Review of the Petroclinoid Ligament

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Summary: An ossified left petroclinoid ligament was found during routine dissection of the skull base in an adult male cadaver. The petroclinoid ligament is clinically and surgically important given its anatomical relationships to cranial nerves III, V, and VI, so its ossification is a risk factor for injuries due to trauma, increased intracranial pressure, and vascular and tumor compression resulting in abducens and oculomotor palsies. The causes of petroclinoid ligament ossification are yet to be completely elucidated although several reports have associated them with age-related and physiological processes. Assessing the integrity of the petroclinoid ligament is important during skull base surgical interventions to avoid postoperative complications. Therefore, this paper reviews the petroclinoid ligament and its variation, the ossified petroclinoid ligament.

Keywords petroclinoid ligament, petrosphenoidal ligament, posterior petroclinoid fold, Gruber’s ligament, Dorello’s canal

INTRODUCTION

The petroclinoid ligament (PCL), also known as the petrosphenoidal ligament or Gruber’s ligament (Figs. 1 and 2), extends from the caudal portion of the posterior clinoid process (PCP) and the cephalic end of the clivus anteriorly to its posterior attachment on the petrous tubercle of the petrous apex. There are many descriptions of intracranial calcifications in the literature. They are classified based on etiologies as physiological, congenital, infectious, endocrine, neoplastic and metabolic [1]. In this report, we review the history, anatomy, recent changes in nomenclature and morphometrics, and surgical implications of the PCL, and report a unique case of the complete ossification of the PCL with bilateral elongation of the PCP. Our findings and discussion may improve our understanding of the PCL as regards surgical planning and improvement of outcomes.

Historical Overview

The petroclinoid ligament (PCL), also called petrosphenoidal ligament or Gruber’s ligament, was first described in 1859 by Wenzel Leopold Gruber, a Russian physician and anatomist. Gruber obtained his doctorate at the University of Prague and was the chair of pathological anatomy and a professor between 1855 and 1882 [2]. He described the petrosphenoidal ligament as well as other anatomical structures such as the internal mesogastric hernia and the Martin-Gruber...
anastomosis involving the median and ulnar nerves in the forearm [2]. Although the ligament was described by Gruber, other prominent authors described significant findings related to it. Primo Dorello [2,3] described Dorello’s canal (DC) in 1905 as an osteofibrous canal marking the passage of the abducens nerve as it pierces the dura in the subarachnoid space. The PCL provides a roof for this canal, as described below. In 1904, Giuseppe Gradenigo [4,5], an Italian otologist, outlined a series of clinical manifestations resulting from compression of the abducens nerve in DC; today, we call this Gradenigo syndrome [4]. This fundamental structure has been named very differently at different moments of history. However, not all of the given names can fully describe its morphology adequately, and therefore, recent studies have proposed new nomenclature to clarify its anatomy [6].

Anatomical description and relations

PCL patterns have usually been described as butterfly or triangle shapes. Icke et al. [7] reported that 78% of their specimens had a butterfly shape, while 22% were triangular. The trajectory of the PCL follows a lateral to medial, posterior to anterior, and caudocephalic course parallel to the petroclival dura mater and immersed into the petroclival venous confluence (PVC), a venous confluence that drains the cavernous, inferior petrosal and basilar clivus sinuses into the jugular bulb in the ipsilateral jugular foramen. According to Destrieux et al. [8], the PCL divides the PVC into two compartments, superior and inferior. It is vital to emphasize that the PCL and posterior petro-

![Fig. 1. Schematic drawing of the skull base (superior view) noting a superficial dissection (left) where the petroclinoid folds are seen and a deeper dissection (right) where the petroclinoid ligament is seen.](image)

![Fig. 2. Cadaveric example of the superficial view shown in Figure 1.](image)
clinoid fold (PPCF) are independent structures (Figs. 1 and 2); their contents, anatomical relationships, and clinical manifestations – when injured – are very different. The PPCF is a dural tent that contains the PVC, and the PCL is more closely related to the porus trigeminus and oculomotor trigone and is therefore associated with different clinical and surgical relationships[9].

