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Review Article

# Utilization of MR imaging in myodural bridge complex with relevant muscles: current status and future perspectives

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**Abstract**

The aim of this study is to review and discuss the literature on the utilization of magnetic resonance imaging (MRI) in investigating the structure and feasible function of the myodural bridge complex (MDBC) with relevant muscles, which will be useful to understand the function of the MDB. The myodural bridge (MDB) is a soft tissue connective bridge that provides a fascial continuity between the musculature/ligament and cervical spinal dura mater (SDM) in the suboccipital areas. All of these involved structures are referred to as the MDBC. It would transfer tensile forces effectively from involved suboccipital muscles/ligament to SDM during head movement. Despite present achievements, its anatomic and functional role is still unclear. MRI enables not only *in vivo* visualization of ligaments, musculature and spinal dura with conventional $T_1W$, $T_2W$ and PDW imaging, but also functional evaluation of MDBC with relevant muscles, such as muscles' fatty infiltration, cross-sectional area changes and injuries. Though some functional MRI techniques have not been used for the MDBC with relevant muscles now, these techniques have great potential to better understand function of MDBC including its suspected clinical role. MRI is likely the most powerful tool to study MDBC and relevant muscles with only limited exploration so far.

**Keywords:** Cervicogenic Headache, Magnetic Resonance Imaging, Myodural Bridge Complex, Spinal Dura Mater, Suboccipital Muscles



## Introduction

The myodural bridge (MDB) is a soft tissue connective bridge that provides a fascial continuity between the suboccipical musculature and cervical spinal dura mater (SDM) at the posterior atlanto-occipital (PAO) and posterior atlantoaxial (PAA) intervals[1-6]. It is proven that the MDB originating from the rectus capitis posterior minor muscle (RCPmi), rectus capitis posterior major muscle (RCPma) and obliquus capitis inferior muscle (OCI) in the suboccipital region coexists[1,4,6]. This complex structure is named to be myodural bridge complex (MDBC), which would transfer tensile forces effectively from involved suboccipital muscles to SDM during head movement[7]. Its presence in a large spectrum of animals including mammals signifies evolutionary conservation of the MDB which might indicate its vital role[8,9].

The function of the MDBC is still not fully understood. Anatomically, the MDB is considered to play an important role in resisting dural infolding and maintaining posture of the spinal cord during extension of the upper cervical segment[1-6]. In addition, the MDB may help to maintain the flow of cerebrospinal fluid (CSF) which contributes to the pathophysiology of various CNS diseases[10-12]. Clinically, it has been suspected to primarily associate with the etiology of headaches[13-16].

Most previous studies of the MDBC focused on its physical structures[1-6]. Anatomical dissection, cross-sectional plastination and histology observation were the main methods used for its structural and functional speculation *in vitro*[17-27]. However, recent trends in research revolving around the MDBC with relevant suboccipital musculature have led to a proliferation of studies to confirm its potential function *in vivo*[28]. Magnetic resonance imaging (MRI) is a powerful tool that has been used to investigate the MDBC with relevant musculature due to its

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noninvasiveness, excellent resolution for soft tissues, and its capability of functional evaluation *in vivo*[29-30]. Several reviews have been published on the topic of its anatomy and functional significance[31-33]. However, there is no review focusing on the utilization of MRI regarding the imaging and assessment of the MDBC and relevant musculature with respect to anatomical visualization and potential functional investigation. The primary objective of this review is to summarize the current literature relating to MR imaging of the MDBC with relevant musculature and to outline future applications of this technology with regards to visualization and functional evaluation. This review consists of the following sections: I. The brief introduction of MR imaging techniques for investigating anatomy and clinical potential function of MDBC with relevant musculature. II. MDBC with relevant musculature anatomy evaluation with MRI. III. MDBC relevant musculature potential function evaluation with MRI including fatty infiltration, cross-sectional area changes and injuries.

