Clinical Anatomy 25:415–422 (2012)

REVIEW

Connection Between the Spinal Dura Mater and Suboccipital Musculature: Evidence for the Myodural Bridge and a Route for Its Dissection—A Review

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A connective tissue link between the spinal dura mater and the rectus capitis posterior minor muscle was first described in 1995 and has since been readily demonstrated via dissection, magnetic resonance imaging, and plastinated cross-sections of the upper cervical region (Hack et al. [1995] Spine 20:2484–2486). This structure, the so-called ''myodural bridge,'' has yet to be included in any of the American anatomy textbooks or dissection guides commonly used in medical education. This direct anatomic link between the musculoskeletal system and the dura mater has important ramifications for the treatment of chronic cervicogenic headache. This article summarizes the anatomic and clinical research literature related to this structure and provides a simple approach to dissect the myodural bridge and its attachment to the posterior atlanto-occipital membrane/spinal dura mater complex and summarizes the case for its possible inclusion in medical anatomy curricula. Clin. Anat. 25:415–422, 2012.

Key words: suboccipital; myodural bridge; dura mater; headache; musculoskeletal dissection; pain; cervical

INTRODUCTION

A connective tissue link between the rectus capitis posterior minor (RCPMi) muscle and the cervical dura mater, hereafter referred to as the ''myodural bridge'' was originally described by Hack et al. (1995) and has since been implicated as a source of cervicogenic headache pain. Subsequent investigators have verified this connection and described attachments between the cervical dura mater and nuchal ligament (Mitchell et al., 1998; Dean and Mitchell, 2002; Humphreys et al., 2003). There is now solid evidence for the existence of this structure and its clinical importance in relation to cervicogenic headache. This readily dissected anatomical feature has not yet been presented in any of the commonly used medical anatomy texts (Snell, 2004; Drake et al., 2005; Snell, 2007; Hartwig, 2008; Snell, 2008; Moore et al., 2010; Moore et al., 2011), atlases (Moses et al., 2005; Netter, 2006; Schuenke et al., 2006; Abrahams et al., 2008; Gilroy et al., 2008; Agur and Dalley, 2009; Tank and Gest, 2009; Clemente, 2011a; Rohen et al., 2011) or anatomical dissection guides (Hansen, 2002; Morton et al., 2007; Tank, 2009; Clemente, 2011b) in the United States. In fact, the only text known to contain a reference to the myodural bridge is page 742 of the British edition of Gray's Anatomy (Standring, 2008) with reference to the work of Zumpano et al. (2006). This article will summarize the evidence for the exis-

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Received 10 December 2010; Revised 2 July 2011; Accepted 23 July 2011

Published online 30 August 2011 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/ca.21261

tence of this cervical myodural bridge, the clinical implications of its existence, and finally describe a method for dissecting it that will readily fit into the dissection or prosection scheme of most gross anatomy courses.

Evidence of Connections Between Cervical Musculature and Dura Mater

Dissection of 11 cadavers by Hack et al. (1995) revealed a dense band of tissue connecting the RCPMi and the posterior atlanto-occipital (PAO) membrane in each subject. In addition, the authors found that the PAO membrane was intimately connected to the spinal dura mater by many fine connective tissue bands, allowing them to move as a unit, a construct identified as the ''posterior atlanto-occipital membrane-spinal dura complex'' (PAOM-SDC). A later confirmatory study by Mitchell et al. (1998) verified the PAOM-SD complex and also a direct physical connection of this complex to the RCPMi in a study of six dissected and four parasagittally sectioned cadavers. This same relationship was also identified in the visible human female dataset by Hack et al. (1996).

