Review

Cervical spine meniscoids: An update on their morphological characteristics and potential clinical significance

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Abstract

Purpose: Cervical spine meniscoids are intra-articular folds of synovial membrane that have been theorised to have potential clinical significance in neck pain. Recent anatomical and clinical research has re-visited the pathoanatomical capacity of these structures. The purpose of this review is to discuss cervical spine meniscoid morphology in light of recently published work, to provide an update on the plausible relevance of these structures to clinical practice.

Methods: Narrative review critically discussing basic science and clinical research regarding cervical spine meniscoids, with focus upon implications for clinical practice.

Results: Basic science research indicates that cervical spine meniscoids can be innervated and appear to vary in morphology in the presence of articular degeneration. In a clinical population, associations have been observed between cervical spine meniscoid morphology and presence of cervical spine symptoms.

Conclusions: Recent studies regarding cervical spine meniscoid morphology provide further evidence of pathoanatomical capacity of these structures. Further research is required however in clinical populations to empirically investigate specific theorised mechanisms of cervical spine meniscoid involvement in neck pain.

Key Words: cervical spine; zygapophyseal joint; meniscoids; synovial folds; whiplash

Introduction

Cervical spine meniscoids, also referred to as synovial folds or intra-articular inclusions, are folds of synovium that extend between the articular surfaces of the joints of the cervical spine [1,2]. These structures have been identified within cervical zygapophyseal, lateral atlantoaxial and atlanto-occipital joints, and have been hypothesised to be of clinical significance in neck pain through their mechanical impingement or displacement, as a result of fibrotic changes, or via injury as a result of trauma to the cervical spine [1,3]. Cervical spine meniscoids are currently a focus of renewed scrutiny because improvements in medical imaging allow visualisation of their form and location *in vivo* [4-6]. Imaging cervical spine meniscoids *in vivo* with tools such as magnetic resonance imaging (MRI) now has the potential to assist clinical decision making processes and, as a result, their form, composition and function appear to be clinically relevant. The purpose of this narrative review is to discuss cervical spine meniscoid morphology in light of recently published work, in order to provide an update on the potential significance of these structures in neck pathology and their relevance to clinical practice.

History

The first description of spinal meniscoids was by Henle in 1855 who identified synovial folds that protruded from one side of an intervertebral joint to the other [7]. Dörr [7] performed examinations of meniscoids throughout the vertebral column, identifying their presence in both the lateral atlantoaxial joint and cervical zygapophyseal joints, as well as expanding upon Henle's description by suggesting their function was protective, through reducing intra-articular friction and mechanical force. Numerous dissection studies focusing on cervical spine meniscoids were performed in the mid-20th century, providing descriptions of their gross morphology [7-12]. More recently, studies of cervical spine meniscoids have explored these structures' morphology and histology in greater detail to facilitate a better understanding of their function [1,2,13]. In addition, studies have also been performed that investigate the association between cervical spine meniscoid morphology and articular pathology or neck pain [6,13-15].

Morphology

Basic Structure of Cervical Spine Meniscoids

An understanding of the basic structure of meniscoids is necessary to assess their potential role in cervical spine pathology. As described above, cervical spine meniscoids are folds of synovium that protrude into a joint from its margins. Meniscoids lie between the articular surfaces at the ventral and dorsal poles of their enclosing joint [2,13] (Figure 1). Their basic structure includes a base, which attaches to the joint capsule, a middle region and an apex that protrudes approximately 1-5 mm into the joint cavity [1]. In sagittal cross section, these structures are triangular in shape, and when viewed superiorly they often appear crescent-shaped or semi-circular [3,15] (Figures 2 and 3). Cervical spine meniscoids are thought to function to improve the congruence of articular structures, and to ensure the lubrication of articular surfaces with synovial fluid [1,2].

