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Original Article

Ossified ligaments in relation to foramina and bony landmarks of the middle cranial fossa

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ABSTRACT

Introduction: Sporadic reports on individual ossified ligaments of the middle cranial fossa (MCF) fail to do justice to their grave clinical consequences. The present study attempts a comprehensive search for all ossified ligaments and associated accessory foramina in relation to MCF, in order to standardize baseline prevalence pertinent for the Indian subcontinent.

Methods: Fifty well-preserved and intact, adult (age >20 yrs), dry, macerated skulls were obtained from the Anatomy departments of medical colleges in Delhi, including the All India Institute of Medical Sciences. All the skulls were subjected to a meticulous, bilateral examination and digital photography of internal & external aspects of the skull base, to look for presence of partially or completely ossified ligaments and resulting accessory foramina.

Results: The incidence values recorded from the present sample ($n = 50 \times 2$) for completely (C) and incompletely (IC) ossified MCF ligaments are as follows: Caroticoclinoid: C = 6 (6%), IC = 2 (2%); Interclinoid: C = 3 (3%), IC = 2 (2%); Pterygospinous: C = 2 (2%), IC = 3 (3%); Pterygoalar: C = 1 (1%), IC = 2 (2%); Petrosphenoid/petroclinoid: C = 2 (2%), IC = 0 (0%). All completely ossified ligaments were found to be associated with accessory foramina.

Discussion: Presence of ossified MCF ligaments cannot be overlooked in patients with symptoms arising from compression of neurovascular structures and those undergoing skull-base neurosurgery, necessitating pre-surgical screening for presence of calcified ligaments in close proximity to vital structures – a scenario that may influence surgical outcome.

1. Introduction

Ossified ligaments in relation to the skull base, especially when associated with vital structures crowding the middle cranial fossa (MCF) may have grave clinical implications[1–3]. They may compress[4] or entrap[5,6] closely related neurovascular structures leading to clinical sequelae of variable magnitude. They may also obstruct surgical and anesthetic approaches aimed at these critical neurovascular structures[3]. When completely ossified, they often form new, accessory foramina surrounded by the ossified ligaments and closely placed bony prominences to which they are attached, with a potential to create constrictions around neurovascular structures passing in the vicinity[7,8]. The possibility of this being causally related to the observed clinical picture is difficult to diagnose and often gets overlooked[3].

On undertaking a comprehensive literature survey, we did not encounter a single study that surveyed all the ossified ligaments and related accessory foramina occurring in the MCF, and correlated their grave clinical implications for the neurosurgeon. We found a few sporadic case reports and surveys on individual occurrence of ossified pterygospinous and caroticoclinoid ligaments. But even individual reports on ossified petroclinoid/petrosphenoid, interclinoid and pterygoalar ligaments in indexed journals were very few. None of these studies reported the incidence of all the MCF ligaments and accessory foramina. Moreover, little or no data obtained from subjects of the Indian subcontinent was found for all these MCF features in standard indexed journals. Each ossified ligament/accessory foramen would have a distinctly characteristic clinical presentation, diagnostic criteria and surgical management, thus underscoring the relevance of a comprehensive study on MCF structures. The present study was designed for this purpose and to fill the above-mentioned gaps in knowledge. The frequency of occurrence of each ossified ligament and accessory foramen found in the present study was compared with that reported in literature, in order to standardize

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baseline data pertinent for Indian subjects. Such a study is important for directing a neurosurgeon's attention towards the possibility of ossified ligaments complicating the planned approach to this immensely complex surgical arena. Since this study is performed on a population with a mixed ethnic heritage[9–11], findings of this study may also be generalized to a similar population elsewhere.

2. Materials and methods

Fifty well-preserved and intact, adult (age >20 yrs), dry, macerated skulls were obtained from the Anatomy departments of various medical colleges in Delhi, including the All India Institute of Medical Sciences, following written permission from the respective department heads and due approval from their respective institutional ethics committees. Skulls with gross anomalies (deformities/fractures) were excluded. The skulls are likely to be of Indian ethnicity judging from their sources; however this could not be absolutely confirmed.