Mitchell et al. (1998) also claimed to have found a physical connection between the nuchal ligament to the midline of both the posterior atlanto-axial (PAA) and PAO interspaces, although they described the nuchal ligament as attaching to the dura mater rather than the more posterior membranes. These assertions were not confirmed by Johnson et al. (2000) in a study of nine cadavers, one of which was sectioned transversely following plastination, a process that removes much of the fatty material in a specimen. Instead, they described a well-defined nuchal ligament inferior to the axis but found no evidence of it within the PAO and PAA interspaces, implying that the loose vascular connective tissue in the region had been misidentified as the nuchal ligament.

Dean and Mitchell (2002) attempted to clarify the connections of the nuchal ligament at the PAO and PAA interspaces in 10 cadavers. They described definite connections in all subjects between the nuchal ligament and the spinal dura mater at both interspaces although the consistency of the connective tissue was not mentioned explicitly. The same authors also described the RCPMi as connecting to the PAO membrane, but not the spinal dura mater. However, the authors stated that during the dissection the spinal dura mater was displaced anteriorly, a process that could possibly disrupt the multiple small connections of the PAOM-SD complex, of which the authors made no mention. In a study of 30 cadavers, where the spinal dura mater was not displaced anteriorly, Humphreys et al. (2003) described a connection between the spinal dura mater and the RCPMi as it passed through the ''wafer-thin'' and tightly adherent PAO membrane in each and every specimen, again corroborating the original findings of Hack et al. (1995). They also consistently found a connection between the nuchal ligament and the cervical dura mater at the PAA interspace. Humphreys et al. (2003) also described a connective tissue attachment between the RCPMi and the nuchal ligament in 27 out of 30 cadavers. Moreover, the connection between the RCPMi and PAO-spinal dural complex was also obvious enough to be visualized by MRI as an incidental finding in a case study by Demetrious (2007) of a patient with cervical subluxation.

An intricate autofluorescence study was carried out by Nash et al. (2005) who explored the collagen fibers in the posterior atlanto-occipital space on plastinated cross-sections. During the preparation, the specimens were degreased and much of the adipose tissue was removed. Nash found direct collagen fiber connections extending anteroinferiorly from the RCPMi to the spinal dura mater just anterior to the posterior arch of the atlas. No collaginous connections between the nuchal ligament and the spinal dura were seen in the atlanto-occipital interspace, just fatty connective tissue that did not survive the degreasing procedure. This reinforces the findings of Johnson et al. (2000) who also found no direct connections between the nuchal ligament and the spinal dura at either the atlanto-occipital or atlanto-axial interspaces and contradicts Mitchell et al. (1998) and Dean and Mitchell (2002). However, potential functional importance of the loose fatty connective tissue in the region was not addressed and only the stout connective tissue bundles were visualized. Interestingly, Nash was unable to identify a distinct PAO membrane. Instead, he describes that the presumptive PAO consisted laterally of the tendon of the RCPMi, superiorly by the muscle's fusion to the occipital bone and inferiorly by its fusion to the spinal dura and vertebral vascular plexus sheath. Medially, the presumptive PAO was described as being discontinuous, consisting of the RCPMi fascia and sheath of the vertebral vascular plexus.

The most comprehensive study was by Zumpano et al. (2006) who undertook an extensive investigation, dissecting 75 cadavers via a posterior approach to characterize the frequency and consistency of any soft tissue structure connecting the RCPMi to the PAO membrane-spinal dura complex. They stated that the bridge was found bilaterally in 93% of their subjects with no instances of a unilateral myodural bridge. Visual inspection demonstrated that the most frequent type of connection was tendon-like, with the myodural bridge running between the PAO membrane and inferior attachment of the RCPMi to the atlas. The next most frequent type, muscle-like, contained muscle fibers bridging the RCPMi and PAO membrane while the least frequent type, fascia-like, consisted of connective tissue without muscle fibers running directly from the belly of the RCPMi muscle to the PAO membrane complex.