Prevalence of Meniscoids

At the lateral atlantoaxial joint, mensicoids have been reported as being present at the ventral and dorsal aspects of joints [2,6,14,16-19]. Reports of their prevalence in either a dorsal or ventral location within the joint (i.e. of either a dorsal or ventral meniscoid, or both, being present) have described their prevalence as ranging from 0-100%. Kawabe *et al.* [20] described their prevalence as 0% in adult lateral atlantoaxial joints, Chang *et al.* [21] as 78%, and Tang *et al.* [22] reported 85%, while further studies suggest a prevalence of 100% in adult lateral atlantoaxial joints. Studies to find 100% prevalence include recent studies of lateral atlantoaxial joints by dissection (n = 12) [14], sheet plastination (n = 2) [3] and MRI (n = 40) [6], with these findings in concurrence with those of Kos *et al.* [23], Webb *et al.* [18], Webb *et al*. [16,17] and Yu *et al.* [24]. Findings suggest that prevalence of meniscoids is likely to be very high, possibly supporting the premise that they are located in every lateral atlantoaxial joint.

In the cervical zygapophyseal joints, co-existing ventral and dorsal meniscoids have been reported in 36-60% of joints, only ventral meniscoids in 7-19% of joints, only dorsal meniscoids in 17-29% of joints, and no meniscoids in 14-23% of joints [3,6,13,15]. The frequency of meniscoids reported at any location in adult cervical zygapophyseal joints has varied ranging from 0% [25] to 100% [3] of joints. Recently, prevalence was assessed in studies applying a range of methodologies to examine cervical spine meniscoid morphology, with these structures being reported as present in 86% [15], 100% [3] and 78% [6] of joints when investigated using dissection (n=12), sheet plastination (n=2) and MRI (n=40) respectively, with these findings consistent with previous examinations by Inami *et al.* [13], Mercer, Bogduk [2] and Kos *et al.* [23]. The convergent findings of these studies employing a variety of methodologies refute reports of cervical spine meniscoids being uncommon in adults [20,21,24,25], instead supporting the hypothesis that these structures are likely highly prevalent in the adult population in cervical zygapophyseal joints.

Meniscoid Composition

Cervical spine meniscoids are composed of a central core comprising adipose tissue, fibrous tissue, or a mixture of both fibrous and adipose tissues (fibroadipose) (Figure 4) [1,2,13]. Between the meniscoid core and the joint cavity is a layer of synovial membrane continuous with that lining the joint capsule [1]. Cervical spine meniscoids may or may not contain blood vessels [1,14,15].

Fibroadipose and fibrous meniscoids are common in the lateral atlantoaxial and cervical zygapophyseal joints, whereas adipose meniscoids appear to occur more frequently at the lateral atlantoaxial and atlanto-occipital joints than the cervical zygapophyseal joints [2,13-15]. Tang *et al.* [22] found a higher percentage of adipose meniscoids in the atlantoaxial and atlanto-occipital joints of children (46%, n = 30 cadavers) as compared to adults

(31%, n = 20 cadavers) in a study employing dissection and light microscopy. This finding suggests that in childhood, meniscoids are primarily adipose in composition, and that through the lifespan meniscoids may transition to fibrous composition.

At the cervical zygapophyseal joints, Inami *et al.* [26] described seven of ten (70%) meniscoids to be primarily adipose in composition in group of five surgical patients (mean age 53 years). This percentage appears to decrease with advancing age, as studies using elderly cadavers report 4-20% of cervical zygapophyseal joint meniscoids to be primarily adipose in composition [13,14]. Further data on whether meniscoid composition may alter with age are required to clarify how composition may vary with different age-groups, in order to assist with differential diagnosis when undertaking imaging of these structures. This information is inherently difficult to attain using dissection, given the typically advanced age of those that kindly bequeath their body to anatomical research facilities [27], however improvements in MRI technology appear promising and capacity to examine cervical spine meniscoid composition across the lifespan *in vivo* is now feasible.

