Ossification of the Posterior Petroclinoid Dural Fold: A Cadaveric Study with Neurosurgical Significance

David Kimball¹ Heather Kimball¹ Petru Matusz² R. Shane Tubbs^{1,3,4} Marios Loukas^{1,5}
A. Aaron Cohen-Gadol⁶

¹Department of Anatomical Sciences, St. George's University School of Medicine, Grenada, West Indies

²Department of Anatomy, Victor Babes University, Timisoara, Romania

³Department of Pediatric Neurosurgery, Children's Hospital, Birmingham, Alabama, United States

⁴Department of Anatomy and Human Identification, Dundee University, United Kingdom

⁵Department of Anatomy, Medical School Varmia and Mazuria, Olsztyn, Poland

⁶Department of Neurological Surgery, Goodman Campbell Brain and Spine, Indiana University

Address for correspondence Marios Loukas, MD, PhD, Department of Anatomical Sciences, St George's University School of Medicine, Grenada, West Indies (e-mail: mloukas@sgu.edu).

J Neurol Surg B 2015;76:272–277.

Abstract

Objectives The roof of the porus trigeminus, composed of the posterior petroclinoid dural fold, is an important landmark to the skull base surgeon. Ossification of the posterior petroclinoid dural fold is an anatomical variation rarely mentioned in the literature. Such ossification results in the trigeminal nerve traversing a bony foramen as it enters Meckel cave. The authors performed this study to better elucidate this anatomical variation.

Design Fifteen adult cadaveric head halves were subjected to dissection of the middle cranial fossa. Microdissection techniques were used to examine the posterior petroclinoid dural folds. Skull base osteology was also studied in 71 dry human skulls with attention paid to the attachment point of the posterior petroclinoid dural folds at the trigeminal protuberances.

Setting Cadaver laboratory

Main Outcome Measures Measurements were made using a microcaliper. Digital images were made of the dissections.

Results Completely ossified posterior petroclinoid folds were present in 20% of the specimens. Of the 142 dry skull sides examined, 9% had large trigeminal protuberances.

Conclusions Based on this study, the posterior petroclinoid dural fold may completely ossify in adults that may lead to narrowing of the porus trigeminus and potential compression of the trigeminal nerve at the entrance to Meckel cave.

Keywords

- ▶ microanatomy
- ▶ petroclinoid dural fold
- ▶ neurosurgery
- ▶ cadaver dissection

Introduction

The posterior petroclinoid dural fold arises from the posteromedial extension of the attached tentorium cerebelli and

thereby connects the posterior clinoid process with the anterior petrous ridge (–**Figs. 1** and **2**).^{1,2} It forms the medial border of the oculomotor trigone and the roof of the porus trigeminus (the entrance to Meckel cave), both of which are

received

March 10, 2014

accepted

October 27, 2014

published online

March 2, 2015

© 2015 Georg Thieme Verlag KG
Stuttgart · New York

DOI <http://dx.doi.org/10.1055/s-0034-1396598>.
ISSN 2193-6331.

Fig. 1 Artist's illustration of a wet-specimen skull base. The posterior clinoid process, anterior petroclinoid dural fold, and posterior petroclinoid dural fold are illustrated. The entrance to Meckel cave is in relation to the posterior petroclinoid dural fold. Ant., anterior; CN, cranial nerve; ICA, internal carotid artery; Post., posterior; Vert. A., vertebral artery.

Fig. 2 Superomedial view of a wet-specimen skull base. The brain and brainstem have been removed and the nerve roots can be seen. The internal carotids and vertebral arteries have been transected to facilitate the removal of the brain. The posterior petroclinoid dural fold is highlighted in yellow. The trigeminal nerve enters Meckel cave just below the fold. CN, cranial nerve; For. Mag., foramen magnum; Int. Car. A., internal carotid artery; Vert. A., vertebral artery.

two important neurosurgical landmarks. Erroneously, the petroclinoid fold has also been described as the posterior petroclinoid ligament.¹⁻⁶ The posterior petroclinoid fold, which normally contains the superior petrosal sinus,⁷ is accompanied by the anterior petroclinoid fold, the continuation of the tentorial incisura onto the anterior clinoid process, and forms the lateral border of the oculomotor trigone.

