Assessment of the dynamic disc model in the cervical spine: the role of McKenzie's conceptual model of disc displacement

Areej Elmaazi

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Department of Exercise & Sport Science

The Manchester Metropolitan University

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Conferences

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Abbreviation	Definition
CT	Computed tomography
DDM	Dynamic disc model
FCR	Flexor carpi radialis
ICC	Intra-class correlation
IVD	Intervertebral disc
LoA	Limits of agreement
MDT	Mechanical diagnosis and therapy
MMU	Manchester Metropolitan University
MRI	Magnetic resonance imaging
MR	Magnetic resonance
MSK	Musculoskeletal
NP	Nucleus pulposus
PI	Principle investigator
PIS	Participant information sheet
RCT	Randomised control trial
ROM	Range of movement
SD	Standard deviation

Abstract

The effects of lumbar spine posture on position of the lumbar disc has been extensively researched in the literature, with findings supporting early assertions that flexed postures, through vertebral loading of the anterior disc, cause posterior disc displacement with extended postures causing anterior displacement. This loading is thought to occur through anterior and posterior approximation of the vertebral segments in flexed and extended postures respectively. The late Robin McKenzie, a world renowned and accredited physiotherapist, promoted this concept of disc displacement through spinal loading. With this biomechanical reasoning, he created a series of spinal exercises, now taught worldwide, aimed at repositioning herniated disc material for those presenting with what he termed to be a 'derangement syndrome'. To date, there have been no published studies that have assessed whether cervical flexion and extension cause an alteration in position of the cervical disc in the same pattern of movement that has been shown to occur in the lumbar spine. There have also been no direct measurements of cervical disc position following performance of one of McKenzie's extension based exercises. Therefore, the aim of this programme of studies was to assess the effects of three cervical postures on position of the posterior NP at the C5-6 and C6-7 disc levels in an asymptomatic population. It also aimed to assess whether McKenzie's 'retraction-extension exercise in sitting' produced anterior displacement of the posterior NP at the C5-6 and C6-7 disc levels in a symptomatic population. Measurements were also taken of vertebral segment angles in three cervical postures to assess whether approximation of the vertebral segments occurred in a similar pattern as has been shown to occur in the lumbar spine. Cervical MR images were obtained from asymptomatic participants positioned in supine with their cervical spines in a neutral, followed by a flexed and finally an extended position. These images were used to assess the effects of posture on anterior and posterior C5-C6 to C7-T1 vertebral position, as well as on position of the posterior C5-6 and C6-7 posterior NP. The second group of symptomatic participants were scanned before and after performance of McKenzie's retraction-extension exercise in sitting. Findings support the assertion that vertebral position and position of the posterior cervical disc can be manipulated by posture. Results showed significant changes in both anterior and posterior vertebral position in flexion compared to neutral, as well as significant changes in the posterior nucleus pulposus at both disc levels in flexion compared to neutral and extension. McKenzie's retraction-extension exercise in sitting was found to cause anterior displacement of the posterior NP at the C5-6 disc level. These findings support the assertion that, compared to a neutral head posture, a flexed head posture causes a significant degree of posterior disc nucleus displacement. Therefore, avoiding a flexed head posture, and maintaining a neutral head position, may help to reduce the potential for developing pain provocative posterior disc herniations. These findings also help support the reasoning behind McKenzie's extension-based retraction-extension exercise in sitting for those presenting with spinal pain classified as a 'derangement syndrome'. Further research assessing various cervical postures in sitting will provide further information regarding the effect of a common occupational posture on cervical disc and vertebral angle position.

Chapter One

Literature review

1.1 Introduction

In the UK, an estimated 9.3 million working days were lost due to musculoskeletal (MSK) disorders between 2008-2009 (Foster et al., 2012). Each year £13 billion are spent on benefits such as incapacity benefit and the cost to industry in 2005 was at least £11 billion (Henderson et al., 2005). The three most frequently reported MSK pain sites include the lower back, shoulders and neck (Picavet and Schouten, 2003). As the shoulder is a common site of pain referral from the neck (Daffner et al., 2003), the incidence of neck pain may be underestimated. In Britain, the one year prevalence of neck pain is estimated between 27% (Webb et al., 2003) and 34% (Palmer et al., 2001). North America and Europe also report a high prevalence of neck pain with between 34.4% and 66.7% of the combined populations experiencing at least one incidence of neck pain in the last year (Bovim et al., 1994; Cote, 1998; Guez et al., 2002). Research on the specific cost of neck and arm pain to UK industry and the government is sparse. However in 1996, The Netherlands estimated the total cost of illness of neck pain at $686.2 million per year (Borghouts et al., 1999). Despite their government supported cycling culture, a recent British Heart Foundation survey found that adults in the Netherlands reported a comparable amount of time spent in sitting to adults in England (BHF, 2015).