Innervation

The innervation of cervical spine meniscoids is important as the capacity for anatomical structures to contribute to pain and pathology is in part based upon their ability to generate impulses to nociceptive stimuli. Cervical spine meniscoid innervation was first investigated by Inami *et al.* [26]. These authors used immunohistochemistry to demonstrate the presence of nerve tissue with suspected nociceptive and vasoregulatory functions in ten cervical zygapophyseal joint meniscoids excised from five patients during laminoplasty for cervical myelopathy. These findings are in keeping with studies examining meniscoid innervation in the lumbar spine [28-30]. Recently, Farrell *et al*. [31] examined the presence of nerve tissue in 77 lateral atlantoaxial and cervical zygapophyseal joint meniscoids from 12 elderly cadavers using immunohistochemistry. This study found nerve fibres within joint capsules adjacent to 14 meniscoids (18%), and nerve fibres within the meniscoid proper of just two adipose specimens (3%).

The considerable difference in number of nerve fibres found between Inami *et al.* [26] and Farrell *et al*. [31] could possibly be attributable to a number of variables. These include mean sample age (Inami *et al*. 53 years, Farrell *et al*. 83 years), meniscoid composition (Inami *et al*. 70% adipose, 30% fibroadipose; Farrell *et al*. 7% adipose, 40% fibroadipose, 53% fibrous), or neck pain status (Inami *et al*. patients with cervical myelopathy, Farrell *et al*. neck pain status unknown). There are also differences between the studies specific to immunohistochemical method to be considered: Inami *et al.* used fresh tissue excised during surgery and Farrell *et al.* excised meniscoids from cadavers that had been embalmed, which may have impacted upon antigen binding [32,33]. Further, Inami *et al*. processed between four and six sections across the breadth of each meniscoid, whereas Farrell *et al.* sampled a smaller portion of the tissue, processing two sections from the sagittal midpoint of each meniscoid.

Whilst these explanations for the disparity in findings are speculative, results of these two studies have interesting implications. First, they suggest that cervical spine meniscoids can be innervated and consequently a possible source of nociceptive input, and second, that the innervation status of cervical spine meniscoids appears to vary between individuals or groups. These studies raise the possibility that innervation status of meniscoids may be dependent upon meniscoid composition, as nerve fibres were solely located in adipose meniscoids in the study by Farrell *et al.*, and the meniscoids of Inami *et al.* were primarily adipose in composition and contained a greater number of nerve fibres. These results are also consistent with the suggestion that meniscoid innervation varies with age, as elderly meniscoids were found less likely to be innervated. This may be related to hypothesised changes in meniscoid composition associated with age, and in turn, raises the possibility that the pain generating capacity of these structures may vary with age. The inconsistent presence of nerve tissue is arguably comparable with prior observations of blood vessels being present in some meniscoids, but absent from others [1,14,15], and could plausibly be related to the high oxygen demands of nerve tissue.

Clinical Significance

Previous research has highlighted the potential role of cervical meniscoids in cervical pain and pathology. These hypotheses have arisen as extrapolations based upon the morphology of cervical spine meniscoids, and include mechanical entrapment, displacement from the joint cavity (extrapment), injury during whiplash or other trauma, and fibrosis leading to hypomobility [1]. Recent studies of cervical spine meniscoid morphology have extended current understanding of their potential clinical significance, including studies undertaken utilising dissection, histology, immunohistochemistry, sheet plastination and MRI in samples of elderly cadavers, individuals with chronic whiplash associated disorder (WAD) and pain-free volunteers [3,6,14,15,31].

Clinical Manifestations

The specific clinical presentation of pain arising from cervical spine meniscoids has not been established, as cervical spine meniscoids have not yet been confirmed as being responsible for symptoms in a clinical population. In addition, there are no reports of experimentally induced pain from meniscoids that would better inform clinicians about referred pain patterns [34] and how cervical motion may be affected when meniscoids are symptomatic. It is feasible that pain arising from a lateral atlantoaxial or cervical zygapophyseal joint meniscoid may be perceived in a location consistent with established pain patterns for these joints [35,36] given the common source of innervation for both structures [31]. However the specific manifestation of pain arising from a cervical spine meniscoid requires further investigation.