The posterior petroclinoid fold occasionally may ossify, either partially or completely, and form a bar of bone spanning the roof of the porus trigeminus (—Fig. 3).^{1,4,6,8} Furthermore, it has been suggested that a completely ossified posterior petroclinoid fold may compress the trigeminal nerve root at the entrance to Meckel cave, leading to symptoms of trigeminal neuralgia.^{9,10}

To the best of our knowledge, limited data exist regarding the incidence and clinical sequelae of ossified posterior petroclinoid dural folds. Therefore the aim of our study was to provide a clear gross anatomical picture, report the incidence, and comment on the variations of ossified posterior petroclinoid dural folds. Additionally, we hypothesize the pathologic significance of a completely ossified posterior petroclinoid dural fold as it relates to trigeminal neuralgia.

Materials and Methods

Wet Specimens

Fifteen human adult formalin-fixed midsagittally hemisected cadaveric heads were subjected to dissection at St. George's University School of Medicine. These cadavers (8 female, 7 male) ranged in age at the time of death from 68 to 93 years

Fig. 3 Artist's illustration of a superomedial view of a dry skull base and right trigeminal nerve. The trigeminal nerve is seen entering Meckel cave underneath the petroclinoid bone. Top right inset depicts an impinged trigeminal nerve as it passes under a completely ossified posterior petroclinoid dural fold. Bottom left inset depicts a superior view of a dry skull base. The red box represents the anatomical location of the figure. Trigeminal N., trigeminal nerve; V1, ophthalmic division of the trigeminal nerve; V2, maxillary division of the trigeminal nerve; V3, mandibular division of the trigeminal nerve.

with a mean age of 78 years. All cadavers were fixed with formalin/phenol/alcohol solution. None of the specimens revealed any evidence of previous surgical procedures, traumatic lesions, or gross pathologies to the head and neck. The brains and brainstems were carefully dissected out in all specimens, leaving the cranial nerve roots, dura mater, and tentorium cerebelli intact. The posterior clinoid process and posterior petroclinoid folds were left intact in all specimens. Using a Seiler Evolution xR6 and Seiler IQ Medical ENT Surgical Microscope (St. Louis, Missouri, United States) (working medially to laterally) the longitudinal dural fibers of the posterior petroclinoid dural folds were dissected away from any underlying bone. The specimens were then classified as having complete, incomplete, small pieces, or absent petroclinoid bones. The complete petroclinoid bones were defined as bony extensions from the posterior clinoid process to the petrous ridge, without breaks. The incomplete petroclinoid bones were defined as bone extending more than half the distance from the petrous ridge to the posterior clinoid process but were not complete. The small pieces of petroclinoid bone were defined as bone > 1 mm in diameter embedded within the posterior petroclinoid dural fold that did not connect with the petrous ridge or posterior clinoid process. Measurements were taken of the complete petroclinoid bones using a dial caliper with 1/10-mm precision.

Dry Specimens

The skull base osteology was studied in 71 dry human skulls (142 sides) derived from the skull museum of the Department of Anatomical Sciences at St. George's University in Grenada. These cadavers ranged in age at the time of death from 68 to 93 years with a mean age of 78 years. None of the specimens revealed any evidence of previous surgical procedures, traumatic lesions, or gross pathologies. The calvaria of all skulls were removed with a Stryker bone saw (Portage, Michigan, United States), exposing the skull bases. The bony protuberance jutting anterosuperiorly from the trigeminal protuberances was measured when present. Measurements were taken from the base of the petrous ridge to the superior-most point of the protuberance in each of the skulls using a dial caliper with a 1/10-mm precision. The protuberances were then classified as large, small, or absent, based on the point of maximal protuberance elevation above the petrous ridge. Protuberance elevations > 2.0 mm were classified as large, elevations between 0.5 and 2.0 mm were classified as small, and elevations < 0.5 mm were classified as absent or smooth petrous ridges.

