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Protrusion of the carotid canal into the sphenoid sinuses: evaluation before endonasal endoscopic sinus surgery

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Background: *Many reports have previously indicated the vast number of anatomical variations of the sphenoid sinuses, e.g. presence of the recesses. Notwithstanding, there are a few crucial neurovascular structures directly neighbouring with the sinuses. The following research aimed to evaluate frequency prevalence of the carotid canal's protrusion into the sphenoid sinuses in adult population.*

Materials and methods: *Computed tomography (CT) scans of the paranasal sinuses of 296 patients (147 females, 149 males) were analysed in this retrospective study. The patients did not present any pathology in the sinuses. Spiral CT scanner Siemens Somatom Sensation 16 was used in the standard procedure in the option Siemens CARE Dose 4D.*

Results: *Protrusion of the carotid canal was found in the majority of the patients — 55.74%, more frequently in males (65.1% of the patients) than in females (46.26% of the patients). The said variant — regardless of gender — was noted more often bilaterally (41.55% of the cases: 29.93% females, 53.02% males) than unilaterally (14.19% of the cases: 16.33% females, 12.08% males). In the unilateral type (regardless of gender), the protrusion was more common for the left sphenoid sinus — 10.81% of the patients (12.24% females, 9.4% males) than for the right — 3.38% of the patients (4.08% females, 2.68% males).*

Conclusions: *Complicated structure of the paranasal sinuses, derived from the high prevalence of their anatomical variations, may perplex routine surgical interventions. Henceforth, referral for a CT scan is imperative in order to abate the risks associated with an invasive procedure in the said region.* (Folia Morphol 2021; 80, 3: 642–649)

Key words: sphenoid sinus, carotid canal, anatomy, radiology, laryngology

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INTRODUCTION

Sphenoid sinuses may be found within the diaphysis of the sphenoid bone. Their antrum is lined with the mucous membrane. There is a high prevalence of anatomical variations surrounding them. Size, shape, number of septa present and degree to which they fill in with air are just a few examples of the diversity encountered in the sinuses [15–17].

Vascular and neural structures are located in the proximity of the sphenoid sinuses — they adjoin them through the sinuses' wall. The closeness of these structures and the varied morphological features of the sinuses are crucial factors that have an impact upon a surgery in this region. In order to curtail the surgical risks and potential complications associated with the invasive intervention (including endoscopy), it is advisable for medical professionals to analyse the anatomical parameters of the sinuses [1, 11, 13, 19, 21, 22, 27, 29, 32, 34, 41].

The carotid canal is an osseous structure within the petrous temporal bone that enables the internal carotid artery, the sympathetic nerve plexus and the internal carotid venous plexus to enter the cranium [37]. The internal carotid artery has been divided by Bouthillier et al. [6] into 7 distinct parts, with the petrous segment (C2) and the lacerum segment (C3) related to the carotid canal.

A clear-cut representation of the osseous structures in the paranasal sinuses is the best obtained via a computed tomography (CT) scan, as this method allows separating the diverse anatomical variants of the sinuses.

Functional endoscopic sinus surgery (FESS) is a method that develops quite dynamically these days [4, 5]. The number of the classical extensive surgical interventions carried out on the paranasal sinuses has diminished thanks to the use of the minimally invasive endoscopic procedures.

Since the 1990s, chronic sinusitis has been commonly treated by the FESS that became the method of choice for this type of surgery. Shorter recovery period, smaller number of iatrogenic injuries, as well as excellent insight into the hardly accessible areas, made the endoscopic procedures more preferable to the classical operations [11, 23].

Detailed knowledge of the variant anatomy of the sphenoid sinuses is warranted prior to conducting an invasive procedure e.g. the FESS, the transsphenoidal approach for a pituitary adenoma surgery or closure of the cerebrospinal fluid leakage. Henceforth, the following study aimed to present the prevalence of the protrusion of the carotid canal into the lumen of the sphenoid sinus by retrospectively analysing CT scans of Polish adult population. One of the possible iatrogenic injuries is damaging the carotid canal what might lead to a hard to control bleeding [14, 28]. We hope that by utilising the CT and providing a fresh view onto the carotid canal's protrusion, our study will contribute towards a higher efficacy and safety of the surgeries carried out within the sphenoid sinuses.