Relationship of Meniscoid Composition to Articular Degeneration

A number of studies have reported that cervical spine meniscoid composition is related to the degree of articular degeneration present in the joint [4,13-15].

In the cervical zygapophyseal joints, Inami *et al.* [13] noted an association between fibrous meniscoid composition and articular degeneration, with fibrous meniscoids more prevalent with increased levels of articular degeneration: 96% of fibrous meniscoids located in joints with evidence of articular degeneration, compared to 67% and 64% of adipose and fibroadipose meniscoids respectively. This relationship between articular degeneration and fibrous meniscoid composition has also been described in both the lateral atlantoaxial and cervical zygapophyseal joints in dissection studies [14,15], and at the lateral atlantoaxial and cervical zygapophyseal joints in MRI studies of pain-free [4] and chronic WAD [6] populations. Conversely, meniscoids composed primarily of adipose tissue have been noted to occur more frequently in joints with intact cartilage [14,15].

The relationship between fibrous meniscoid composition and cartilage degeneration could plausibly suggest a relationship between cervical spine meniscoids and degenerative articular pathology. It is understood that degeneration of articular cartilage can occur as a component of osteoarthritis [37,38]. Farrell *et al.* [14] suggest that excess joint loading, an established contributor to osteoarthritis, may result in chronic inflammation and in turn, fibrosis of enclosed meniscoids [39,40].

Whiplash Associated Disorder

As a number of authors have noted, cervical spine meniscoids have been implicated as structures potentially vulnerable to injury in a whiplash trauma [1,41,42]. Kaneoka *et al.* [42] and Grauer *et al.* [43] found that during the S-shaped phase of rear-end whiplash trauma, the lower cervical spine moves into extension and the upper cervical spine moves into flexion. The extension forces acting on the lower cervical zygapophyseal joints exceed physiological limits and may therefore lead to sub-failure injuries to these joints [43]. During this loading, the superior articular surfaces of the lower cervical zygapophyseal joints are driven inferiorly into the articular facets of the vertebrae below, potentially resulting in damage to the meniscoids that lie between the joint surfaces [41,42].

Further to this biomechanical evidence, autopsy investigations have reported tears and contusions of cervical spine meniscoids in victims of fatal motor vehicle collisions or blunt head trauma [44,45]. Given the clinical evidence indicating the cervical zygapophyseal joints are a source of nociceptive input in chronic WAD [41,46-49], as well as the biomechanical and autopsy evidence described above, it is conceivable that the cervical spine meniscoids may contribute to pain in WAD.

Investigation of cervical spine meniscoid morphology in a living sample has been made possible through the use of MRI [4,5,16,18] (Figure 5). Farrell *et al*. [6] have recently published findings of a case-control study investigating cervical spine meniscoid size and composition in individuals with chronic WAD (n = 20, mean [SD] age 39.3 [11.0] years, ten female, symptoms > 3 months) compared to age- and sex-matched pain-free controls (n = 20, 39.1 [10.6] years) using 3-Tesla MRI. The study found morphological differences between the meniscoids of the two groups, namely smaller lateral atlantoaxial joint meniscoids and increased likelihood of fibrous composition of dorsal zygapophyseal joint meniscoids in the chronic WAD group. Lateral atlantoaxial joint meniscoids were found to be both smaller in the WAD group when measured in mm and when analysed as a proportion of articular cartilage size. The authors theorised that the smaller size of lateral atlantoaxial joint meniscoids may represent regressive changes affecting the structures, possibly secondary to pain and decreased or altered neck movement associated with chronic WAD. It must however be noted that the cross-sectional nature of this study restricts inference of the origins or implications of this morphological difference, and further study is required to determine the significance of this finding with greater certainty.