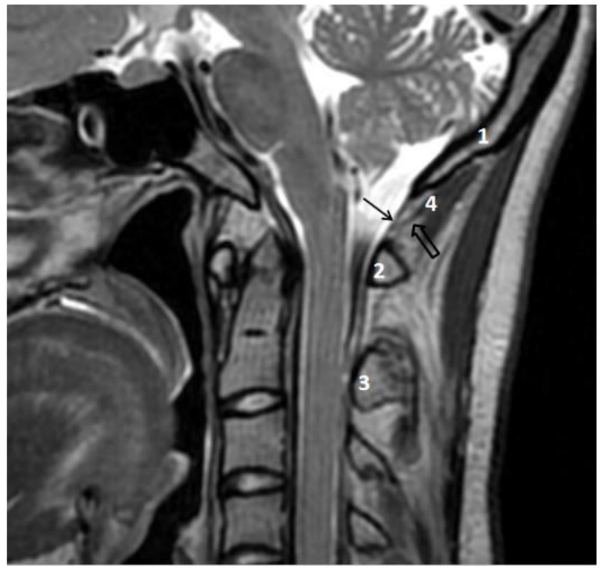


**Figure 1.** Oblique sagittal $T_2$-weighted MR image demonstrates hypo-intense myodural bridge (blank arrow) between the rectus capitis posterior minor muscle and cervical spinal dura mater (black thick arrow) at the posterior atlanto-occipital interval. (1. occipital bone, 2. atlas, 3. axis, 4. rectus capitis posterior minor muscle).

### *I. MR imaging techniques for investigating anatomy and clinical function of MDBC and relevant musculature*

Historically, MR imaging has provided an unparalleled evaluation of the soft tissue in the suboccipital region, including the MDBC[29-30]. For the purpose of investigating the anatomy of the MDBC, proper visualization of ligaments, musculature, and spinal dura is a necessity. Different imaging modalities have therefore been employed to better capture certain aspects of the MDBC. Among them are $T_1$-weighted, $T_2$-weighted, and proton density weighted (PDW) images[29,30]. MRI's first use in investigating the structures connected to MDB *in vivo* ranges back to a 2001 study by Krakenes et al., in which the posterior atlanto-occipital membrane was evaluated on sagittal PDW images[29]. The use of low echo time in a PDW imaging increases the contrast resolution and thus provides a wider range in gray scale in tissues with short $T_2$ times. Hence it is good at discriminating the PAA membrane and SDM from their surrounding tissue. Detection of MDB *in vivo* and *in vitro* with its original muscles by conventional $T_1$ and $T_2$-weighted imaging has been promising. On $T_1$-weighted and $T_2$-weighted spin-echo images, the signal intensity of the MDB has the same hypo-signal intensity as that of muscles due to their long $T_1$ and short $T_2$ times compared with surrounding suboccipital fat[3,30].

In addition to anatomical information, MRI can provide information on the physiological and functional properties of the MDBC relevant musculature. However, contrary to the techniques employed for the anatomical visualization, functional evaluation of this complex relevant musculature can be achieved by using a different set of imaging modalities. These include MR spectroscopy (MRS), diffusion-weighted imaging (DWI), and diffusion tensor imaging (DTI)[34-36]. Although these techniques have not been used for the imaging of the muscles connected to MDBC, there are several potential future applications. MRS provides a quantitative analysis of the chemical composition of the imaged structure. In MDB complex imaging, proton MRS is used to measure the fat to water ratio providing us with an estimation of the fat content within the suboccipital musculature[34]. DWI is dependent on the tissue microstructure and the resultant changes in the Brownian motion of the water molecules[35]. Similar to DWI, DTI generates a three-dimensional map based on the movement of the water molecules in the tissue and provides us with an image of the tissue microstructure. The significance of this technique rests in the two parameters measured based on DTI, the fractional anisotropy (FA) and the apparent diffusion coefficient (ADC). Subsequent to any changes in the tissue or musculature, these parameters alter accordingly and can therefore observe an abnormality that may otherwise be seen as normal by conventional MRI[36].

### *II. MRI evaluation of MDBC with relevant musculature anatomy*

Excellent assessment of the MDBC along with structural details can be achieved through the use of MR imaging. Initially uncovered through dissection, the use of MRI for the evaluation of the MDBC has increased following the discovery. The MDB was first discovered in 1995 by Hack et al. which revealed a dense band of tissue connecting the RCPmi to the PAO membrane, a membrane that was intimately attached to the spinal dura[1]. Following studies used MRI to confirm these structures. In a 2001 study, Krakenes et al. demonstrated the PAO membrane to be a well-defined dark structureby using MRI with a PDW sequence and 2-mm-thick slices in