One difficulty with describing these structures is applying a consistent and accurate nomenclature to them. While the importance of the PAO membrane has been questioned, only the study by Dean and Mitchell (2002) suggested that the RCPMi does not have a functional attachment to the spinal dura mater. However, in this same study the spinal dura mater was displaced anteriorly and this may have disrupted the connections between the PAO membrane and the spinal dura mater. However, at this time there is indeed strong evidence for a functional connection from the RCPMi to the spinal dura, either

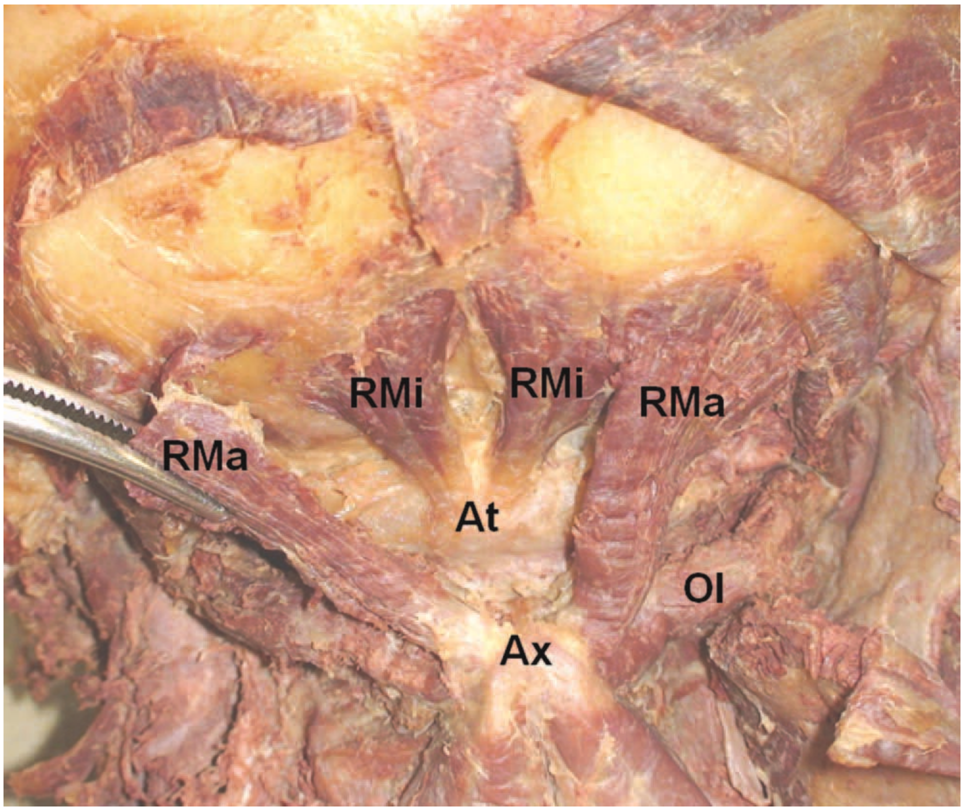

Fig. 1. Forceps detaching left rectus capitis posterior major muscle (RMa) from occipital bone. At, posterior arch of atlas; Ax, posterior arch of axis; OI, obliquus capitis inferior; RMa, rectus capitis posterior major; RMi, rectus capitis posterior minor. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

directly or via a PAOM-SDC. We will hereafter refer to this entire complex as the ''myodural bridge'' (Lipton and Hack, 1995; Hallgren et al., 1997). Contrarily, the connections between the nuchal ligament and the spinal dura are more difficult to describe with consistency and there is not enough evidence at this time to assert that these connections are regular enough to form a functional ''nuchodural bridge.''

Action of the Myodural Bridge

While most medical anatomy texts, atlases, and dissectors state that the function of the RCPMi is extension of the head (Drake et al., 2005; Moses et al., 2005; Schuenke et al., 2006; Morton et al., 2007; Gilroy et al., 2008; Hartwig, 2008; Agur and Dalley, 2009; Moore et al., 2010; Clemente, 2011a,b; Moore et al., 2011) at the atlanto-occipital joint, the normal function of the myodural bridge has been a topic for speculation. Hack et al. (1995) suggested that the myodural bridge may act to prevent in-folding of the dura mater during extension of the upper cervical segment. It has been reported that the posterior cervical dura mater is significantly thicker than the anterior dura and that this thickening may be influenced by the presence of the myodural bridge (Taylor et al., 1996).