All the skulls were horizontally sectioned to remove their calvaria, level with a transverse plane passing 1 cm above the supra-orbital margins & the external occipital protuberance, with the skulls being positioned in the Frankfurt (eye-ear) plane. Each skull was subjected to a meticulous, bilateral examination of internal (MCF) & external (norma basalis) aspects of the skull base, to look for presence of partially or completely ossified ligaments and resulting accessory foramina in the MCF. The ligaments and foramina observed were duly recorded using digital photography.

The findings were tabulated as the number of complete (C) and incomplete (IC) ossified ligaments observed on each side, and the total number of each partially or completely ossified ligament was computed as a percentage of the total sample size ($n = 50 \times 2$). Data was matched for completely ossified ligaments and the accessory foramina created by them.

3. Results

The following 5 ossified ligaments and accessory foramina were observed in relation to the MCF, the first three seen within the internal aspect of the fossa and the last two detected on the outer aspect of the skull base:

1. Caroticoclinoid ligament (Fig. 1): a partial or complete osseous bar uniting the anterior and middle clinoid processes on one/both sides, resulting in the formation of the caroticoclinoid foramen within the MCF.
2. Interclinoid ligament (Fig. 2): a partial or complete osseous bar uniting the anterior and posterior clinoid processes on one/both sides, resulting in the formation of an accessory interclinoid foramen across the middle of the carotid groove within the MCF.
3. Petrosphenoid/petroclinoid ligament (Fig. 3): a partial or complete osseous bar uniting the anterior/posterior clinoid processes with the petrous apex on one/both sides, resulting in the formation of the petrosphenoid/petroclinoid foramen within the MCF.
4. Pterygospinous ligament (Fig. 4): a partial or complete osseous bar uniting the lateral pterygoid plate with the base of spine of sphenoid bone on one/both sides of the outer aspect of the skull base running close to the foramen ovale, resulting in the formation of the pterygospinous foramen (*foramen pterygospinale*).
5. Pterygoalar ligament: a partial or complete osseous bar uniting the lateral pterygoid plate with the greater wing of sphenoid on one/both sides of the outer aspect of the skull base running close to the foramen ovale, resulting in the formation of the pterygoalar foramen (*foramen crotaphitico-buccinatorium*).

The values recorded from the present sample ($n = 50 \times 2$) for completely (C) and incompletely (IC) ossified ligaments in relation to MCF have been tabulated (Table 1). All completely ossified ligaments were found to be associated with accessory foramina (Table 2).

4. Discussion

The clinical consequences of ossified ligaments of the skull base have escaped surgeons' attention and remained poorly understood for several decades. The increasing use of endoscopic and stereotaxic surgical approaches however, is steadily changing clinical perceptions regarding their importance. It seems

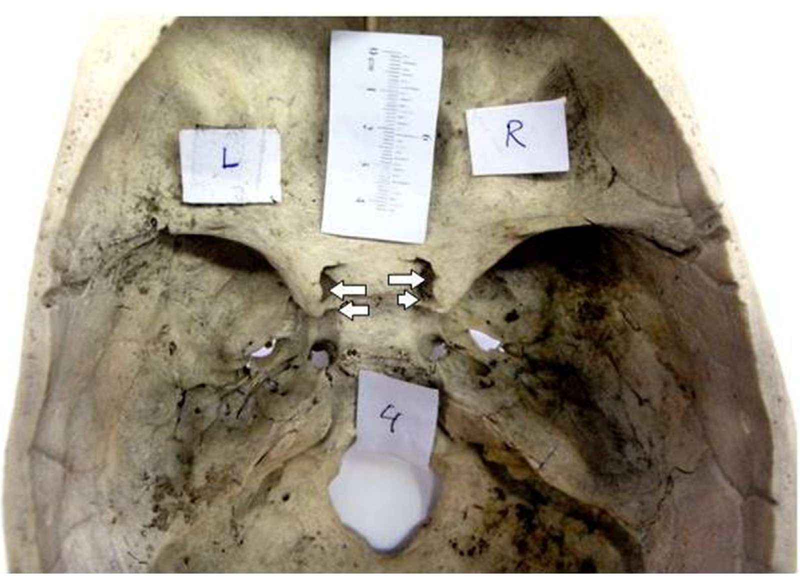

Fig. 1. Bilateral completely ossified caroticoclinoid ligaments and resulting accessory foramina.
[Ossified ligaments are indicated by short arrows and accessory foramina by long arrows]