MATERIALS AND METHODS

There were 296 patients (147 females, 149 males) referred to the Department of Diagnostic Imaging of the University Hospital in Krakow, that were included in this retrospective analysis. The patients had to be over 18 years old and present no pathologies in the paranasal sinuses. They were excluded if they had a history of: a head trauma or a record of nasal, orbital or cranial basis surgery, and this group comprised of 63 patients.

The medical images were obtained using a spiral CT scanner Siemens Somatom Sensation 16. Standard procedure applied in the option Siemens CARE Dose 4D. Furthermore, no contrast medium was administered to any of the patients. Thanks to the use of the multiplans reconstruction tool, both frontal and sagittal planes were visualised via secondary reconstruction from the transverse planes. Siemens Volume Wizard diagnostic station applied during the data analysis.

The analysis of the medical images involved the presence of the protrusion of the carotid canal into the sphenoid sinuses, including its bilateral and unilateral arrangements. The authors decided that for the protrusion to be noted, it has to modify shape of the wall of the sinus near the carotid canal, so that a part of the carotid canal is convex towards the lumen of the sinus

Statistical analysis

STATISTICA version 13.3 by TIBCO Software Inc.® was used to perform the statistical analysis within this manuscript. Chi^2 test and Fisher's exact test were utilised whilst probing for differences between the various laterality of the protrusion present and gender. A statistically significant value of $p < 0.05$ was chosen for all the results.

RESULTS

The carotid canal's protrusion was prevalent in the majority of the patients — in total this variant was found in 165 patients, more frequently in males (97 patients) than in females (68 patients) (Table 1).

Table 1. The prevalence of the protrusion of the carotid canal in the total research group

PCC	F	F%	M	M%	F + M	F + M%
Present	68	46.26%	97	65.1%	165	55.74%
Absent	79	53.74%	52	34.9%	131	44.26%

PCC — the protrusion of the carotid canal; F — females; F% — the percentage derived from all the females studied; M — males; M% — the percentage derived from all the males studied

Table 2. The prevalence of the protrusion of the carotid canal unilaterally or bilaterally in the total research group

PCC	F	F%	M	M%	F + M	F + M%
Unilaterally	24	16.33%	18	12.08%	42	14.19%
Bilaterally	44	29.93%	79	53.02%	123	41.55%
Absent	79	53.74%	52	34.9%	131	44.26%

PCC — the protrusion of the carotid canal; F — females; F% — the percentage derived from all the females studied; M — males; M% — the percentage derived from all the males studied

Table 3. The prevalence of the unilateral protrusion of the carotid canal in the patients with the unilateral protrusion present

PCC	F	F%	M	M%	F + M	F + M%
RSS	6	4.08%	4	2.68%	10	3.38%
LSS	18	12.24%	14	9.4%	32	10.81%

PCC — the protrusion of the carotid canal; RSS — right sphenoid sinus; LSS — left sphenoid sinus, F — females; F% — the percentage derived from all the females studied; M — males; M% — the percentage derived from all the males studied

The prevalence of the carotid canal's protrusion differed significantly between females and males ($p = 0.001$, χ^2 test). The protrusion was noted more often in males (97/165 of all the cases with the protrusion present, 58.8%), but was absent in the majority of females (79/131 of all the cases with the protrusion absent, 60.3%).

The said variant — regardless of gender — was prevalent more often bilaterally (123 patients: 44 females, 79 males) than unilaterally (42 patients: 24 females, 18 males) (Table 2).

The prevalence of the carotid canal's protrusion unilaterally, bilaterally or its absence differed significantly between females and males ($p < 0.001$, χ^2 test). The unilateral protrusion was found more often in females (24/42 cases of the total unilateral protrusion, 57.1%), similarly to the protrusion's absence — also more common in females (79/131 cases with the protrusion absent, 60.3%), but the bilateral protrusion was prevalent more frequently in males (79/123 cases of the total bilateral protrusion, 64.2%).