Results

Wet Specimens

Of the 15 total hemisected heads, a complete petroclinoid bone was present in three (20%) of the specimens (—Fig. 4). One (7%) was present in a left-sided specimen; two (13%) were present in right-sided specimens. Incomplete petroclinoid bones were present in two specimens (13%) (—Fig. 5). One (7%) was left sided and one (7%) was right sided. Small pieces of petroclinoid bones were present in three specimens

Fig. 4 (A, B) Superomedial views of the petrous bone and entrance to Meckel cave in two different right-sided hemisected cadaveric head specimens. The trigeminal nerves have been removed to better show the surrounding osteology. (A) A thin complete petroclinoid bone. (B): A thick complete petroclinoid bone. Notice that the entrance to Meckel cave has been narrowed. Bottom left insets depict a superior view of a dry skull base. The red boxes represent the anatomical location of the figures. 1, posterior clinoid process; 2, petrous apex; 3, petrous ridge; 4, trigeminal protuberances; 5, internal acoustic meatus; 6, facial and vestibulocochlear nerves.

Fig. 5 Superomedial view of the petrous bone and entrance to Meckel cave in a right-sided hemisected cadaveric head. The trigeminal nerve has been removed to better show the surrounding osteology. An incomplete petroclinoid bone can be seen. The anterior portion is connected to the posterior clinoid process. The posterior portion is connected to the trigeminal protuberances. Bottom left inset depicts a superior view of a dry skull base. The red box represents the anatomical location of the figure. 1, posterior clinoid process; 2, petrous apex; 3, petrous ridge; 4, trigeminal protuberances; 5, internal acoustic meatus.

Fig. 6 (A, B) Superomedial view of dry skull bases and right petrous bones. (A) A large trigeminal protuberance can be seen. (B) The petrous ridge is smooth with no trigeminal protuberance. The posterior clinoid process is missing. Bottom right insets indicate the anatomical location of the figure. 1, clivus; 2, pituitary fossa; 3, posterior clinoid process; 3*, anterior clinoid process; 4, petrous apex; 5, trigeminal protuberances; 6, internal acoustic meatus; 7, petrous ridge.

(20%), all left sided. The petroclinoid bones were absent in the remaining seven specimens (47%): Six (40%) were left sided and one (7%) was right sided (►Table 1).

Measurements were taken from the three complete petroclinoid bones. The length of specimen 1 (right sided), taken from the inferior-most bony attachment of the posterior clinoid process to the inferior-most bony attachment of the petrous ridge, was measured as 12.0 mm. The length of specimens 2 (right sided) and 3 (left sided) were both 9.0 mm. The width of all three specimens, measured at the midpoint (the thinnest section of bone), was 1.0 mm. The height of specimen 1, also measured at the midpoint, was 2.5 mm. The height of specimens 2 and 3 were both 3.5 mm (►Table 2).

Dry Specimens

Of the 142 dry skull sides examined, 13 (9%) had large protuberances, 7 (5%) had small protuberances, and 122 (86%) demonstrated smooth petrous ridges with absent

protuberances (►Fig. 6). Nine (13%) of the 71 total skulls examined had large protuberances, with 4 (6%), 1 (1%), and 4 (6%) protuberances present on the left side only, right side only, or bilaterally, respectively. Five (7%) of the total skulls examined had small protuberances. Three (4%) and two (3%) skulls had small protuberances present on the left side only or bilaterally, respectively. None of the skulls had small protuberances on the right side only. Fifty-seven (80%) of the skulls examined had absent protuberances bilaterally. None of the skulls had both large and small protuberances (►Table 3).

