as already highlighted by the literature [18].

However, the most innovative results from the present study concern the relationship between ICA and ON

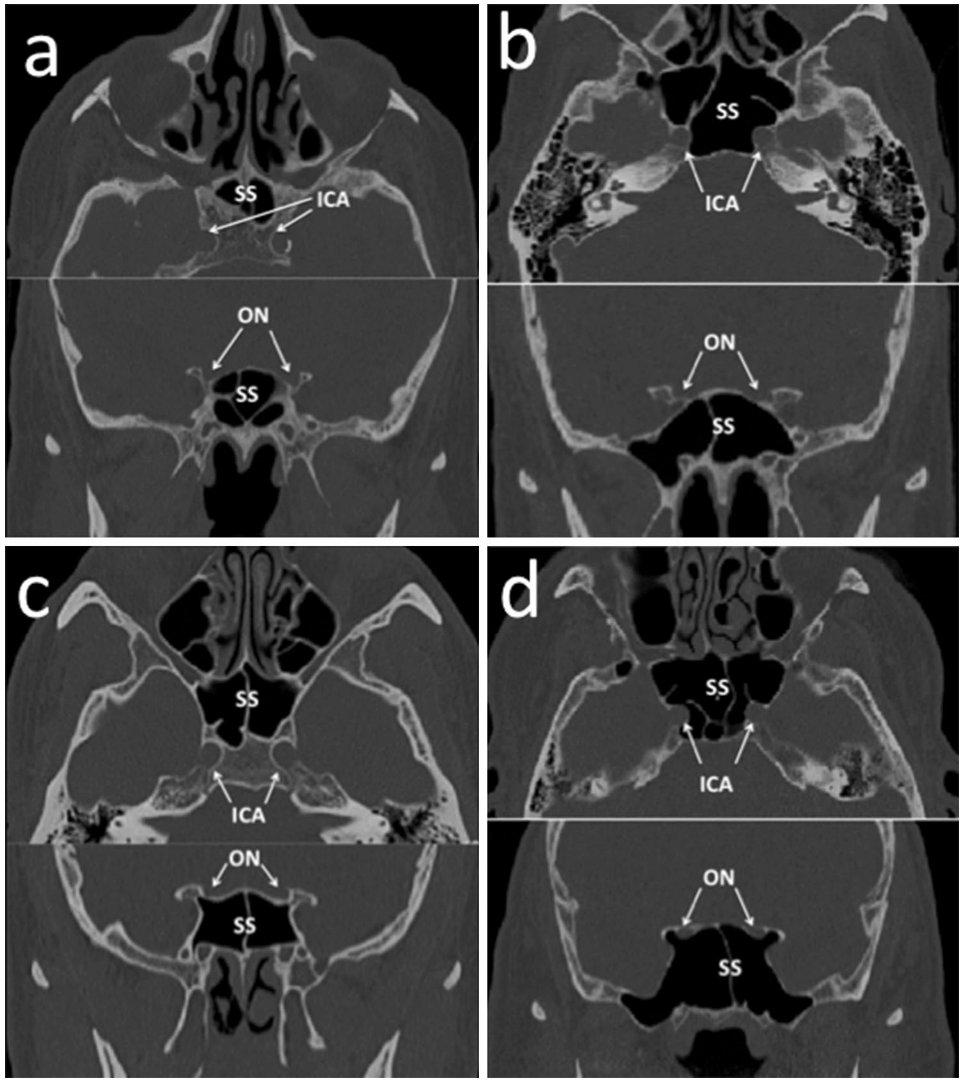

Fig. 2 transverse an coronal view of examples from the four groups of subjects: **a** group 1 (no protrusion of ICA or ON); **b** group 2 (protrusion of ICA only); **c** group 3 (protrusion of ON only); **d** group 4 (protrusion of both ICA and ON): *SS* sphenoid sinuses; *ICA* internal carotid artery; *ON* optic nerve

Table 1 Prevalence, mean volume and standard deviation (SD) for each group, divided between males and females

	Group 1 NO protrusions	Group 2 ICA protrusion	Group 3 ON protrusion	Group 4 ICA + ON protrusion
Males				
%	43.1	16.9	11.5	28.5
Mean (cm^3)	7.612	11.372	7.601	14.154
SD (cm^3)	3.771	4.636	2.924	5.047
Females				
%	36.9	20.0	16.2	26.9
Mean (cm^3)	6.069	9.437	7.376	10.791
SD (cm^3)	1.936	1.981	3.704	3.544

protrusion and volume of sphenoid sinuses. In the last time, research has focused on the possible relationships between protrusion of neurovascular structures into the sphenoid sinuses and anatomical variants of pneumatisation [2, 8, 24, 25]. With time several authors have attempted at exploring the possible relationships between protrusion of neurovascular structures into the sphenoid sinuses and specific morphological variants: for example, Rahmati et al. found a significant correlation between the pneumatisation of anterior clinoid and pterygoid processes, and protrusion of ON and ICA, respectively [9]. Protrusion of neurovascular structures was found more frequently in sellar and postsellar sphenoid sinus types, and in case of extensive pneumatisation [2, 8, 24]. In addition, an association was found between protrusion of ICA and anterior ethmoid artery below the skull base [25]; moreover, protrusions of ICA and ON are often related one with the other [25]. The frequent observation of ICA and ON protrusion with cases of extended pneumatisation of sphenoid sinuses may justify the conclusion that this phenomenon may be related with the volume of air cavities; this theory is also supported by the general idea that the intimate relationships of ICA and ON with sphenoid sinuses are caused by the expansion of air cavities around them during

Table 2 Results of Tukey HSD test applied to volumes of sphenoid sinuses in different groups

Females \ Males	Group 1 No protrusions	Group 2 ICA protrusion	Group 3 ON protrusion	Group 4 ICA + ON protrusion
Group 1 No protrusions		$p < 0.05$	NS	$p < 0.01$
Group 2 ICA protrusion	$p < 0.01$		$p < 0.05$	NS
Group 3 ON protrusion	NS	$p < 0.05$		$p < 0.01$
Group 4 ICA + ON protrusion	$p < 0.01$	NS	$p < 0.01$	

NS not significant

the development [1, 26]. However, to our knowledge, no study has analysed the relationship between the volume of sphenoid sinuses and ICA and ON protrusion.

This study provided novel data about this topic: in detail, results showed that subjects with protrusion of ICA or concomitant protrusion of ICA and ON present a significantly larger sinus. On the other side, isolated ON protrusion is not related with sphenoid sinuses volume, as there was no difference in volume with subjects without any protrusion. From a surgical point of view, this result is of great interest: in fact, whereas in cases of extended pneumatisation of sphenoid sinuses we have to expect a protrusion of ICA, ON may protrude also in subjects with a small volume. In other words, ON protrusion is more insidious than ICA protrusion, and should be verified in all cases, independently from the volume of sphenoid sinuses.

In addition, the present data first highlight that protrusion and dehiscence of neurovascular structures into the sphenoid sinuses may not be related with extended pneumatisation, but is influenced by other variants, including probably the reciprocal position of sinuses and ON and their respective orientation. Further studies are needed to verify if the same phenomenon may be shared by other neural structures often protruding into the sphenoid sinuses, and in detail the maxillary and vidian nerves.

In conclusion, the present study provided an innovative point of view on the long-time debated issue of anatomical variants of sphenoid sinuses and protrusion of sensitive structures which may be injured during transsphenoidal surgical procedures. Results will give a contribution to improve our knowledge of this anatomical structure, universally considered as the most variable of human body.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

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