In case of the unilateral arrangement (42 cases), regardless of gender, the protrusion was found more frequently in the left sphenoid sinus — 32 patients (18 females, 14 males) than in the right sphenoid sinus — 10 patients (6 females, 4 males) (Table 3).

Notwithstanding, gender was not a significant factor determining the side of the presence of the unilateral protrusion ($p = 0.999$, Fisher's exact test). In both female and male groups, the protrusion on the left side predominated in the majority of cases (approximately 75% of the patients of the respective gender with a unilateral protrusion) (Fig. 1).

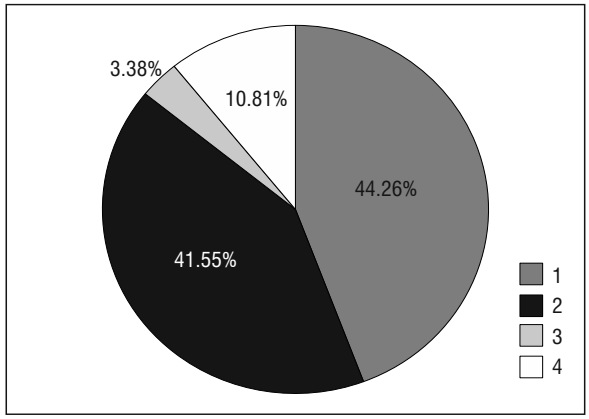

Figure 1. The prevalence of the protrusion of the carotid canal in the total research group (including its location) — cumulative data; 1 — absent; 2 — bilaterally present; 3 — present on the right side; 4 — present on the left side.

Protrusion of the carotid canal was found in total of almost half of the sinuses studied — in 288 sinuses out of the 592 sinuses researched (294 female sinuses, 298 males sinuses), slightly more common on the left side — 155 sinuses (62 in females, 93 in males), than on the right side — 133 sinuses (50 in females, 83 in males).

Table 4. The prevalence of the protrusion of the carotid canal in the total number of the sphenoid sinuses studied

PCC altogether	F	F%	M	M%	F + M	F + M%
Present	112	38.1%	176	59.06%	288	48.65%
Absent	182	61.9%	122	40.94%	304	51.35%

PCC — the protrusion of the carotid canal; F — female sinuses; F% — the percentage derived from all the female sinuses studied; M — male sinuses; M% — the percentage derived from all the male sinuses studied

Table 5. The prevalence of the unilateral protrusion of the carotid canal in the total number of the sphenoid sinuses studied

PCC altogether	F	F%	M	M%	F + M	F + M%
RSS	50	17.01%	83	27.85%	133	22.47%
LSS	62	21.09%	93	31.21%	155	26.18%

PCC — the protrusion of the carotid canal; RSS — right sphenoid sinus; LSS — left sphenoid sinus; F — female sinuses; F% — the percentage derived from all the female sinuses studied; M — male sinuses; M% — the percentage derived from all the male sinuses studied

Figure 2. Axial computed tomography scan of the paranasal sinuses showing absence of the protrusions of the carotid canals.

Figure 3. Axial computed tomography scan of the paranasal sinuses showing unilateral protrusion of the carotid canal into the left sphenoid sinus.

The proportion of the present and absent protrusions differed significantly between female and male groups ($p < 0.001$, χ^2 test). In females, it was not noted in approximately 62%, whereas in males it was prevalent in approximately 60% (Tables 4, 5).

The proportion of the presence of the unilateral protrusion of the carotid canal on the right and left sides did not differ significantly between females and males ($p = 0.676$, χ^2 test). In both female and male groups, the unilateral protrusion of the carotid canal on the left side was slightly more common (it comprised approximately 55% of the sinuses of the respective gender with a unilateral protrusion) than on the right.

Figures 2–5 present examples of the carotid canal's protrusion into the sphenoid sinuses, evaluated during this research.

DISCUSSION

Protrusion of the carotid canal was prevalent in the majority of the patients — in total this variant was noted in 55.74% of the patients, more frequently in males (65.1%) than in females (46.26%). The said variant — regardless of gender — was present bilaterally more often (41.55% of the patients: 29.93% females, 53.02% males) than unilaterally (14.19% of the patients: 16.33% females, 12.08% males). In case of the unilateral variant, regardless of gender,

Figure 4. Axial computed tomography scan of the paranasal sinuses showing unilateral protrusion of the carotid canal into the right sphenoid sinus.