However, through EMG studies, McPartland and Brodeur (1999) suggested that the RCPMi is not activated during extension of the head. Rather the RCPMi is active when the head is translated forward at the atlanto-occipital joint. Also noteworthy are the finding of Peck et al. (1984), who reported substantially higher density of muscle spindle fibers of the suboccipital musculature. The RCPMi and rectus capitis posterior major (RCPMa) were reported to contain spindle densities of 36 spindles/g muscle and 30.5 spindles/g. muscle, respectively. This finding is notable in comparison to spindle densities of the splenius capitis (7.6 spindles/g.) and gluteus maximus (0.8 spindles/g.) muscles, suggesting that the RCPMa and RCPMi have a largely proprioceptive activity. The high level of muscle spindle density may act to activate cervical neck extensors that would resist hyperflexion or hypertranslation at the atlanto-occipital joint and in turn aid to protect the cervical dura from a potentially noxious or traumatic rapid stretch.

In addition to preventing in-folding of the dura mater, Rutten et al. (1997) suggested that the RCPMi and myodural bridge might dynamically adjust the tension of the dura mater in conjunction

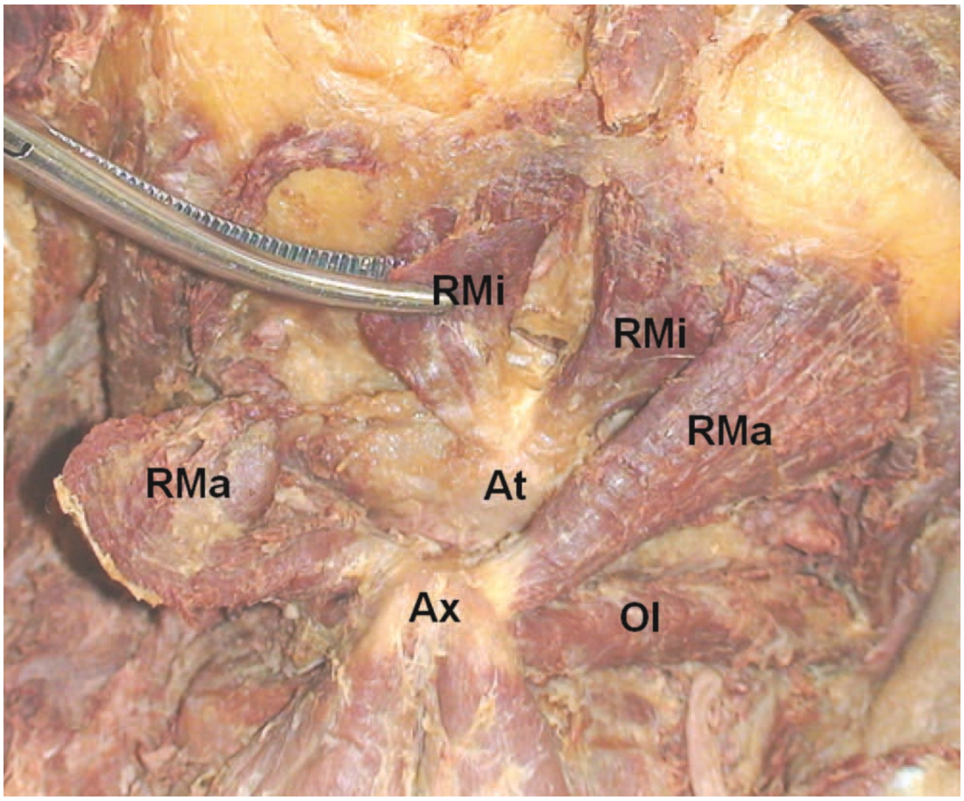

Fig. 2. Forceps detaching the left rectus capitis posterior minor muscle (RMi) from the occipital bone. At, posterior arch of atlas; Ax, posterior arch of axis; OI, obliquus capitis inferior; RMa, rectus capitis posterior major; RMi, rectus capitis posterior minor. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