1.2 Incidence of neck pain

There is a general consensus in the literature that neck pain is more common among women than men (Gunnar, 1994; Cote, 1998; Croft et al., 2001; Palmer et al., 2001; Guez et al., 2002; Webb et al., 2003; Fejer, 2006). A systematic review of the prevalence of neck pain in the world population confirmed this finding with women reporting more neck pain than men in 25 out of the 30 studies (Fejer, 2006). Among men, neck pain was the most prevalent among construction workers - 73% having experienced symptoms in the last year. Among women, the highest prevalence was found for secretarial jobs, and the incidence of pain that interfered with daily activity was the highest among nurses (Palmer et al., 2001). People over the age of 37 were found to be more susceptible to developing chronic neck pain, potentially due to age related changes of spinal structures, as well as the accumulative effect of work related postural stresses (Cassou et al., 2002). A report completed by the Health and Safety Executive in 2012 found the main work activities attributed by respondents as causing their MSK disorders (including neck and arm pain), or making it worse, was manual handling, awkward or tiring positions and keyboard work. A systematic review of the literature assessing the physical risk factors for neck pain reported a positive relationship between twisting or bending the trunk at work and the incidence of neck pain (Ariens et al., 2000). Other risk factors include psychological distress, poor perceived general health (Croft et al., 2001), a previous history of neck pain (Croft et al., 2001; Guez et al., 2002), smoking (Palmer et al., 2001), increasing age and unemployment (Palmer et al., 2001; Webb et al., 2003). A worse prognosis was found with people who reported a higher severity, as well as previous incidences of pain (Borghouts et al., 1998). Those affected by neck pain may complain of a significant impact on their quality of life due to the intensity, frequency and duration of their symptoms. Other associated symptoms may include loss of range of cervical spine movement and at times concomitant neurological symptoms such as paraesthesia, numbness and loss of upper limb strength (Abdulwahab and Sabbahi, 2000; Croft et al., 2001; Guez et al., 2002; Fejer, 2006).

1.3 Cervical discs and production of pain

In the majority of cases, no specific structural cause to neck pain is identified, thus terming those presentations as 'non-specific neck pain' (Borghouts et al., 1998). There are, however, structures in the spine that have been shown to be a source of pain including the intervertebral discs (IVD's), ligaments, muscles, facet joints, dura and nerve roots (Bogduk et al., 1988). Less common causes include tumours, trauma (e.g. fractures, whiplash), infection, inflammatory disorders (e.g. rheumatoid arthritis) and congenital disorders (Bogduk et al., 1988) such as spina bifida occulta (Avrami et al. 1994). A structure that is commonly identified as the source of spinal pain, and the main focus of this thesis, is the IVD (McKenzie, 1981). The cervical disc was identified as a source of pain as early as the 1800's (Brain et al., 1952) and this is thought to be due to its afferent nerve supply (Cloward, 1959; Bogduk et al., 1988). Microdissection and histological studies were undertaken by Bogduk et al. (1988) which helped to confirm innervation of the outer cervical disc by the cervical sinuvertebral nerve. This nerve has been implicated in the production of discogenic pain (Raoul et al., 2002). An earlier study by Cloward (1959) also demonstrated the disc to be a pain sensitive structure. Through the use of discography, he found that puncturing different parts of the disc with a needle produced pain in different sections of the shoulder blade. Puncturing the anterior discs of C3-4 to C6-7 produced pain along the region of the medial border of the scapula and was described as 'a deep, dull ache in the shoulder blade' (Cloward, 1959, p. 1055). When the IVD was stimulated in the exact centre the pain was felt along the mid-line of the thoracic spine. On puncture of the posterior or posterolateral aspect of the disc, the pain was more commonly felt along the 'upper shoulder', 'base of the neck' and 'upper arm as far as the elbow' (Cloward, 1959, p.