The finding of increased likelihood of fibrous composition of dorsal zygapophyseal joint meniscoids in the chronic WAD group may be relevant to the pathoanatomical underpinnings of WAD. As described above, biomechanical and autopsy evidence implicates cervical spine meniscoids as structures susceptible to injury during a whiplash incident, through compression between the enclosing articular surfaces. Over time, this tissue damage may feasibly lead to scar tissue formation and fibrosis, as has been previously described in immobilised joints [50,51], and which may be reflected by the findings reported by Farrell *et al.* [6]. However the relevance of such theorised changes to ongoing pain and disability remain unknown.

Role in other Cervical Spine Pathology

Mechanical snaring of a cervical spine meniscoid between the surfaces of the enclosing joint (entrapment) or displacement of a meniscoid outside of the articular surfaces (extrapment) have been hypothesised as potential mechanisms responsible for acute torticollis [1,20,52-54]. It is suggested that rotation or traction-based manual therapy techniques may encourage the entrapped or extrapped meniscoid to return to its resting place, accounting for the reported clinical effectiveness of such treatment [1,23,54,55].

These assertions however remain speculative, as no study has demonstrated an entrapped or extrapped cervical spine meniscoid in a clinical population. Friedrich *et al.* [4] reported identifying entrapped meniscoids in a sample of healthy volunteers, however these individuals were pain-free, so the clinical implications of this finding are not clear.

Clinical Diagnosis and Treatment

In a research setting, MRI has been used to examine the morphometry and composition of cervical spine meniscoids [4,6,16,18,56], however as yet the use of medical imaging as a diagnostic tool to identify meniscoid pathology (e.g. bruising or tears) has not been reported. Morphometric assessment of meniscoids has been undertaken as anterior-posterior depth of protrusion [4,6], cross sectional area [16] and volume [16,18]. Sequences employed in MRI protocols used in research to date include T1-weighted volumetric interpolated breath-hold examination (VIBE) sequences with and without fat suppression [4,6], T2-weighted sampling perfection with application optimised contrasts using different flip angle evolution (SPACE) sequences [4,6] and double echo steady state (DESS) sequences [4,6,16,18], with in-depth descriptions of the protocols provided in the respective publications. The diagnostic utility of these measurement techniques and sequencing series for assessing meniscoids in a clinical setting remains unclear.

As there is no clear diagnostic method to implicate meniscoids as the primary source of patients' perceived symptoms, intervention (surgical, medical or physiotherapeutic) explicitly targeting cervical spine meniscoids has not been specifically tested or validated. One may speculate that should a cervical spine meniscoid be a source of nociceptive input, radiofrequency neurotomy [48] of the branches innervating the enclosing joint may plausibly relieve patient symptoms, given the established effectiveness of this intervention for zygapophyseal joint pain [41]. Furthermore, rotation or traction-based manual therapy techniques have been theorised as treatments for impinged or displaced meniscoids, however these models of pain generation and mechanism of treatment require further, empirical investigation.

Future Research

To gain a clearer understanding of the role of cervical spine meniscoids in neck pain, ongoing research is required to investigate the relationship *in vivo* between meniscoid morphology and clinical presentation in a variety of neck pain conditions, such as WAD, insidious onset neck pain and acute torticollis. As MRI technology continues to develop, new hardware such as 7-Tesla units [57] will improve visualisation of cervical spine meniscoids, thereby facilitating the ability of clinicians to visualise meniscoid damage or position *in vivo*. Therefore, it is likely cervical spine meniscoids will require specific attention in the course of imaging assessment for spinal pathologies where their involvement is a plausible differential diagnosis (e.g. acute torticollis) or such as where tears and contusions [44,45] of these structures are suspected, such as following cervical spine trauma. Studies are therefore required using new technologies to provide data on their form in normal and neck-pain populations in order to provide a platform for normal values for position and morphology. The findings of such studies would potentially provide empirical evidence to underpin clinical practice for some spinal pathologies. Findings would also evaluate the plausibility of theories about how cervical spine meniscoids are involved in spinal pathology, such as entrapment or extrapment of meniscoids as explanations of the mechanisms underpinning acute torticollis.