Figure 5. Axial computed tomography scan of the paranasal sinuses showing bilateral protrusions of the carotid canals into the sphenoid sinuses.

the protrusion was found more frequently in the left sphenoid sinus (10.81% of the cases: 12.24% females, 9.4% males) than in the right sphenoid sinus (3.38% of the cases: 4.08% females, 2.68% males). To the best knowledge of the authors, it is so far the first study that has comprehensively taken into the consideration the possible correlation between the carotid canal's protrusion and gender, probing for its statistical significance in all presented here variants amongst the Polish population. Most notably, we have found that the protrusion was absent in 62% of the females studied, whereas in males it was present in approximately 60% of the patients, a statistically significant result ($p < 0.001$, χ^2 test).

The results presented in this work are in accordance with the data provided by other scientists. Mamatha et al. [28] stated the total prevalence of the carotid canal's protrusion as 50% (their research material: 20 CT scans), where it was bilaterally present in 15% and unilaterally in 35% (on the right side in 5%, on the left side in 30%).

On the other side, Lupascu et al. [26] provided the prevalence of the protrusion of the carotid canal as 55% (in case of the C3 segment of the artery) and as 57% (in case of the C4 segment of the artery). Moreover, Ozturan et al. [31] also noted this variant very often — in 64.5%, as well as Tan and Chong [40] — 65–72%, and Tan and Ong [39] — 67.7%.

Slightly lower prevalence was given by Hewaidi and Omami [14] — 41% (11.3% on the right side, 7% on the left side, 22.6% bilaterally). They researched 300 CT scans of people of Lebanese origins.

Elwany et al. [10], stated the prevalence of the protrusion of the carotid canal basing on the division into three types relative to the segments of the carotid canal: the presellar segment (42.7%), the subsellar segment (29.5%) and the postsellar segment (17.7%), noting that the protrusion may involve the carotid canal as a whole (18.2%), but they did not provide the criteria of the evaluation of the protrusion.

Kantarci et al. [19] evaluated the presence of this variant as 16% (bilaterally) and 7% (unilaterally). The study was conducted on the Turkish population (512 CT scans), but the age of the patients was not provided. Similar results were given by Kajoak et al. [18] — 25.4%, Tomovic et al. [42] — 28.2%, Chinese researchers — Li et al. [25] — 29.25% (8.68% unilaterally, 20.57% bilaterally), Turkish scientists — Bademci and Unal [3] — 31.1%, and Thai researchers — Nitinavakarn et al. [30] — 32.4% (17% unilaterally, 24% bilaterally).

Definitely lower prevalence of this variant was found by Anusha et al. [2] — 10% (36.7% on the right side, 53.3% on the left side and 10% bilaterally) in their study of 300 CT scans of the adult Malaysians. Even lower prevalence was provided

Table 6. The prevalence of the protrusion of the carotid canal

Author (materials and methods)	Present	Unilateral	On the right side	On the left side	Bilateral
Mamatha et al. (20 CT scans)	50%	35%	5%	30%	15%
Lupascu et al. (200 CT scans)	55%/57%	–	–	–	–
Ozturan et al. (999 CT scans)	64.5%	–	–	–	–
Tan and Chong (–)	65–72%	–	–	–	–
Tan and Ong (48 skulls, dissection and endoscopic study)	67.7%	–	–	–	–
Hewaidi and Omami (300 CT scans)	41%	18.3%	11.3%	7%	22.6%
Elwany et al. 1999 (93 skulls, dissection and endoscopic study)	89.9%	–	–	–	–
Kantarci et al. (512 CT scans)	23%	7%	–	–	16%
Kajoak et al. (201 CT scans)	25.4%	–	–	–	–
Tomovic et al. (170 HRCT)	28.2%	–	–	–	–
Li et al. (350 CT scans)	29.25%	8.68%	–	–	20.57%
Bademci and Unal et al. (45 CT scans)	31.1%	–	–	–	–
Nitinavakarn et al. (88 CT scans)	32.4%	17%	–	–	24%
Anusha et al. (300 CT scans)	10%	90%	36.7%	53.3%	10%
Kazkayasi et al. (267 CT scans)	5.2%	2.6%	–	–	2.6%
Cope (–)	?	–	–	–	–
Priyadarshini et al. (100 CT scans)	0%	–	–	–	–
Jaworek-Troć et al. (296 CT scans)	55.74%	14.19%	3.38%	10.81%	41.55%