1057). Although pain in this study was invasively stimulated with needle puncture, pain has also been shown to arise through internal derangement of the disc itself and through its subsequent compression of adjacent neural structures such as the nerve root and spinal cord (Michelsen and Mixter, 1944).

1.4 Internal derangement and its potential reversal

Internal derangement of the disc has been described as internally displaced tissue (Kaiser and Holland, 1998; Lurie et al., 2008). It is this internal displacement that is the main focus of this thesis. Specific definitions for the varying degrees of disc displacement, or herniation, have been created by a combined task force of the North American Spine Society, American Society of Spine Radiology and American Society of Neuroradiology. They define a herniation as 'a localised displacement of disc material beyond the limits of the intervertebral disc space exclusive of osteophytic formations' (Fardon and Milette, 2001, p. E95). The disc space is defined vertically as the distance between the vertebral body endplates above and below the disc (disc base) as well as by the outer edges of the vertebral ring (disc circumference) (see figure 1.1). A herniation may take the form of a protrusion or an extrusion depending on the shape of the displaced material. A protrusion is present if the edges of the herniated disc material is less than the distance between the edges of the disc base from where the disc has herniated (see figure 1.2). An extrusion would describe a herniation in which the edges of the disc material has travelled further than the edges of the disc base (see figure 1.2). An extrusion may be described further as a sequestration if the herniated disc material has completely severed from the original disc (see figure 1.2). These definitions, although created by Fardon and Milette (2001) specifically for lumbar spine discs, are transferable to the cervical spine where evidence of herniations – of both protrusions and extrusions - have been described with the use of magnetic resonance (MR) imaging (Grisoli et al., 1989; Matsumoto et al., 1998). There are however fewer reports of these changes occurring in the cervical spine, presumably due to the early fibrotic changes and lack of gelatinous nucleus within the cervical disc (Mercer and Jull, 1996; Mercer and Bogduk, 1999). This may also be due to the reduced loadbearing role of the cervical spine compared to the lumbar spine (Mercer and Jull, 1996).

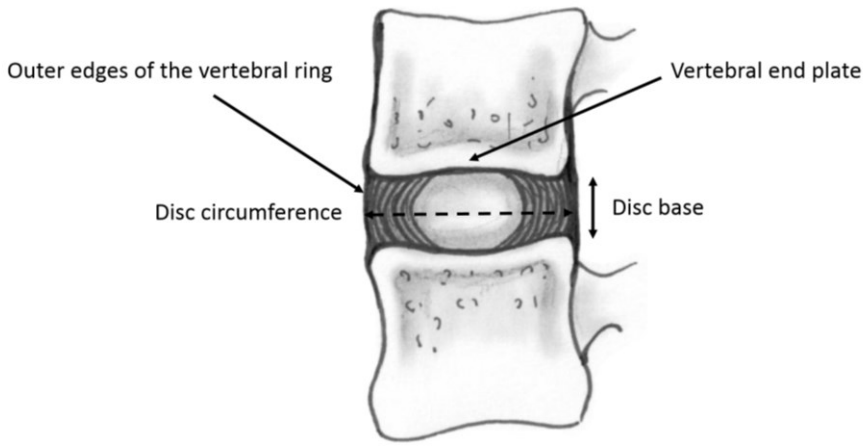


Figure 1.1. Image of the disc space. Defined vertically by the distance between the vertebral endplates above and below the disc (disc base) and peripherally by the outer edges of the vertebral ring (disc circumference). Figure taken from (Fardon et al., 2014).

A B C

Figure 1.2. Schematic representations of the various degrees of herniation. The distance between the edges of the disc material presenting outside the disc space is represented by the solid arrow in figure A. The distance between the edges of the base of the displaced disc material is represented by the dashed arrow in figure A. (A) represents a disc protrusion, (B) an extrusion and (C) a sequestration. Figures taken from (Fardon et al., 2014).