Conclusion

Knowledge of the morphology of cervical spine meniscoids and their potential role in neck pain has continued to develop as a result of recent research. Despite historical reports indicating low and varying rates of prevalence, recent data has confirmed that meniscoids are highly prevalent in both the lateral atlantoaxial and cervical zygapophyseal joints. Their composition has been shown to vary in the presence of articular degeneration, and evidence exists suggesting variation in their composition may be related to age. The nociceptive capacity of these structures has also been demonstrated, yet precisely how innervation may vary in relation to age and pathology remains unclear. Lateral atlantoaxial joint meniscoids are suggested to be smaller in people with chronic WAD, and zygapophyseal joint dorsal meniscoids appear to be more frequently fibrous in people with chronic WAD, however further research is required using longitudinal designs and examining a variety of neck pain presentations to extend understanding of the role of these structures in pathology. As imaging technology continues to advance, so too will the capacity to examine cervical spine meniscoids *in vivo*, in turn improving our understanding of the potential pathoanatomical significance of these structures.

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Figure Legends

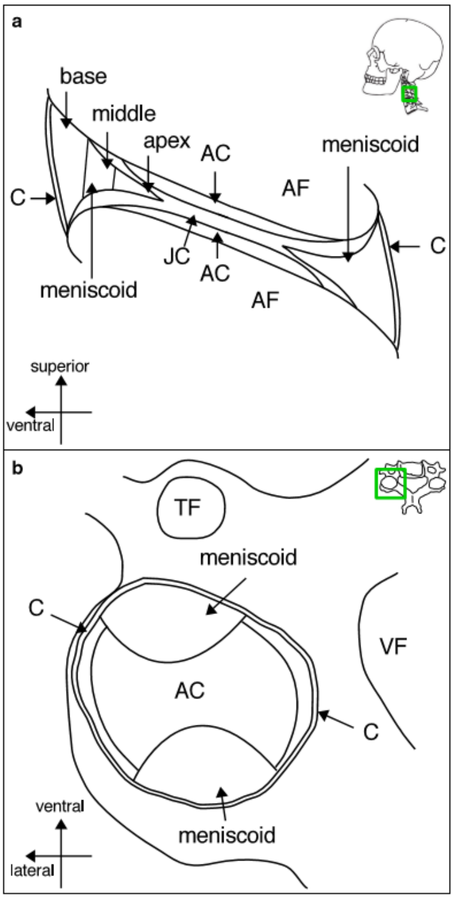

Figure 1: Schematic illustrations of a) sagittal cross section and b) superior view of a left cervical zygapophyseal joint. Apex, middle and base of a meniscoid are shown as per Webb *et al.* (2011). AC – articular cartilage; AF – articular facet; C – capsule; JC – joint cavity; TF – transverse foramen; VF – vertebral foramen

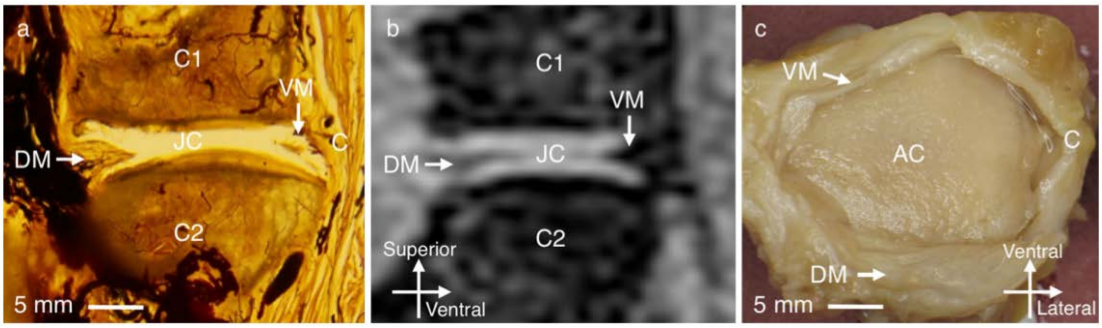

Figure 2: Lateral atlantoaxial joint meniscoids as seen using a) sagittal section of E12 sheet plastinate; b) sagittal magnetic resonance imaging T1-weighted sequence with fat suppression; c) superior view of disarticulated right lateral atlantoaxial joint. AC – articular cartilage; C – capsule; DM – dorsal meniscoid; JC – joint cavity; VM – ventral meniscoid