Several reports have mentioned the dimensions of the PCL. One case series of 20 specimens by Icke et al. [7] found a mean length of 13.4 mm, and a mean width of 6.1 mm at the posterior end and 4.2 mm at the anterior end. Xiao-Dong et al. [10] examined ten specimens and showed that the mean length of the PCL was 13.8 ± 2.2 mm, and the mean width 5.41 ± 1.7 mm at its anterior attachment and 5.5 ± 2.6 mm at its posterior insertion. Both accounts described a central narrowing of the ligament that embodies the butterfly or triangle shape depending on its width at the extremes.

In a recent anatomical study, thirty-six sides from eighteen fresh-frozen adult cadaveric heads were inspected to establish variations and morphologic characteristics of the PCL. The authors found that when present (86% of cases), the ligament demonstrated several types of variations. In 58.1% of the cases, it was observed as a single-band that could be anteriorly attached to either bone or dura mater; in 32.3% of cases it was found as a Y-shaped structure attached anteriorly to both the clivus and the dura mater; and in 9.7%, it was observed as a duplicated structure with lateral and medial components. Interestingly, the dissection showed that the PCL’s anterior attachment was primarily to the upper extension of the clivus instead of to the posterior clinoid process. Therefore, the authors concluded that its current name did not accurately describe the real anatomy of the structure and proposed the term petroclival ligament [6].

The PCL forms the roof of DC. DC is an osteofibrous compartment at the anterior end of the petrous apex and clivus transmitting the abducens nerve to the cavernous sinus. It also contains the dorsal meningeal artery in 80% of cases, along with the inferior petrosal sinus [5,11]. The relationships among its contents are essential for understanding the clinical and surgical implications of DC. Umansky [11] described the abducens nerve as in the middle third of the foramen in 52% of specimens, the outer third in 39%, and the inner third of the canal in 9%. Vail [12] proposed the spatial relationships of DC contents as follows: CN VI in a lateral position, the meningeal artery in a medial position, and the inferior petrosal sinus covering the nerve. PCL variations include ossifications, hypoplastic presentations, variable insertion points in the dura mater, and duplications. The PCL and DC are contained in the inferomedial paraclival triangle, which is defined as the entry point of CN IV, CN VI, and the petrosal vein, according to Isolan et al. and Drazin et al. [13-15].

The superior wall of the cavernous sinus is also related to the PCL and its relationships. It is bordered laterally by the anterior petroclinoid ligament, anteriorly by the endosteal dura mater of the carotid canal, medially by the dura mater of the diaphragm selle, and posteriorly by the PCL [16]. Several clinical implications have been described related to trauma, compression by meningiomas, aneurysmal compression, and tumoral entities, as discussed below [5,17].

Cranial nerve VI, the abducens nerve, originates from its nuclear portion situated in the dorsal pontine tegmentum at the level of the lower pons, lying ventral to the fourth ventricle and being separated from it by fibers originating in the CN VII nucleus [18]. It has seven segments or portions, two of them (the nuclear and fascicular portions) in the brain stem and the other five outside the brain stem: cisternal in the subarachnoid space, petrosal at the petrous apex, and cavernous, fissural and intraconal or intratraheal orbit when it enters the orbit. Importantly, DC is the boundary between the petrosal and cavernous portions of the nerve. Injury can occur to any segment of the nerve, but it is in DC that ossification of the PCL is reported as a probable mechanistic risk to nerve integrity [19].