Certain spinal postures have been shown to cause immediate displacement of healthy lumbar disc material, away from an area of loading, thus exhibiting a hydrostatic pressure (Fredericson et al., 2001; Parent et al., 2006; Kolber and Hanney, 2009). With sustained spinal postures applied over time, displacement of the disc may eventually result in disc protrusions. Although protrusions do not necessarily imply a pathological process, they can, in some cases, become a source of pain and disability (Moneta et al., 1994). The more significant displacements in the form of extrusions and sequestrations have been linked to the production of spinal pain and dysfunction (Saal et al., 1990; Boos et al., 1995; Schellhas et al., 1996; Kaiser and Holland, 1998). There have been several studies in the literature that have demonstrated a reversal of posterior disc displacement in the lumbar spine by adopting varying sitting, standing and lying postures (Beattie et al., 1994; Fredericson et al., 2001; Alexander et al., 2007; Kolber and Hanney, 2009). To date, there have been no published *in vivo* studies that have assessed, with the use of MRI, whether certain cervical postures cause reversal of posterior disc displacement, in the same manner that has been exhibited in the lumbar spine . There have also been no published studies that have directly measured whether specific cervical exercises can manipulate position of the IVD.

To better understand why one cannot presume that cervical discs will behave in the same manner as lumbar discs, it is important to understand the differences in anatomical structure between them.

1.5 Anatomy

This section will aim to describe and explain the anatomy of the cervical disc, as well as the adjacent bony structures and ligaments in the cervical spine which have some marked differences from those of the lumbar spine (Mercer and Bogduk, 1999). The majority of the anatomical descriptions below are taken from the seminal work of Mercer and Bogduk (1999) who were able to provide some excellent photographic and illustrative descriptions of the cervical anatomy after dissecting 59 cervical IVD's obtained from 12 male and female adult cadavers, aged between 39 to 82 years.

1.5.1 Vertebral bodies

The cervical spine consists of seven vertebral bodies with the first two, the atlas and the axis, having a unique, distinct shape. The atlas (C1) cradles the occiput (skull) through the atlanto-occipital joints on either side of its ring shaped bone (see figure 1.3). These joints allow for flexion and extension (nodding) of the head. The axis (C2), also ring shaped, is located below the atlas and assists in weightbearing of the head (see figure 1.3). It also provides approximately 25% of axial rotation through the antlantoaxial joints (Zhang et al., 2006). At the superior aspect of the C2 vertebral body sits an odontoid process (superior bony projection) upon which the C1 and head rotate (Moore et al., 2010; Moulton, 2014). Because of their unique design and function, there is no IVD located between the C1 and C2 vertebral segment (Bogduk and Mercer, 2000).

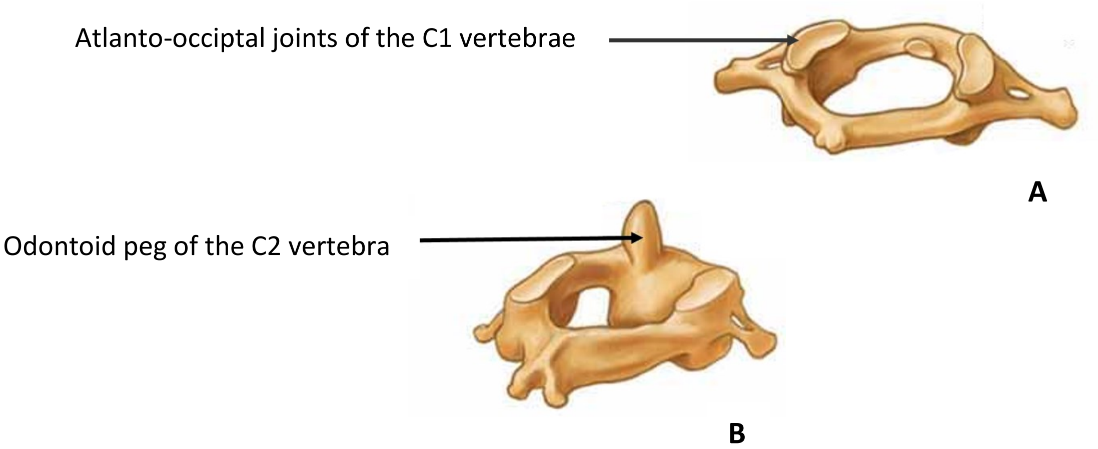
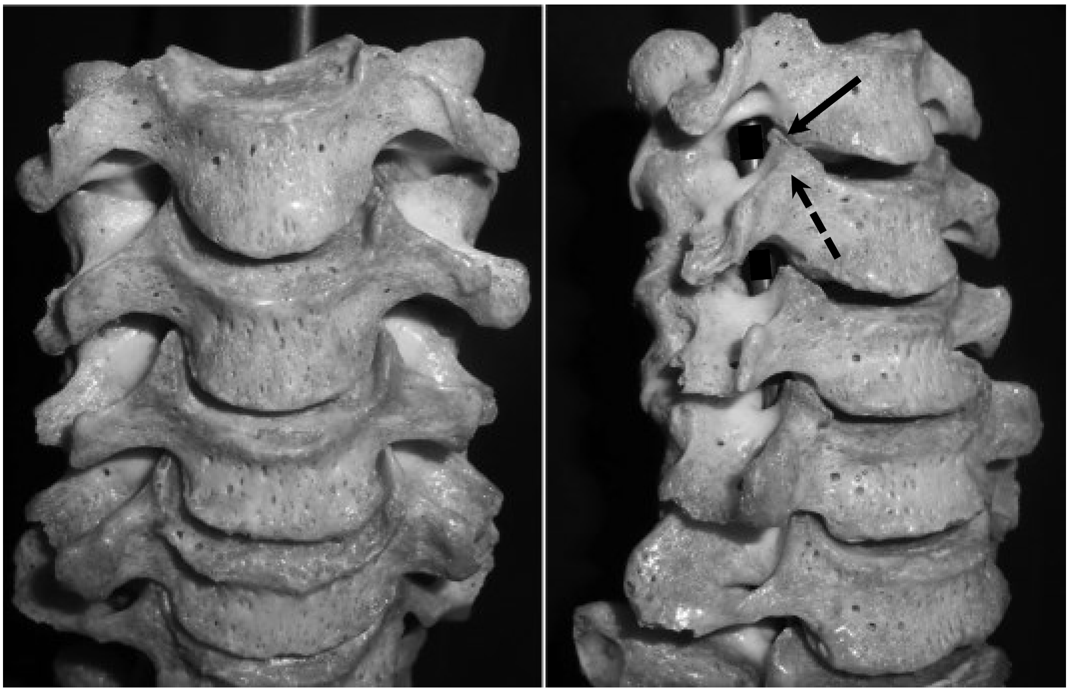