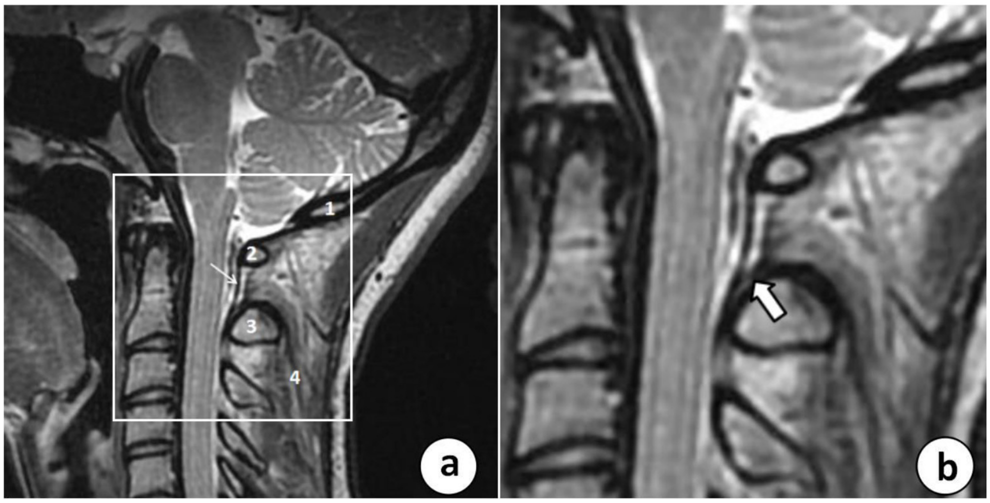


**Figure 2 (a,b).** Midsagittal $T_2$-weighted MR images show hypo-intense myodural bridge (b: blank thick arrow) from nuchal ligament attaching to the dura mater (a: white thin arrow) in the posterior atlanto-axial interspace. (1. occipital bone, 2. atlas, 3. axis, 4. nuchal ligament).

sagittal plane[29]. Subsequently, Humphreys et al. compared MR images of RCPmi's MDB with anatomical dissection of four embalmed cadavers[3]. The MDB between the RCPmi and the dura mater appeared as a small low signal intensity band coursing from RCPmi towards the posterior SDM on $T_1$-weighted images. In 2013, Scali et al. examined the anatomy of the PAA interspace *in vivo* using midsagittal $T_2$-weighted MR imaging[30]. 240 living subjects were examined for the presence of oblique hypointense fibers between the PAA intervals. However, the specific connection and function of these hypointense fibers was not confirmed in this MR study. These findings might represent normal, nonpathological anatomical findings on MR images and could also be related to the myodural bridge[30]. Further imaging and analysis is necessary to demonstrate these structures.

There are still no MRI studies that depict the morphology of the MDB from the RCPma and OCI *in vitro* and *in vivo*. This is important due to the clinical significance of the MDBC. The dural attachment sites could be injured during trauma or whiplash injuries, resulting in altered images on MRI. In studies using MRI, sagittal plane is optimal for spine and spinal cord demonstration. However due to the orientation of the suboccipital musculature, an oblique plane parallel to the RCPmi, RCPma and OCI muscles would provide a more accurate evaluation of these structures[16]. High resolution MRI, especially three dimensional sequences, possesses outstanding spatial resolution and post processed multiplanar reconstruction that allows us to investigate the deep suboccipital muscles. It lessens the partial volume effect that may otherwise obscure closely related structures. Therefore, MRI is potentially beneficial in visualizing these underestimated connective tissues *in vivo* and can provide definite anatomic evidence (Figures 1, 2).

## *III. MDBC relevant musculature potential function evaluation with MRI including fatty infiltration, cross-sectional area changes and injuries*

*MRI evaluation of fatty infiltration of MDBC relevant muscles*

MRI has been used to evaluate the role of MDBC relevant musculature in cervicogenic pain syndrome and headaches[13-16,37,38]. The fatty infiltration of the suboccipital muscles has been the subject of focus due to the muscles physical connection with the cervical SDM and potential influence on cervicogenic pain syndromes and headaches. Recently, two studies have suggested that there is a relationship between musculature signal intensity changes and symptoms of chronic neck pain[37,38]. Hallgren et al. considered fatty degeneration of the RCPmi and RCPma muscles to be a positive predictor of chronic neck pain[37]. Moreover in a case study by Andary et al., they discovered that in a patient with persistent head and neck pain, atrophy and fatty infiltration of the RCPmi was prominent on MRI[38]. Although the atrophy and fatty infiltration of RCPmi and RCPma muscles were first observed in a small number of patients with chronic neck pain, whether this change was due to age or other factors was unknown[37,39]. However, in a 2005 study using MR images, Elliot et al. showed that relative fatty infiltration was not a feature correlated to age in the suboccipital musculature of women aged 18-45 years[40]. With regards to headaches, female patients suffering from persistent insidious-onset neck pain did not show quantifiable MRI changes in the fat content of the suboccipital muscles with $T_1$-weighted images and their fat levels mirror those with no history of neck pain[39]. However, larger amounts of fat infiltration were observed in the RCPma and RCPmi muscles in elderly with cervicogenic headache compared to controls in 2017[15].