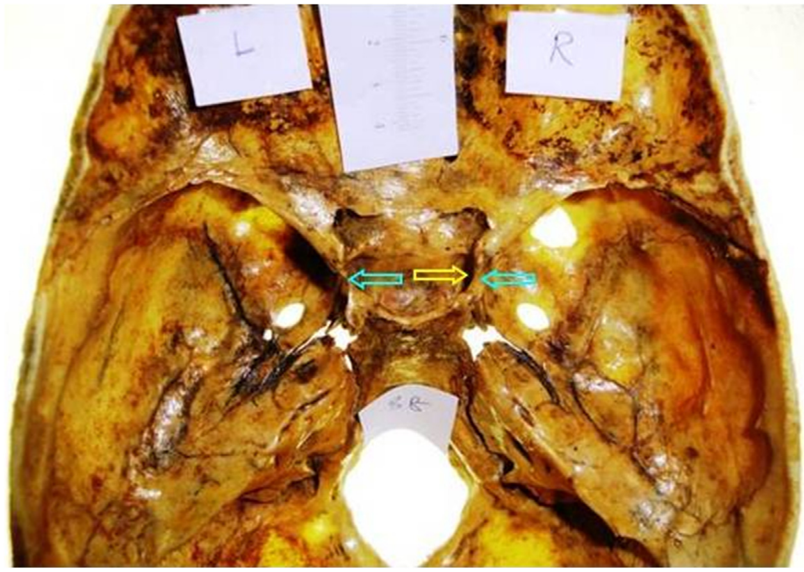

Fig. 2. Bilateral completely ossified interclinoid ligaments and resulting accessory foramina.
[Ossified ligaments are indicated by blue arrows and the right accessory foramen by yellow arrow]

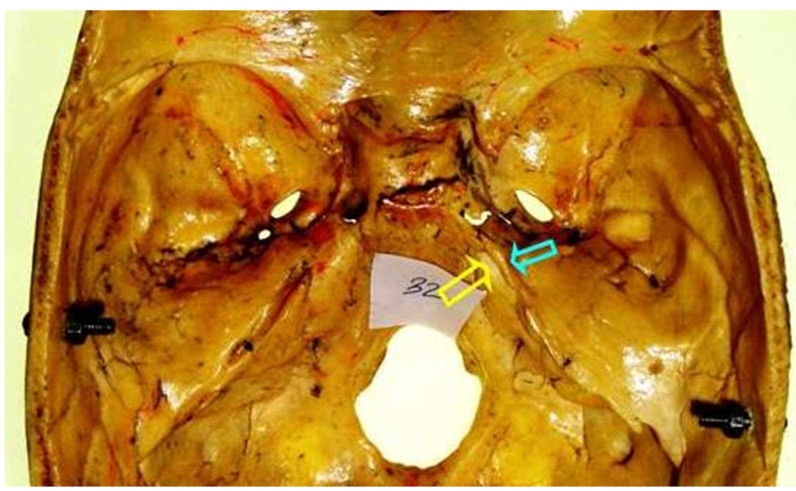

Fig. 3. Completely ossified right petroclinoid/petrosphenoid ligament and resulting accessory foramen.
[Ossified ligament is indicated by blue arrow and accessory foramen by yellow arrow]

reasonable to implicate them as possible culprits when the neurosurgeon using a surgical approach to the skull base is confronted by a sudden intractable bleed, or when slippage of an instrument leads to accidental damage of a neural structure. A completely ossified ligament creates a foramen surrounding the bony landmarks providing it attachment[7,12]. Furthermore, it is difficult to predict whether incompletely ossified ligaments are likely to cause more clinical symptoms than completely ossified ligaments. The completely ossified ligaments certainly have the potential to create greater obstacles to a surgical approach targeted at anatomical structures enclosed by them or in their vicinity. These may also enhance the risk of compression[4–6] or of accidental injury to the enclosed neurovascular structures, and may lead to either uncontrolled intra-operative bleeding or loss of function.