with ligamentous structures in the vicinity of the foramen magnum and occipital condyles. According to Hallgren et al. (1997) the myodural bridge could help maintain the flow of cerebrospinal fluid (CSF) through the subarachnoid space and nearby cisterna magna by preventing in-folding of the dura mater during prolonged neck extension.

Evidence for the Clinical Importance of the Myodural Bridge in Neck Pain and Headache

Evidence exists that dysfunction of the RCPMi is involved in the etiology of headache. Elliott et al. (2005, 2006, 2008) demonstrated through a series of MRI studies that the RCPMi of individuals with chronic neck pain due to whiplash trauma contained significant amounts of fatty infiltration, possibly due to damage of the suboccipital musculature. Hallgren et al. (1993, 1994) also reported significant fatty infiltration in MRI images of subjects with chronic neck pain when compared to control subjects. Another study of seven patients by McPartland et al. (1997) also found fatty infiltration and atrophy of the RCPMi in patients with chronic neck pain, reinforcing Hallgren's findings. A single-subject case study by Andary (1998) demonstrated that a patient with persistent head and neck pain had fatty infiltration of the rectus capitis posterior minor as demonstrated by MRI. The same patient's RCPMi was studied with EMG with the results suggesting that the muscle had been traumatically de-innervated. Fernández-de-las-Peñas et al. (2008) found that patients with a history of chronic tension-type headaches and active trigger points had significantly smaller RCPMi muscles than control subjects. Perhaps dysfunction of the RCPMi and its proprioceptive activity could negatively impact the cervical muscles creating these trigger points, defined by Alvarez and Rockwell (2002) as distinct spots of hyperirritable muscle fibers within a band of skeletal muscles.

It should be noted that chronic cervicogenic headaches may arise from hypertrophy of the RCPMi, which may lead to increased tension directly onto the spinal dura via the myodural bridge. Hack and Hallgren (2004) published a case report of a patient suffering from chronic, debilitating headaches, whose MRI test revealed hypertrophy of the RCPMi muscle. As a treatment of last resort, surgery was carried out to sever the connective tissue attachments between the RCPMi muscle and the spinal dura, a procedure coined as the ''myodural release.'' Hack reported that the patient had significant headache relief at a 2-year post-operative follow-up examination.