Fat infiltration of suboccipital muscles can also play an important role in whiplash-associated disorders (WAD)[41-42]. The presence of fatty infiltration in cervical extensor musculature including the RCPmi and RCPma in a cohort of chronic whiplash patients and healthy control subjects was compared quantitatively across muscle and cervical segment levels by Elliot et al. in 2006[41]. The WAD subjects had significantly larger amounts of fatty infiltration for all of the cervical extensor muscles compared with healthy control subjects. In 2008, Elliott et al. investigated the presence of fatty infiltration in the cervical extensor musculature in patients with insidious onset neck pain in chronic WAD[42]. There was a difference in the fat indices of the cervical extensor muscles including RCPmi, RCPma and OCI with WAD participants. They demonstrated significantly higher amounts of total fatty infiltration when compared with the insidious-onset neck pain participants. Investigations of whiplash had attempted to identify and link structural pathology with symptoms, however, the results were not consistent. These questions related to the origin of muscle degeneration following traumatic whiplash injury and the overall contribution to long-term outcomes might correlate with the myodural bridge and required further evaluation[30-42].

However, to quantifiably measure the muscle/fat content in the cervical musculature, researchers established a simple method that took a ratio of the pixel intensity profiles of muscles against those of the intermuscular fat for the RCPma, RCPmi, and OCI muscles bilaterally in all above studies[40-42]. From this, fat signal intensities on axial spin echo $T_1$W images were quantitatively classified. Although it is impossible to determine the absolute concentration of fat, the intensity of the signal provides a reliable indication of the relative fat content of muscles. This technique is reliable, and intra- and inter- observer agreement is excellent. This measurement of relative fatty infiltration for bilateral suboccipital muscles is a time consuming process and operator dependent. The muscular fat content can also be analyzed in detail with a relative or absolute lipid quantitation by proton($^1$H)-MR spectroscopy, which has previously been applied to investigate the muscular lipids in paraspinal muscles in patients with low back pain[43,44]. However, due to the interference of the adjacent occipital bones, the signal to noise ratio and field inhomogeneity become major issues. An active shimming, a process whereby a corrective magnetic field could be implemented in order to create a more homogenous field.

### *MRI evaluation of cross-sectional area (CSA) changes of MDBC relevant muscles*

Cross-sectional area changes of MDBC relevant muscles can play an important role addressing the issue of headache, however the results were controversial. The use of MRI to visualize the CSA of these muscles *in vivo* allows us to make a connection between headaches and suboccipital muscle changes[13-16]. In 2007, Fernfindez-de-las-Penas et al. analyzed the differences in the CSA of several cervical extensor muscles on axial $T_1$-weighted images between patients with chronic tension-type headache (CTTH) and healthy controls[13]. CTTH patients showed reduced CSA for both RCPmi and RCPma muscles, but not for semispinalis and splenius capitis muscles, compared with controls. The greater headache intensity, duration or frequency correlated with the smaller CSA in the RCPmi and RCPma muscles. Whether this selective muscle atrophy was a primary or secondary phenomenon remained unclear. In 2008, Fernfindez-de-las-Penas et al. investigated the association between CSA of the suboccipital muscles and active trigger points (TrPs) in CTTH[14]. CSA for both RCPmi and RCPma muscles were measured from axial $T_1$-weighted images, using axial MRI slices aligned parallel to the C2/3 intervertebral disc. CSA of the RCPmi was significantly smaller in the patients with active TrPs than in patients with latent TrPs. No significant differences were found for CSA of the RCPma between the patients with either active or latent TrPs. From this, it was suspected that the RCPmi muscles with a greater concentration of muscle spindles might be more sensitive to muscle atrophy than others in CTTH.

Although CSA has been associated with headaches, whether hypertrophy or atrophy is the cause has been the subject of debate. Uthaikhup et al. examined the CSA in the cervical muscles of elders with cervicogenic headaches[15]. They discovered that elderly women with cervicogenic headache had significantly reduced CSA of the RCPma compared to controls. However in a study by Yuan et al., they found that patients with chronic headaches suffered from hypertrophy of the RCPmi as opposed to the control group[16]. It is noteworthy to mention that in this study that displayed hypertrophy of the RCPmi, the CSA was measured in the plane parallel to the long axis of the RCPmi. However, in the previous studies that displayed atrophy, the CSA was measured in the axial plane.