CT — computed tomography; ? — the authors were aware of this variant but did not provide numerical values

by Kazkayasi et al. [21] — 5.2% (2.6% unilaterally, 2.6% bilaterally) — study of 267 CT scans of Turkish population.

Cope noted that the protrusion of the carotid canal may happen, but did not provide the frequency and location of the said variant [8].

Priyadarshini et al. [33] stated completely different results in their research of 100 CT scans of the patients, as they did not find even one case of the protrusion of the carotid canal. The research material studied (people of the Indian origins) and/or the evaluation criteria of the presence of the protrusion (not provided in the work) might have influenced the data (Table 6).

Precise and current anatomy of the sphenoid sinuses is of immense importance, especially whilst trying to gain access to the sella turcica using endoscopic or microscopic approaches [28]. One of the possible iatrogenic injuries caused during a transsphenoidal intervention is damaging the internal carotid artery or the optic nerve. Ciric et al. [7] have found that for the transsphenoidal approach to the pituitary surgery, the risk of injuring the internal carotid artery was 1.1%. Notwithstanding, the rate of iatrogenic vascular damage during expanded endoscopic endonasal resection of suprasellar craniopharyngomas was noted in 5% by Gardner et al. [12]. Interestingly, patients with acromegaly were found to have the protrusion of the carotid canal into the sphenoid sinuses present more often than the control group (33.5% vs. 13.3%) [35], although the limited number of patients studied (45 with acromegaly and 45 controls) might diminish the significance of the research, as also noted by the authors.

Henceforth, it is crucial for surgeons to become acquainted with the various anatomies of the sphenoid sinuses, particularly with the protrusion of the carotid canal into the sphenoid sinuses. Its unawareness might lead to fatal complications due to the arterial bleeding from the internal carotid artery that would not be easy to repair within the closed and narrow space of the sphenoid sinus [14, 28]. Lastly, it might also be a case that an infectious disease of the sphenoid sinuses may make the protruded internal carotid artery more prone to injuries [36].

In furtherance of avoiding the injury to the internal carotid artery, it is possible to utilise three-dimensional CT angiography or micro-Doppler probe to help localise the vessel [9, 24]. Notwithstanding, even when the micro-Doppler probe was applied,

there were mistakes with proper identification of the artery [9]. Stecco et al. [38] have found the use of virtual dissection tables very helpful whilst diagnosing perplexing Le Fort fractures (all of them involve the pterygoid process of the sphenoid bone) that were noted as doubtful on the standard Picture Archiving and Communication System, and hence allowed for a more confident diagnosis. It might be possible that the virtual dissection tables will also prove useful in preoperational planning involving the sphenoid sinus, which is well known to be the least accessible of the paranasal sinuses. Yet another novel technology is the use of virtual endoscopy, which in the study led by Kapakin [20] allowed presence of transmural lesions to be visualised in addition to expected visualisation of the inner surface of the paranasal sinuses. It is undoubtedly prudent to know as much about the location of the internal carotid artery prior to surgery as possible. Furthermore, we would like to acknowledge Sasagawa et al. [35] and emphasise that there is still need to correlate and report the intraoperative findings with preoperative imaging investigations (i.e. the CT).

CONCLUSIONS

As shown in our study, the protrusion of the carotid canal was found in the majority of the patients and the said variant was bilateral more frequently than unilateral. In case of the unilateral arrangement, the protrusion into the left sphenoid sinus was noted more commonly. In order to conduct a safe procedure in the paranasal sinuses, it is advisable for medical professionals to refer their patients for a CT scan before the planned operation, so as to become acquainted with the anatomical variations that may be present in the sinuses.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study formal consent is not required.

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