Figure 1.3. Unique shapes of the C1 (A) and C2 (B) vertebral bodies. Figure taken from (Schnuerer and Mummaneni, 2016).

IVD's are located between the remaining five cervical vertebrae, which have a slight curve in the sagittal plane compared to the more linear shaped lumbar vertebrae (see figure 1.4). The superior surface slopes downwards, resulting in the plane of the disc sitting at an oblique angle to the vertebral bodies. This is a result of the primary flexion and extension movements which occur at these joints (Bogduk and Mercer, 2000). Biomechanical stresses, resulting from postures and movement, are likely greatest in the lower part of the cervical spine (Shea et al., 1991).



A **B**

Figure 1.4. Sagittal plane of the cervical vertebrae (A). Dashed arrow points to the uncinate process while the solid arrow points to the C2-3 uncovertebral joint (B).

1.5.2 Uncinate process

A unique feature of the cervical vertebral body is the presence of uncinate processes. These are raised lateral margins of the superior surface of the cervical vertebrae and with aging they often extend superiorly, contacting the superior vertebrae, forming an uncovertebral joint (Kotani et al., 1998) (see figure 1.4). The uncovertebral joints, also known as the joints of Luschka, extend from C3 to C7 (Kotani et al., 1998). As these uncinate processes reach their maximum height between 9 to 14 years of age, they give rise to uncovertebral clefts that appear in the postero-lateral aspect of the cervical disc (see figure 1.5). The major biomechanical function of uncovertebral joints is the regulation of extension and lateral bending motion, followed by rotation (Kotani et al., 1998).

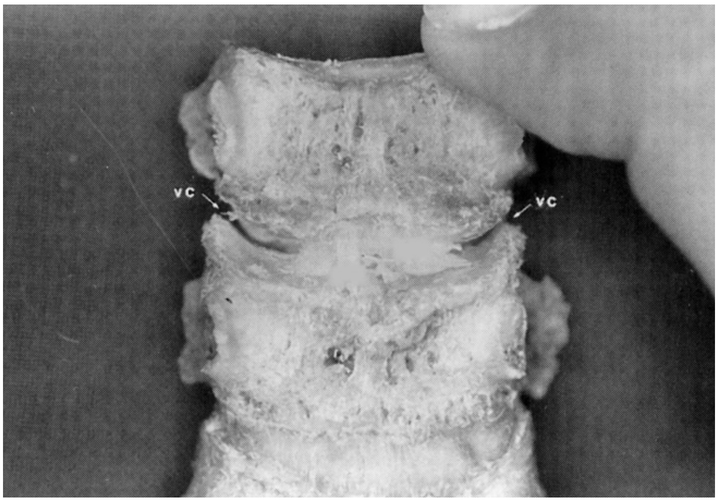


Figure 1.5. Posterior view of a cervical disc showing uncovertebral clefts (vc). Photograph taken from (Mercer and Bogduk, 1999).