The correlation between CSAs of MDBC relevant muscles and mild traumatic brain injury (mTBI) has been a major area of study[45]. Studies were conducted to determine the correlation of CSAs of MDBC relevant muscles and the degree of pathology of mTBI. Studies showed that headaches secondary to mTBI, as well as symptom severity and recovery time were correlated with lower CSAs of RCPmi. This correlation between the MDBC relevant muscles, particularly RCPmi, and the pathology of mTBI is most likely due to its connection to the cervical dura. Although RCPmi, RCPma and OCI muscles are involved in the composition of MDBC, only CSA of RCPmi was found to have this correlation. This is likely due to RCPmi being the most receptive to the load of low-energy impacts as experienced in mTBIs. Weak or atrophic RCPmi experiences greater strain with traumatic injuries, and that energy is more likely to be transmitted to the cervical dura causing injury. As with primary weakness of the RCPmi, secondary weakness such as with traumatic injury to the RCPmi itself will also cause the cervical dura to be prone to injuries. Therefore with weakness, atrophy, or injury, the RCPmi is less capable of resisting the inward folding of the dura, and hence, the cervical dura is more susceptible to tension and injuries. With the dura being sensitive to tension, such injuries will be experienced as referred pain explaining the pain pathology[45]. There is no doubt, more evidences need to be found to confirm this correlation between the clinical symptoms and MDBC relevant musculature alteration.

Although the selected slices were somewhat different in the several previous studies[13-15,45], axial $T_1$ weighted images were optimal for CSA calculation. In studies by Fernfindez-de-las-Penas and Uthaikhup, CSA values of MDBC relevant muscles were measured using axial MR slices at C1 and C2 levels parallel to the C2/3 intervertebral disc for the RCPmi and RCPma muscles on both sides, respectively[13-15]. In a study by Fakhran, the CSA of RCPmi and RCPma were evaluated on slices through the anterior arch of C1, and the CSA of OCI was calculated at the middle level with an orientation parallel to the foramen magnum[45]. However, as mentioned by Fernfindez-de-las-Penas in the study limitations, there was a methodological limitation relating to the level and orientation of MRI slices[14]. However, the layout of suboccipital muscles is often not equal across subjects, and the direction of the RCPmi muscle is more tangential than that of the RCPma and OCI muscles. This is especially important considering the CSA value of fan-shaped RCPmi would affect results to a significant degree. In studies conducted by Yuan et al., it was noteworthy that the CSA of RCPmi was measured in the plane with a 30° deviation from the sagittal $T_2$W image passing throughthe mid-posterior arch of atlas,which paralleling to the orientation of RCPmi and demonstrating its maximal CSA[16]. 3D MR imaging has the potential to the dedicated CSA measurement of MDBC relevant muscles in the future[46].

*MRI evaluation of MDBC relevant muscles injuries*

The RCPmi muscle has been found to have a prominent role in the pathology of WAD secondary to injuries or trauma such as mTBIs[45]. MR imaging is the optimal method to visualize such injuries. Hallgren et al reported that the RCPmi is susceptible to injury when the load on the muscle is greater than 16.2 N[20]. Injuries or trauma from mTBI, such as rear end motor vehicle accidents, can injure the RCPmi and consequently the MDBC. Histologically, the MDBC is mainly formed by parallel running collagen fibers. Stretching of soft tissues beyond the elastic limits results in an incomplete injury[3]. It's been reported that chronic headaches could be a result of such incomplete injury to the relevant muscles of the MDBC[15]. However, more research is needed to correlate MRI findings to clinical signs and symptoms. The aforementioned injuries of MDBC relevant muscles may not be readily visualized on standard imaging protocols[47]. Utilization of high resolution MRI may provide a better visualization and assessment into injuries, especially incomplete injuries of MDBC with relevant muscles that can't be detected with standard imaging protocols. For instance, it's been reported that the utilization of high resolution $T_2$-weighted images have been found to be a reliable assessment tool for muscular injuries by producing increasing signal intensity[47]. Utilization of such high resolution techniques might prove useful in further understanding how previously undetected injuries can produce pathological changes such as chronic headaches.