Discussion

Although no report exists at the gross anatomical level, the incidence of ossified petroclinoid dural folds have been reported via radiographic studies.^{1,8} In a study by Cederberg et al,¹ 23 (9%) of 255 subjects had completely ossified petroclinoid folds seen on radiograph. Completely ossified petroclinoid folds were found in 2% of patients age < 13 years and 15% of patients age < 35 years. In a separate study by Sedghizadeh et al,⁸ petroclinoid dural folds were identified

Table 1 Petroclinoid bones within cadaveric heads

	Head sides		
	n (%)		
Petroclinoid bone	Left side	Right side	Total
Complete ^a	1 (7)	2 (13)	3 (20)
Incomplete ^b	1 (7)	1 (7)	2 (13)
Small pieces ^c	3 (20)	0 (0)	3 (20)
Absent	6 (40)	1 (7)	7 (47)
Total	11 (73)	4 (27)	15 (100)

^aBone extending from the posterior clinoid process to the petrous ridge, without breaks.

^bBone extending more than half the distance from the petrous ridge to the posterior clinoid process, but is not complete.

^cBone > 1 mm in diameter embedded within the petroclinoid dural fold that does not connect with the petrous ridge or posterior clinoid process.

Table 2 Complete petroclinoid bone measurements

Complete petroclinoid bones	Measurements, mm		
	Length ^a	Width ^b	Height ^b
Specimen 1 ^c	12.0	1.0	2.5
Specimen 2 ^c	9.0	1.0	3.5
Specimen 3 ^d	9.0	1.0	3.5

^aMeasured from the inferior-most bony attachment of the posterior clinoid process to the inferior-most bony attachment of the petrous ridge.

^bMeasured at midpoint (thinnest section of bone).

^cRight side.

^dLeft side.

Table 3 Trigeminal protuberances observed in dry skulls

	Skulls				Sides
	n (%)				n (%)
TP	Present left side only	Present right side only	Bilateral	Total	Total
Large ^a	4, (6)	1, (1)	4 (6)	9 (13)	13 (9)
Small ^b	3, (4)	0, (0)	2 (3)	5 (7)	7 (5)
Absent ^c	NA	NA	57 (80)	57 (80)	122 (86)
Total	7, (10)	1, (1)	63 (89)	71 (100)	142 (100)

Abbreviations: NA, not applicable; TP, trigeminal protuberance.
^aA > 2.0-mm elevation above the horizontal petrous ridge.
^bA 0.5- to 2.0-mm elevation above the horizontal petrous ridge.
^cA smooth petrous ridge, or < 0.5-mm elevation above the horizontal petrous ridge.

via computed tomography (CT) scans. Of 500 patients studied, 40 patients (8%) were identified as having ossified petroclinoid folds bilaterally. Our study, however, found 3 (20%) completely ossified posterior petroclinoid dural folds in the dissection of 15 cadaveric head halves. In addition to the complete petroclinoid dural folds identified in our cadaveric dissection, we also studied 71 dry skull bases (142 sides) and found that 20 dry skull sides (14%) demonstrated small or large bony protuberances from the posterior border of the porus trigeminus. We believe that these protuberances may represent remnants of ossified petroclinoid dural folds that were destroyed or dissolved secondary to preparation techniques of the dry skull.

The higher incidence of completely ossified petroclinoid dural folds in our study likely reflects a higher sensitivity secondary to our use of cadaveric dissection as compared with radiographic studies. Conversely, the different incidences may also be due to differences in sample sizes. As such, a large-scale cadaveric study should be performed to better estimate the true incidence of ossified petroclinoid dural folds according to age group.

Anatomically, the trigeminal nerve root passes through the porus trigeminus to reach Meckel cave within the middle cranial fossa. The porus trigeminus is formed superiorly by the posterior petroclinoid dural fold and inferiorly by the petrous apex within the trigeminal impression.

It has been suggested that compression of the trigeminal nerve at the porus trigeminus may occur,^{9,10} but a sufficient pathologic mechanism of the disease process was lacking. Based on our study, we postulate that the trigeminal nerve root may become compressed secondary to complete and extensive ossification of the posterior petroclinoid dural fold. This may lead to symptoms of trigeminal neuralgia in a small select group of idiopathic trigeminal patients who may have otherwise failed microvascular decompression (►Fig. 3).