Thus the MCF is potentially an extremely challenging zone for the neurosurgeon. The present study was aimed at a thorough examination of this complex and vitally significant surgical arena, with special attention to ossified ligamentous structures which have the potential to misguide or create unexpected hurdles to neurosurgical approaches. The data thus generated was compared with that available in literature – mostly isolated studies – and an impressive compatibility and consistency was found with our findings for each ossified ligament. The relatively minor differences in data pertaining to ossified ligaments and foramina maybe explained in terms of variations in sample size, ethnic population and observational criteria.

A comparative evaluation of our findings for each ossified ligament and accessory foramen (if present), with reference to earlier reports on such skull base features, is given below:

4.1. Caroticoclinoid ligament & foramen

The anterior clinoid process is joined to the middle clinoid process (if present) by the caroticoclinoid ligament, that is sometimes ossified and may result in the formation of the caroticoclinoid foramen. Ossified caroticoclinoid ligament was seen incompletely ossified at 2 (2%) and completely ossified at 5

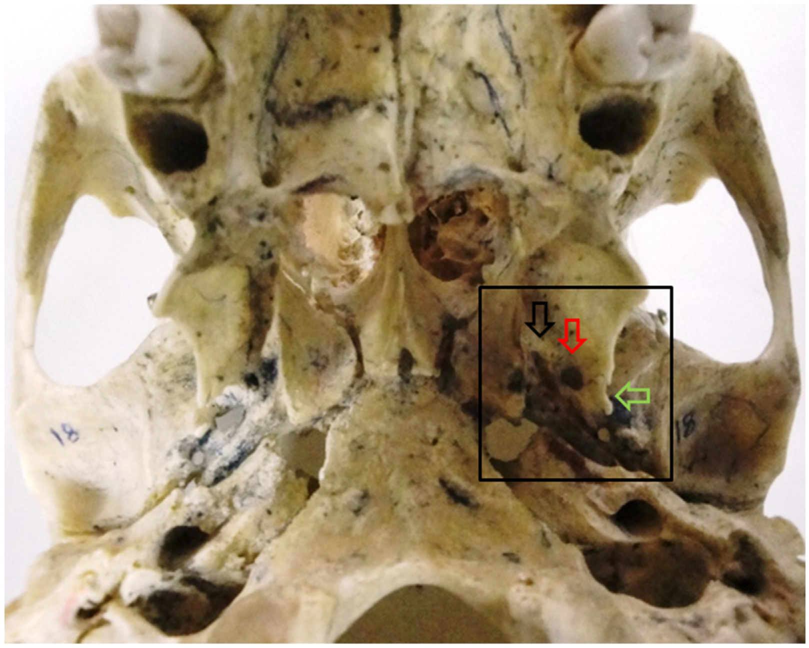

Fig. 4. Completely ossified left pterygospinous ligament & resulting accessory foramen.
[Colored arrows in black square indicate: ossified ligament by green arrow, accessory foramen by red arrow and foramen ovale by black arrow]

Table 1
Ossified ligaments in relation to the middle cranial fossa.

S. No.	Ossified ligament	Unilateral				Bilateral		Total ($n = 50 \times 2 = 100$)[a]	
		Left		Right					
		C	IC	C	IC	C	IC	C	IC
1.	Caroticoclinoid	3	0	2	2	1	0	6 (6%)	2 (2%)
2.	Interclinoid	1	0	1	1	1	1	3 (3%)	2 (2%)
3.	Petrosphenoid/petroclinoid	2	0	0	0	0	0	2 (2%)	0 (0%)
4.	Pterygospinous	2	0	0	2	0	1	2 (2%)	3 (3%)
5.	Pterygoalar	1	0	0	0	0	2	1 (1%)	2 (2%)

[a] Total no. of skulls = 50; observations (Left & Right): $\boldsymbol{n} = 50 \times 2 = \mathbf{100}$; **C**: completely ossified ligament; **IC**: incompletely ossified ligament.

Table 2
Accessory foramina in relation to completely ossified ligaments in the MCF.