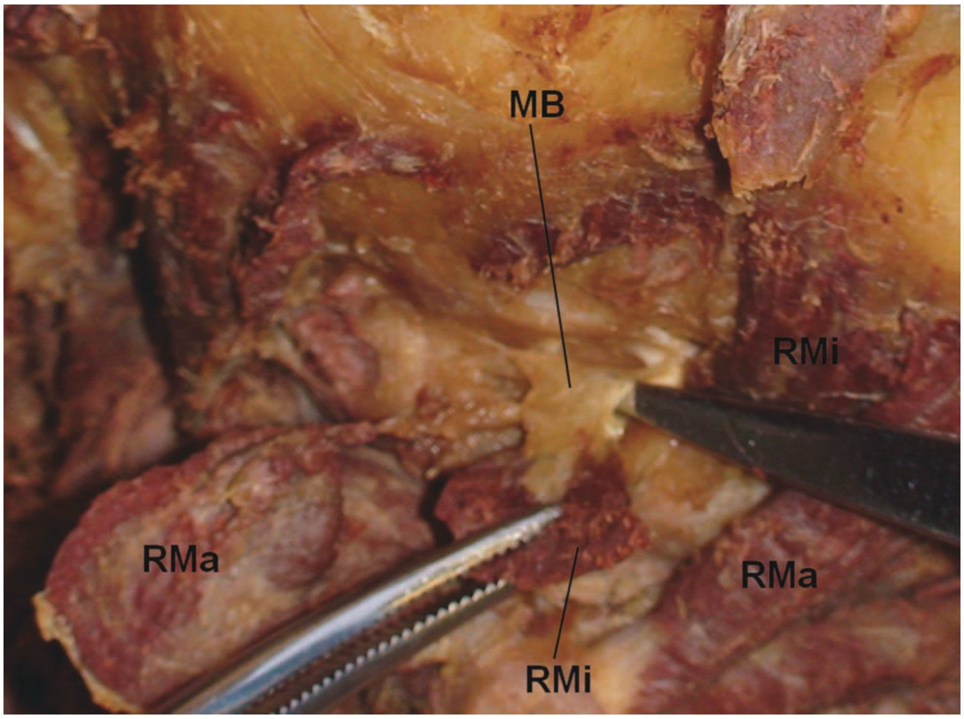

Fig. 3. Demonstration of the myodural bridge (MB) originating from the left rectus capitis posterior minor muscle (RMi), which is being held by forceps. MB, myodural bridge; RMa, rectus capitis posterior major; RMi, rectus capitis posterior minor. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

While a link between RCPMi dysfunction and chronic pain has been shown, the pain sensitivity of the cervical dura mater has been called into question by an immunohistochemical study of mouse dura mater by Kumar et al. (1996). They found that cranial dura mater contained large numbers of mast cells and sensory nerves with substance P, both markers of pain sensitivity. However, they observed a sharp decrease in both mast cells and substance P in cervical dura mater immediately below the foramen magnum. In answer to these findings, Konttinen (1996) pointed out that the many pain sensitive structures that surround the cervical dura mater may mediate some pain originating from it. Alix and Bates (1999) suggest that the spinal dura mater's potential role in causing headaches could be due to the fact that parts of it are innervated by the C1, C2, and C3 spinal nerves that project to the spinal trigeminal nucleus, where they converge with nociceptive inputs from the head. In addition, the myodural bridge may also directly apply traction to the pain-sensitive cranial dura mater through the foramen magnum but this has not yet been investigated.

The presence of a direct bridge linking the musculoskeletal system to the dura mater provides a potential mechanical explanation for the efficacy of cervical massage and manipulative treatment on headache. Additionally a review of studies reporting on the benefits of manipulative treatment of cervicogenic headaches is provided by Alix and Bates (1999). This myodural bridge could lead to more specific therapeutic options for physicians treating patients with chronic headache. However, dissemination of this information to medical professionals and medical educators has been minimal to date.

Dissection of the Myodural Bridge

The existence of the myodural bridge can be demonstrated through direct visual confirmation during cadaveric dissection. A simple method of dissection that can be added to the normal laboratory dissection of the suboccipital region of the posterior neck is presented here. In fact, since many laboratory guides offer a detailed dissection of the suboccipital region (Hansen, 2002; Tank, 2009; Clemente, 2011b), the myodural bridge can be demonstrated with only two additional cuts and minimal cleaning of loose areolar fascia. For clarity, no abbreviations will be used in the following paragraphs.

Reflect the trapezius, splenius capitis, splenius cervicis, and semispinalis capitis muscles to view the suboccipital region. After the rectus capitis posterior major, rectus capitis posterior minor, obliquus capitis inferior, and obliquus capitis superior muscles have been defined, use a scalpel to detach the rectus capitis posterior major from its superior attachment and reflect it inferiolaterally (Fig. 1). This step has the additional benefit of further exposing the suboccipital nerve.