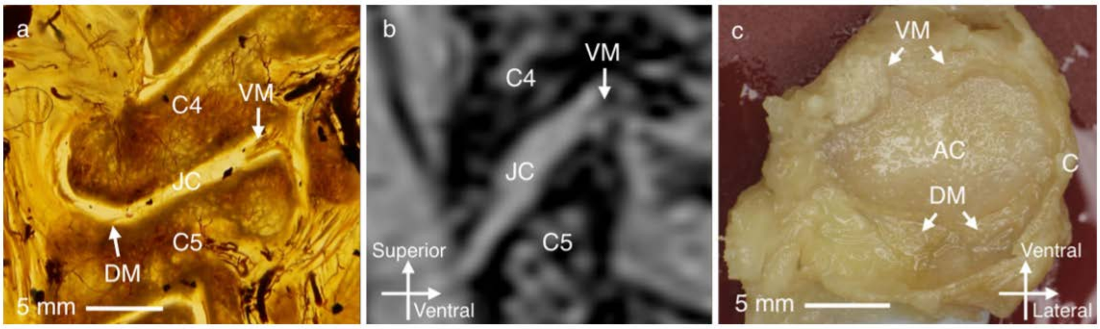

Figure 3: Cervical zygapophyseal joint meniscoids as seen using a) sagittal section of E12 sheet plastinate b) sagittal magnetic resonance imaging T1-weighted sequence with fat suppression c) superior view of disarticulated right C5-6 zygapophyseal joint. AC – articular cartilage; C – capsule; DM – dorsal meniscoid; JC – joint cavity; VM – ventral meniscoid