S. No.	Accessory foramen	Unilateral		Bilateral	Total ($n = 50 \times 2 = 100$)[a]
		Left	Right		
1.	Caroticoclinoid	3	2	1	6 (6%)
2.	Interclinoid	1	1	1	3 (3%)
3.	Petrosphenoid/petroclinoid	2	0	0	2 (2%)
4.	Pterygospinous	2	0	0	2 (2%)
5.	Pterygoalar	1	0	0	1 (1%)

[a] Total no. of skulls = 50; observations (Left & Right): $\boldsymbol{n} = 50 \times 2 = \mathbf{100}$.

(5%) sites, being bilateral in only 1 skull specimen in our study (Table 1). The clinical relevance of ossified caroticoclinoid ligament is in possibly compressing the internal carotid artery (ICA) and the clinical effects arising from this.[4,12]

Erturk et al[7] surveyed one hundred and nineteen adult dry skulls and 52 adult cadaveric heads in a Turkish population to look for this ligament. They observed the caroticoclinoid foramen in 35.67% of their specimens; the foramen being unilateral in 23.98%, and bilateral in 11.69% cases. The complete type caroticoclinoid foramen was observed in 4.09% of their specimens and the incomplete type in 14.91%. These findings compare well with our observation of unilateral foramen associated with completely ossified ligament at 5 sites (5%) and the bilateral foramen in one skull.

4.2. Interclinoid ligament & foramen

The interclinoid ligament may exist as a bony bridge between the anterior and posterior clinoid processes of the skull base. It was found to be incompletely ossified at two sites (2%), completely ossified at four sites (4%) and bilaterally completely ossified in one skull during the course of this study. Ozdogmus et al[1] studied 50 fresh autopsy cases to look for the ossified interclinoid ligament. They found bilateral complete ossification of the interclinoid ligament in only three male autopsied cadavers (6%).

The presence of a considerably thick bony trabecula within the sellar region may directly impact the course of the ICA or the oculomotor nerve, causing compression of these structures[1]. This ossified ligament may also present an obstacle during surgical approaches targeted at the anterior and posterior clinoid processes, these unusual approaches being often essential in cavernous sinus surgeries, certain endoscopic approaches to the sellar region, or in surgical removal of an ICA aneurysm in the cavernous sinus with complications[1,13].

4.3. Petrosphenoid/petroclinoid ligament and foramen

The petrosphenoid/petroclinoid ligament is a fold of duramater extending between anterior and posterior clinoid processes and the petrous temporal, having an anterior & posterior fold stretched between the petrous apex and the anterior/posterior clinoid processes respectively[2]. However in most cases a dural fold stretches between the anterior clinoid process and petrous apex in the roof of the cavernous sinus, while a well-defined ligament stretches between the petrous apex and the posterior clinoid process. The abducent nerve passes inferior to this petroclinoid ligament in the Dorello's canal on its way anteriorly from the brainstem towards the superior orbital fissure through the cavernous sinus. Only two (2%) completely ossified petrosphenoid/petroclinoid ligaments were found in our study. Skrzat et al[2] performed a normal study of this ligament on 24 sections of human heads and looked for remnants of the ossified form of this ligament in 73 dry human skulls. They found only one partially ossified ligament in their dry skull samples.

The present study confirms the relatively rare incidence of an ossified petrosphenoid ligament. Ossification of this ligament maybe clinically relevant in surgical approaches directed at the petrous apex;[2,14,15] it may also cause compression of either the abducent nerve which passes deep to it in Dorello's canal[16,17] or of the paraclinoid internal carotid artery[18]. There is a close relationship between the petroclinoid ligament and the oculomotor nerve which passes through the roof of cavernous sinus to reach its lateral wall en route to the superior orbital fissure and orbit. The oculomotor nerve runs inferior to the fold of the dura mater, which stretches between the petrous part of temporal bone and the lesser wings of the sphenoid bone; so an ossified petroclinoid ligament may also entrap this nerve[2].

4.4. Pterygospinous and Pterygoalar ligament

The foramen ovale is notoriously associated with several incompletely ossified ligaments in the extra-cranial region. Earlier workers have proposed that these cranial osseous bridges which are occasionally observed are the outcome of secondary ossification of the associated ligaments[19]. However, Lang and Hetterich[20] contended that the pterygospinous bar is not the result of such an ossification, noting that it was normally present in skulls of children below five years of age.