1.5.3 Periosteofascial tissue

Periosteofascial tissue covers the area of the lateral clefts in the uncovertebral region (see figure 1.6). It is continuous with the periosteum over the posterolateral aspect of the vertebral body and pedicles, but becomes distinctly fascial as it leaves the bone. It consists of unorganised fibrous connective tissue embedded with fat and a large number of blood vessels. Part of its function may be to assist in the provision of a blood supply between the vertebral bodies (Mercer and Bogduk, 1999).

1.5.4 Ligaments

Ligaments connect the vertebral bodies and the posterior sections of the cervical vertebrae, spanning one or more segments, travelling in either a longitudinal or infero-lateral direction, depending on the type of ligament and vertebral level (Yoganandan et al., 2001). They help secure the disc both anteriorly and posteriorly, as well as provide support to the vertebral bodies (Moulton, 2014). Spinal ligaments have been found to be well innervated and this may form the basis of neurological feedback mechanisms for the protection and stability of the spine (Jiang et al., 1995). It may also suggest that they are a potential sources of pain (Bogduk, 1983).

1.5.5 Anterior longitudinal ligament

The anterior longitudinal ligament has four layers and is located directly anterior to the disc. The most superficial layer spans two or three vertebral levels in a perpendicular direction. The second layer also travels in a perpendicular fashion and attaches along the midline of the vertebral bodies above and below one disc level. The third layer of ligament also travels in a perpendicular direction, however, it is shorter in length travelling from the superior aspect of the vertebral body below to the inferior aspect of the vertebral body above. The fourth and deepest layer of ligament has similar attachment points to the third layer, however they travel in a diagonal direction (Mercer and Bogduk, 1999) (see figure 1.6).

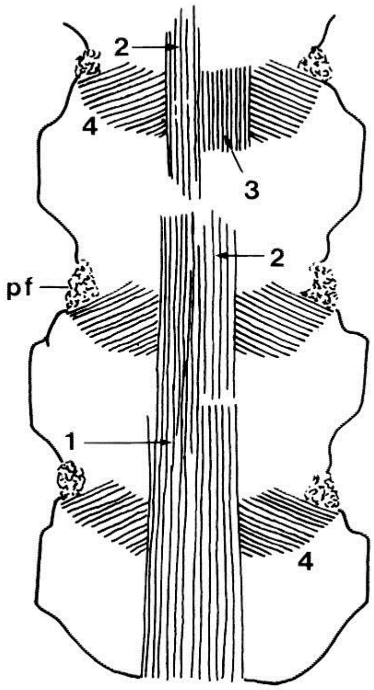


Figure 1.6. An illustrative representation of the anterior longitudinal ligaments. 1 - superficial longitudinal fibres; 2 – second, intermediate longitudinal fibres; 3 – third layer of deep longitudinal fibres; 4 – fourth layer of diagnol fibres; pf – periosteofascial tissue covering the uncovertebral clefts. Image taken from (Mercer and Bogduk, 1999).

1.5.6 Posterior longitudinal ligament

The posterior longitudinal ligament is located directly posterior to the disc, covers the entire floor of the cervical vertebral canal and consists of three distinct layers (see figure 1.7). The most superficial layer travels in a perpendicular direction, spanning two or three vertebral levels, with some lateral fibres travelling diagonally. The second layer of fibres travels perpendicularly from the mid-section of one vertebral body to the next. The last layer is similar to the deepest layer of the anterior longitudinal ligament, travelling in a diagonal direction as far as the posterior ends of the uncinate processes (Mercer and Bogduk, 1999).