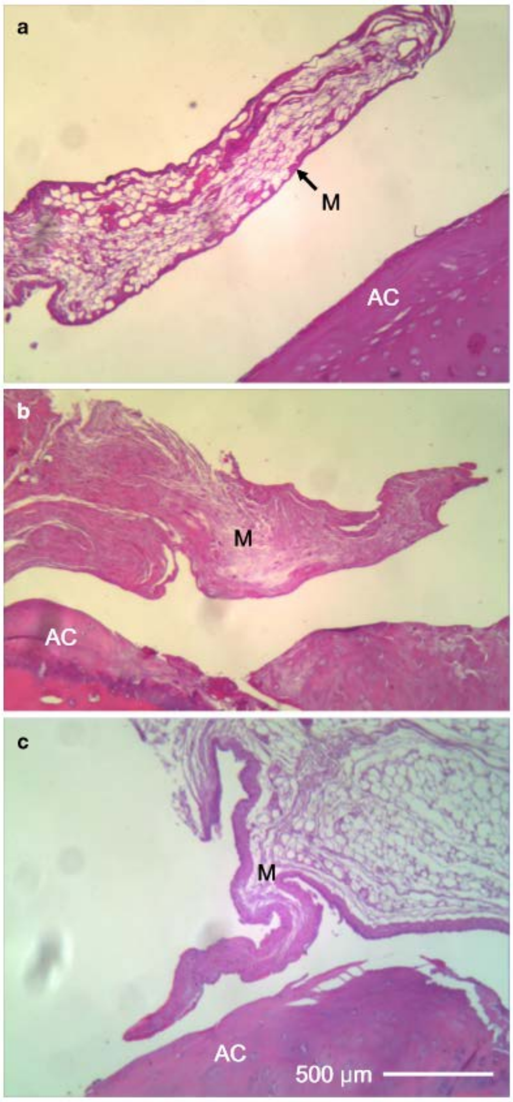

Figure 4: Sagittal sections of cervical spine meniscoids excised from cadavers photographed under a light microscope, demonstrating different histological compositions: a) adipose meniscoid from ventral aspect of a lateral atlantoaxial joint, composed primarily of adipose tissue; b) fibrous meniscoid from ventral aspect of a c2-3 zygapophyseal joint, composed primarily of fibrous connective tissue; c) fibroadipose meniscoid from ventral aspect of a c5-6 zygapophyseal joint, composed of fibrous connective tissue and adipose tissue. AC – articular cartilage; M – meniscoid. Haematoxylin and eosin, x4 magnification, 5 μm section thickness

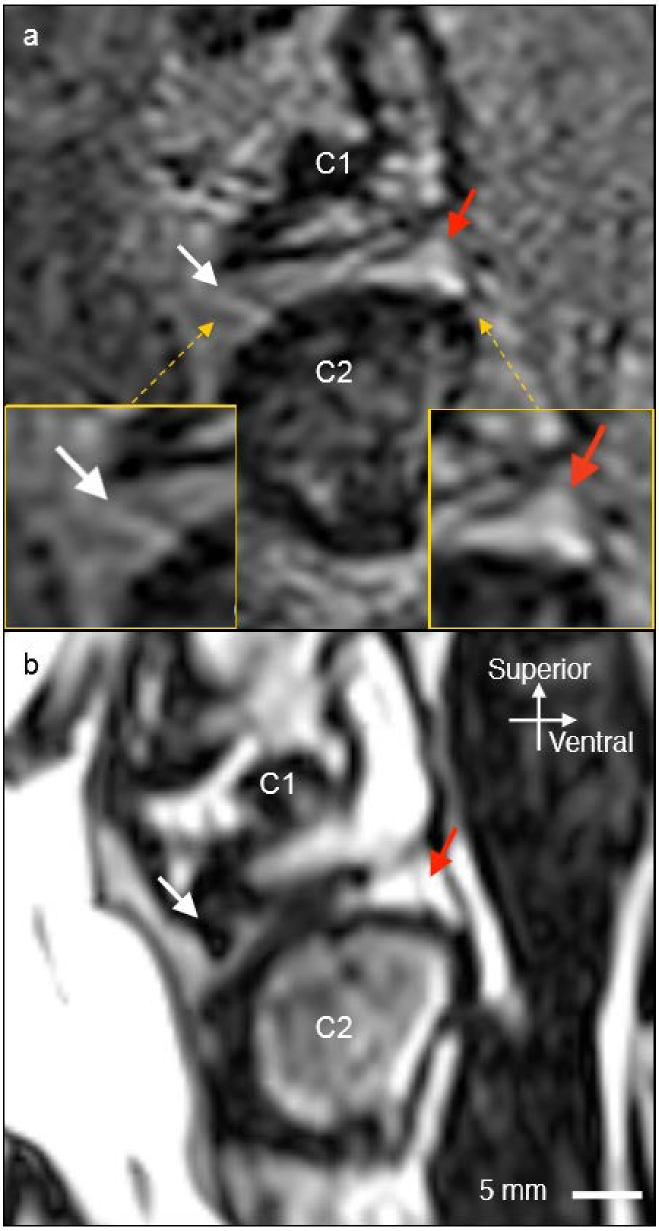

Figure 5: Sagittal magnetic resonance imaging of a lateral atlantoaxial joint with ventral and dorsal meniscoids on a) T1-weighted sequence and b) T2-weighted sequence. Meniscoid denoted by red arrow is likely adipose in composition, as it is hyperintense on T1- and T2-weighted sequences. Meniscoid denoted by white arrow is likely mixed fibroadipose in composition, as it is partly hyperintense and partly hypointense on T1- and T2-weighted sequences [4]. Modified from Farrell *et al.* [6]