Future studies using high resolution MRI to evaluate the MDBC relevant muscles after injury as well as anatomic studies of these structures after application of whiplash-type forces could help develop a better understanding of the functional significance of these connective tissue bridges. Diffusion tensor (DT) imaging is an emerging technique in MRI imaging that can prove useful in evaluating changes in both structural anatomy and physiology by three-dimensional mapping of water molecule movements in soft tissue including muscles[36]. In DT studies, induced injury to muscles in experimental animals have been found to produce decreased FA and increased ADC due to edema secondary to the injuries. On the other hand, the injuries appeared normal on standard $T_1$ weighted and $T_2$ weighted MR images. This demonstrates that DT imaging with FA and ADC parameters might be superior to detecting micro changes in muscles injuries than conventional MRI. In addition to DTI in detecting dynamic changes of the muscles, high resolution $T_2$-weighted images can also be utilized to be fused with FA maps to profile the anatomic structure and the boundaries of the muscles[48].

It's been hypothesized that structural and physiological changes in the RCPmi muscles have been associated with cervicogenic headaches. Therefore, studies were conducted to determine the correlation between alterations in RCPmi muscles and cervicogenic headaches[28,49]. In a study by Hallgren et al., EMG activity of RCPmi muscles were recorded in a group of participants, both in the neutral and retracted positions[28]. They reported that RCPmi muscles in the natural position showed EMG activity, but there was a significant increase in EMG activity when the muscles were held in the retracted position. It's been reported that voluntary retraction of the head increases the posterior load on the superior articular facets of the atlas which results in flexion of the atlanto-occipital joint and lengthening of the RCPmi muscles[28]. The retraction motion of the RCPmi muscles has been shown to produce increased EMG activity which might suggest that retraction can cause hypertrophy of the RCPmi muscles which might be utilized to provide manipulative treatments for cervicogenic headaches and other chronic issues. One study in which manipulative therapy was performed by retracting the head, it was found that there was a decrease in the frequency of cervicogenic headaches in a group of subjects[49]. However, the exact physiologic response of RCPmi muscles from the manipulative treatments is not fully understood. EMG has been proven to be a useful tool to be utilized in myodural bridge studies. However, technical limitations, such as interference from myoelectric signals of the neighboring muscles, can impede the ability of EMG to localize the activity of the MDBC relevant muscles[28].

The dura-muscular connections in the suboccipital area may provide anatomic and physiologic answers to the cause of the cervicogenic headache. This proposal would further explain manipulation's efficacy in the treatment of these headaches. The use of different functional MRI techniques, such as DWI and DTI, can be potentially utilized in detecting structural and physiological changes of MDBC relevant muscles following manipulative treatments[50-54]. Hack reports that chiropractic treatments might prove to be beneficial in the treatment of cervicogenic headaches due to the anatomic relationship of the MDBC and its suboccipital muscles with the pain-sensitive dura[1]. Clark reported significant reduction in $T_2$ time asymmetry after the application of manipulative therapy, and this is most likely due to the increased metabolic activity and consequently increased water content which produced such alterations in imaging properties[50]. Furthermore, it's been demonstrated by DWI that the application of manipulative therapy has been shown to produce changes in muscle diffusion prior to observable macro structural changes[50-51]. Also, DTI with the use of apparent diffusion coefficient and fractional anisotropy parameters have potential applications in detecting the aforementioned changes in the MDBC relevant muscles[36,52-54]. For instance, ADC measures the water diffusion magnitude within tissues while FA describes the degree of anisotropy of this diffusion with eigenvectors (V1, V2 and V3) and their corresponding eigenvalues providing a directional component. There have been studies which experimented with the use of DTI and the FA parameter in different muscles to detect physiological changes during contraction[52]. In a study which DTI was utilized in measuring the activity of the calf muscles, gastrocnemius and soleus. The FA value was noted to be decreased in the exercised calf muscles relative the muscles that remained at rest[53]. Other studies demonstrated opposing DT values with active contraction and passive elongation of muscles[54]. Similar to exercise, physical training, such as in manipulative therapy, can also lead to structural and physiological changes including changes in water diffusion properties[50]. Therefore, DWI and DTI can be potentially utilized in future studies to further explore the dynamics of manipulative therapy to MDBC relevant muscles and its association with cervicogenic headaches.

In conclusion, MRI is probably the most powerful tool to study the MDB complex. MRI can provide not only anatomy information, but also functional information *in vitro* and *in vivo*. Up to date, there are few MRI studies on the topic. 3D-$T_2$WI, MRS, DWI, and DTI imaging has the potential in anatomic visualization and functional evaluation *in vivo*. This technology may have the capability of aiding diagnoses and guiding treatment in cervicogenic disorders related to the myodural bridge complex.

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