Make a similar incision in the rectus capitis posterior minor, detaching it from its cranial attachment (Fig. 2). Using a hemostat, gently reflect the rectus capitis posterior minor muscle inferiorly while clear-

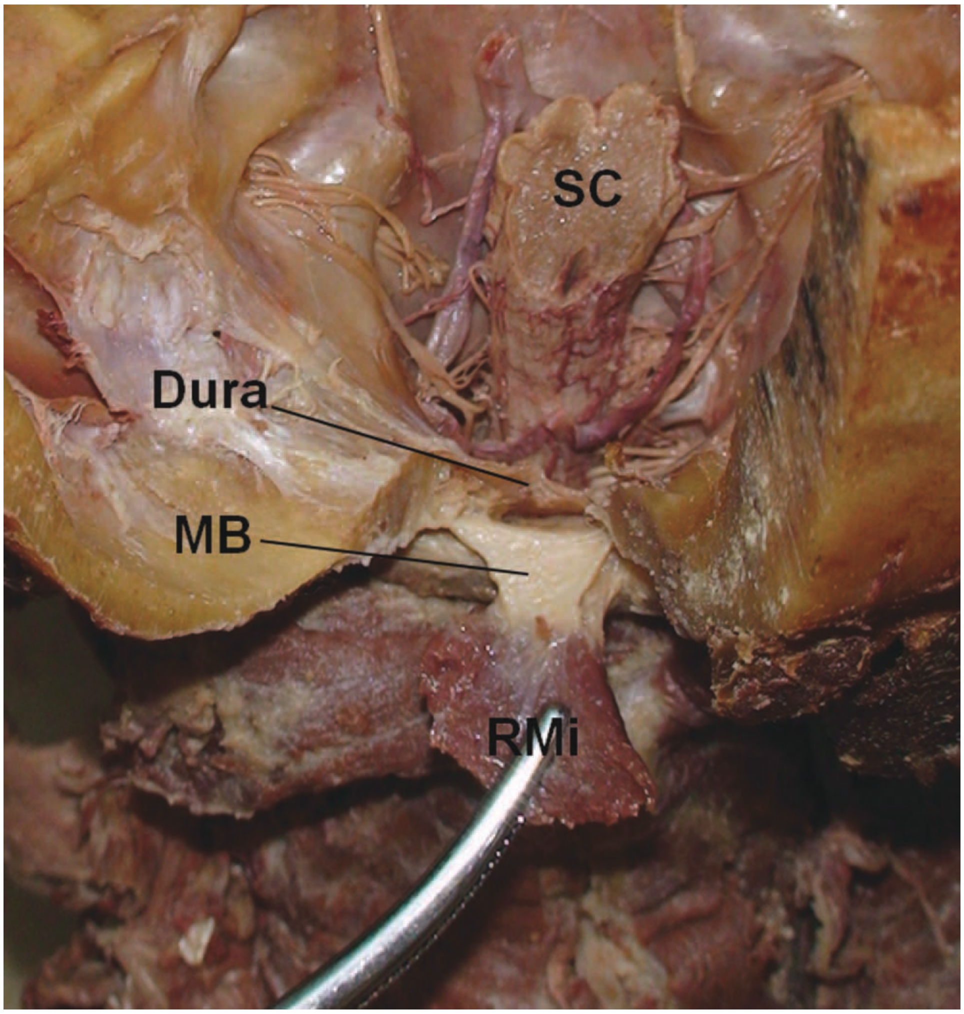

Fig. 4. Removal of a wedge of occipital bone to demonstrate the myodural bridge (MB) connecting the rectus capitis posterior minor (RMi) and the dura mater (Dura) near the foramen magnum. Dura, dura mater; MB, myodural bridge; RMi, rectus capitis posterior minor; SC, spinal cord. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

ing the loose areolar fascia between it and the posterior atlanto-occipital membrane. If present, the cervical myodural bridge will be visible as a band of noticeably stronger connective tissue running between the rectus capitis posterior minor muscle and the foramen magnum (Fig. 3). For further exposure of the area, a wedge of occipital bone can be removed to directly demonstrate the connection between the posterior atlanto-occipital membrane, spinal dura mater, and rectus capitis posterior minor muscle (Fig. 4). A mid-sagittal schematic of this process is also shown (Fig. 5).