**Ossification of the PCL**

The PCL is ossified in approximately 6.5%-12.1% of the general population [20,21]. Ossification can be unilateral or bilateral. Unilateral ossification is more frequent on the left side [1,20]. On a dry skull specimen, Tubbs et al. [19] reported bilateral ossification of the PCL and proposed the ossified ligament as a source of injury of CN VI given that the bony bridge further restricts this nerve, making it vulnerable to trauma and mechanical lesions. PCL ossifications can be classified into complete, with the formation of bony bridges, or partial, found in 52% and 38% of all cases, respectively. Although the most common cause of PCL ossification is age-related physiological degeneration, it has also been reported as a radiographic feature of systemic fluorosis and basal cell carcinoma syndrome [22]. Cederberg et al. [22] presented a radiographic study that revealed a weak but statistically significant correlation between PCL ossification and age and also a relationship between the degree of ossification of the
PCL and the interclinoid ligament (ICL). Other variations relating to the PCL are duplications in up to 10% of cases [20] and those about its insertions, especially on its anterior limit where it can be attached to the posterior clinoid process and the paraclival dura.

Case illustration

A routine anatomical dissection of the skull base in a 76-year-old Caucasian fresh-frozen male cadaver revealed a left ossified PCL (Fig. 3). The dura mater around the abducens and trigeminal nerves was carefully removed to dissect DC and PPCF. The ossified PCL was found to have its anterior insertion into the clival region in the fresh-frozen cadaveric specimen described herein.

Fig. 3. Clival region in the fresh-frozen cadaveric specimen described herein. Cranial nerves V and VI are highlighted in yellow.

a: Superior view of the clival region. The PCP is elongated on both sides. Note the ossification of the PCL is observed on the left but not on the right side. White arrowhead, dorsal meningeal artery.

b: Left ossified petroclinoid ligament (red arrow) is shown superior to cranial nerve VI and its relationship to the passage of cranial nerve V on its most posterior insertion in the petrous tubercle.

CN, cranial nerve; PCP, posterior clinoid process; PPCF, posterior petroclinoid fold

Fig. 4. An ossified left petroclinoid ligament is observed. The bony foramen extends 4.1 mm in its anteroposterior dimension and 1.9 mm in its caudocephalad dimension. Also, a PCP dorsal extension is appreciated. PPC, posterior petroclinoid process; PPCF, posterior petroclinoid fold
most caudal part of the PCP and its posterior insertion onto the petrous apex. A bony foramen was observed in which the abducens nerve entered the cavernous sinus below the PCL. The dimensions of the bony foramen were 4.1 mm × 1.9 mm (Fig. 4). An ossified extension of the PCP was observed above the PCL and inferior to the posterior petroclinoid fold (PPCF) on both sides. CN V was applied to the petrous apex and traveled above the PCL on its posterior attachment. CN VI had no duplications or variations in its course. The right PCL demonstrated no ossification or anatomical variations.

Clinical and surgical overview

Although parasellar ligament ossification has been historically related to physiologic aging processes, it has also been related to pathological states [17,19,23]. Clinical manifestations can vary. For instance, the abducens nerve can be compressed by regional aneurysms [24-28].

Closed traumatic brain injuries have been presented with isolated abducens nerve palsies [29,30]. Some authors have considered that ossified PCL might provide a rigid fulcrum that causes such injury of CN VI [30,31]. Increased intracranial pressure has also been proposed as a source of injury to the abducens nerve and potentially worsened by an ossified PCL [19]. In contrast, some have proposed that the ossified PCL can protect the nerve in the setting of increased intracranial pressure [20]. Lastly, septic thrombosis of the inferior petrosal sinus within DC has resulted in abducens nerve palsies [18,23].

Surgical considerations regarding an ossified PCL include iatrogenic lesions regional cranial nerves [9,10,19-21,32,33]. For example, although most of the literature regarding the clinical relevance of PCL ossification focuses on the abducens nerve, some cases and mechanisms of oculomotor nerve injury have also been reported given the proximity of this nerve to DC and the relationship of DC to the oculomotor trigone [17,32,34].

CONCLUSION

The PCL is an important surgical landmark. Ossification of this ligament has been reported, but the causes are yet to be completely elucidated. The PCL can be calcified unilaterally or bilaterally, the former being the more common presentation. A relationship with physiological aging has been claimed in the literature. Further research is needed to clarify the causes and consequences of the formation of intracranial bony bridges such as the PCL.

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