There are reports in the literature of successful treatment of idiopathic trigeminal neuralgia by decompressing the trigeminal nerve root at the porus trigeminus.^{10–12} In 1952, Taarnhøj¹⁰ successfully treated eight trigeminal neuralgia patients by dividing the dura (i.e., posterior petroclinoid

fold) over the trigeminal nerve root. Kureshi and Wilkins¹¹ reported a “bony ridge” in one patient that arose from the petrous bone and was found to be compressing the trigeminal nerve root. The bone was surgically removed with resultant pain relief. Finally, Standefer et al¹² reported a case of trigeminal neuralgia secondary to tentorial ossification. A posterior fossa exploration disclosed tentorial ossification arising from the posterior petroclinoid dura that compressed the sensory root of the trigeminal nerve. The mass was excised, and the patient made a complete recovery with no recurrence of pain at 11-month follow-up. The final pathologic diagnosis was “mature bone compatible with intradural ossification.”

Many cases of trigeminal neuralgia secondary to ossified posterior petroclinoid dural fold are possibly not recognized because the ossification is overlooked on head CT. As such, further studies correlating idiopathic cases of trigeminal neuralgia and ossification of the posterior petroclinoid dural folds seen on head CT are needed.

Conclusions

Based on our study, the posterior petroclinoid dural fold may completely ossify in adults leading to narrowing of the porus trigeminus. Following additional clinical experience, such physiologic changes may lead to pathologic compression of the trigeminal nerve root, providing an additional etiology for some cases of recalcitrant neuralgia.

References

1 Cederberg RA, Benson BW, Nunn M, English JD. Calcification of the interclinoid and petroclinoid ligaments of sella turcica: a radiographic study of the prevalence. *Orthod Craniofac Res* 2003;6(4): 227–232
2 Lang J. Skull Base and Related Structures: Atlas of Clinical Anatomy [in German]. Stuttgart, Germany: Schattauer; 2001
3 Burgener FA, Kormano M, Pudas T. Differential Diagnosis in Conventional Radiology. New York, NY: Thieme; 2008
4 Butler P. Applied Radiological Anatomy. Cambridge, UK: Cambridge University Press; 1999

- 5 Skrzat J, Walocha J, Jaworek JK, Mróz I. The clinical significance of the petroclinoid ligament. *Folia Morphol (Warsz)* 2007;66(1):39–43
- 6 Tubbs RS, Salter EG, Oakes WJ. Bony anomaly of Meckel's cave. *Clin Anat* 2006;19(1):75–77
- 7 Tubbs RS, Mortazavi MM, Krishnamurthy S, Verma K, Griessenauer CJ, Cohen-Gadol AA. The relationship between the superior petrosal sinus and the porus trigeminus: an anatomical study. *J Neurosurg* 2013;119(5):1221–1225
- 8 Sedghizadeh PP, Nguyen M, Enciso R. Intracranial physiological calcifications evaluated with cone beam CT. *Dentomaxillofac Radiol* 2012;41(8):675–678
- 9 Komminoth R, Woringe E. Trigeminal neuralgia related to anatomical malformations [in French]. *Neurochirurgie* 1964;10:110–114
- 10 Taarnhøj P. Decompression of the trigeminal root and the posterior part of the ganglion as treatment in trigeminal neuralgia; preliminary communication. *J Neurosurg* 1952;9(3):288–290
- 11 Kureshi SA, Wilkins RH. Posterior fossa reexploration for persistent or recurrent trigeminal neuralgia or hemifacial spasm: surgical findings and therapeutic implications. *Neurosurgery* 1998;43(5):1111–1117
- 12 Standefer M, Bay JW, Dohn DF. Trigeminal neuralgia secondary to a tentorial ossification: a case report. *Neurosurgery* 1982;11(4):527–529