CONCLUSION

The myodural bridge between the RCPMi muscle and the cervical dura mater is a recently described anatomical feature that has not yet been incorporated into any American anatomy atlases, texts, or dissection guides. This exclusion is unfortunate since this connection between the musculoskeletal system and the dura mater has been implicated in headache and neck pain, two common musculoskeletal complaints. Perhaps this exclusion reflects a dismissive attitude toward the suboccipital region, which requires time and dedication to dissect properly. Some anatomy textbooks (Snell, 2004, 2007, 2008) neglect the region entirely. It is important for us to realize that this region is important for a variety of reasons and its inclusion in medical gross anatomy is not merely a matter of completeness, but of clinical importance, as demonstrated by the description of the myodural bridge by Hack et al. (1995). Zumpano et al. (2006) suggested that instead of being ignored deliberately, the lack of attention paid to the myodural bridge may be simply due to the fact that most medical anatomy courses go no deeper than the sub-

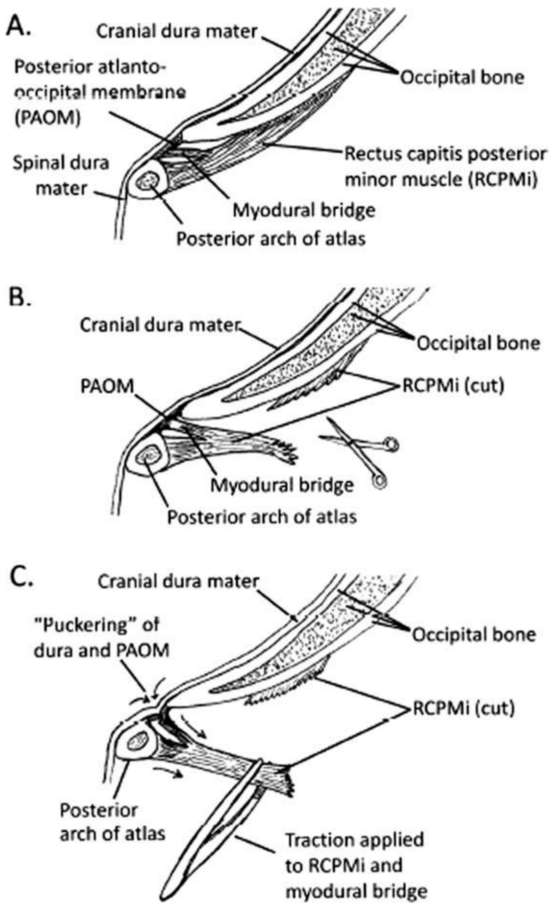

Fig. 5. Reflection of the rectus capitis posterior minor from the occipital bone to reveal the connection of the myodural bridge to the posterior atlanto-occipital membrane-spinal dura mater complex. **A**: Normal anatomy of the myodural bridge. **B**: Reflection of the rectus capitis posterior minor muscle inferiorly. **C**: Traction placed on the myodural bridge and spinal dura mater by forceps.

occipital triangle and that dissections of the upper cervical joint are done in such a way that all intervening soft tissue structures are destroyed.

However, the dismissive attitude toward the suboccipital region may reflect an unfortunate tendency to believe that all the important anatomical features have been described and that anatomy exists as a repertory science. As a definite counter example, I hope that this article has adequately summarized the importance of a recently described structure, the myodural bridge. Rather than just being a curiosity, the myodural bridge may play an important role in the etiology of neckache and headache and the proprioceptive apparatus of the upper cervical region. We hope the preceding dissection instructions and demonstration video (Supporting Information Video S1, which is available online) will help instructors of clinical anatomy to include this structure in their courses and that as a result their students will be better able to treat their future patients.

ACKNOWLEDGMENTS

The authors would like to thank Kevin Evans for his assistance in preparing the specimens used in the figures. We would also like to thank the reviewers whose excellent critique has resulted in a far better final product.

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