The *pterygospinous ligament* (also named after Civinini), arises from the pterygoid fascia in the region of the posterior margin of the lateral pterygoid plate and attaches to the spine of the sphenoid bone. The ossified ligament forms a bony bridge (Civinini's bar) just medial to foramen ovale, thus creating the pterygospinous foramen (Civinini's foramen), through which pass the medial pterygoid vessels and nerves[8]. Ossification of the pterygospinous ligament is to be considered important in some clinical conditions related to the mandibular nerve and foramen ovale, since the branches of mandibular nerve may pass through the associated foramen[5,6].

The pterygospinous ligament was found to be completely ossified unilaterally on the left side in two skulls (2%) and bilaterally in none of the skulls in the present study. It was incompletely ossified at four sites (4%) in the present study; unilaterally in two skulls and bilaterally in one skull (Table 1). Das and Paul[4] studied 50 Indian skulls, wherein they observed presence of a flattened and broad lateral pterygoid plate associated with an incomplete, ossified pterygospinous ligament on the right side, in only one bone specimen. The results of their study differ from those presently seen in this study in a similar sample size and population, the reason for which may be sought in the sampling method or observation criteria. In a Greek survey[8], completely ossified pterygospinous ligaments were observed in only one skull bilaterally (two of 100 sites) and incompletely ossified in 25 of the 100 sites studied. The present study showed results not very different from those seen in the Greek study, except those pertaining to incompletely ossified ligaments. It is our view that an increase in the sample size may narrow these differences.

The *pterygoalar ligament* is stretched between the root of the lateral pterygoid plate and the undersurface of the greater wing of sphenoid on the outer aspect of the skull base running close to the foramen ovale, the ossified ligament being referred to as the pterygoalar bar or *laminae pterygospinosae*. This exists as a bony ridge and forms a foramen along the lateral margin of the foramen ovale. The motor fibres of the trigeminal nerve (i.e. masseteric and deep temporal nerves) pass through this foramen. The limited spaces bounded by the pterygoid process and this structure are termed as *foramen pterygospinale*, pterygoalar foramen or *foramen crotaphitico-buccinatorium*. Occasionally the foramen pterygospinale may transmit nerves and vessels for the pterygoid muscles, particularly to the medial pterygoid. The pterygoalar bar and pterygoalar foramen are rare cranial features, but their presence maybe of clinical importance during trigeminal nerve injection or anaesthesia[8]. Pterygoalar ligaments were observed in the present study to be incompletely ossified bilaterally in two skulls (4%) and completely ossified unilaterally in only one skull (1%).

Skrzat et al [21] surveyed 70 dry human skulls in a Polish population to look for the pterygoalar foramen and found it in only five. An incomplete pterygoalar bar was observed in only one case among all the skulls they studied. They did not find a complete bilateral pterygoalar bar in any skull. However, they observed a complete pterygoalar bar on the right side and an incomplete one on the left side in one skull. Antonopoulou et al[8] reported one complete and seven incompletely ossified unilateral pterygoalar ligaments in a Greek population. Rossi et al[22] surveyed 183 Brazilian adult dry human skulls and reported ossified pterygoalar ligaments in only five skulls, resulting in an overall incidence of 2.73%. They reported incomplete ossification in one sample unilaterally (0.54%) and complete ossification in four skulls unilaterally (2.18%). The data reported in the present study is not very different in this regard, taking into account ethnic differences and the sample size.

Ossified pterygospinous and pterygoalar ligaments have important clinical implications in case of mandibular neuralgia and during therapeutic approaches aimed at the nerve root exiting the foramen ovale[6]. The ossified pterygoalar & pterygospinous ligaments may also be a major cause of lingual nerve entrapment[5].

5. Conclusion

Occurrence of ossified ligaments of the skull base – especially in relation to the MCF cannot be overlooked while planning and undertaking neuro-surgical approaches. A pre-operative radiological evaluation may be necessary in each case to prevent mishaps due to the presence of such an ossified ligament. These ossified ligaments should also be considered in cases where symptoms manifest due to probable compression of neurovascular structures.

Conflict of interest

The authors have no conflicts of interest to declare.

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