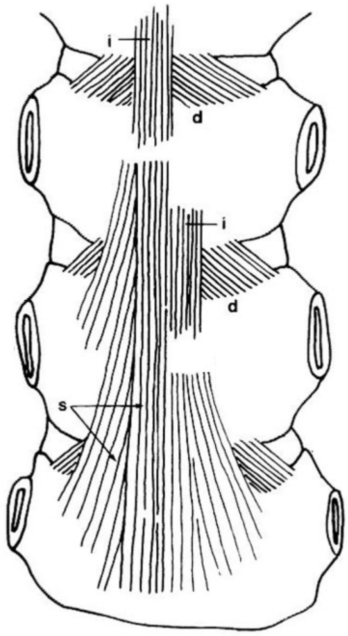


Figure 1.7. An illustrative representation of the posterior longitudinal ligaments. s - superficial fibres and their lateral extensions; i – second layer of intermediate fibres; d - deep fibres travelling diagonally. Image taken from (Mercer and Bogduk, 1999).

1.5.7 Other ligaments

Other posterior ligaments not in direct contact with the disc include the supraspinous ligament which attaches the tip of each spinous process to the other. The ligamentum flavum runs from the base of the skull to the pelvis, in front of the facet joint capsules and lamina, as well as in between the lamina. The interspinous ligament runs in between the spinous processes and attaches to the ligamentum flavum (Moulton, 2014).

1.6 Anatomical structure of the cervical disc

In a similar fashion to the lumbar disc, the cervical disc consists of both an outer annulus fibrosus and a nucleus pulposus layer. Dissimilarly however, at birth, the nucleus in the cervical spine constitutes no more than 25% of the entire disc compared to 50% in the lumbar spine (Mercer and Bogduk, 1999). The nucleus pulposus (NP) in the cervical disc rapidly undergoes fibrosis so that by the third decade there is barely any distinguishable nuclear material (Oda et al., 1988; Mercer and Bogduk, 1999). In adults, the disc is the largest avascular structure in the body, with Type I collagen (as found in tendon) predominating the peripheral annulus and type II collagen (abundant in hyaline cartilage) found in the inner annulus and nucleus pulposus (Grunhagen et al., 2006). Its cells depend on diffusion from adjacent blood vessels arising from the vertebral bodies to supply essential nutrients for cellular activity and to assist with removal of metabolic wastes such as lactic acid (Urban et al., 2004; Grunhagen et al., 2006). The following sections will describe in greater detail, the structure of the cervical disc annulus fibrosis and NP.

1.6.1 Annulus fibrosis – anterior fibres

The structure of the annulus fibrosis in the cervical disc differs to that of the lumbar disc in its shape. In the cervical disc, the anterior annulus is thick towards the median plane, but progressively thinner as it travels laterally to the uncinate processes, deficient along the posterolateral region, looking similar to a crescent from an axial view (see figure 1.8). The posterior section consists of only a thin layer of collagen fibres that attach perpendicularly (Mercer and Bogduk, 1999). Although, in the lumbar spine, the disc annulus is also thicker anteriorly, with some posterior fibres incomplete in parts, there is greater continuity to its structure as it surrounds the disc (Tsuji et al., 1993).

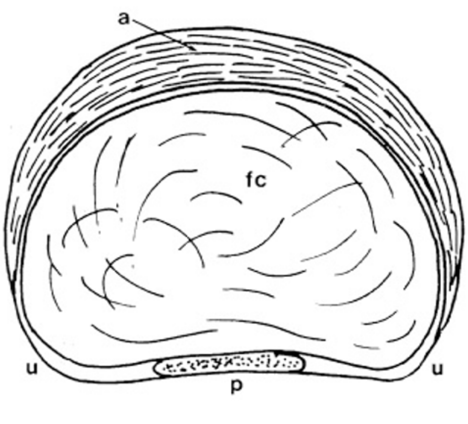


Figure 1.8. An illustrative diagram of a cervical disc. a – annulus fibrosis with greater thickness anteriorly and tapering posteriorly towards the uncinate region (u); fc – fibrocartilaginous core; p – paramedian longitudinal annular fibres, deficient along the posteromedial edges. Image taken from (Mercer and Bogduk, 1999).

In the cervical annulus, Mercer and Bogduk (1999) identified three layers of collagen fibres: transitional fibres, superficial fibres and deeper fibres (see figure 1.9). The orientation of the transitional fibres travel in a perpendicular direction from the superior aspect of the vertebral body below to the inferior aspect of the vertebral body above. The superficial fibres arise from the upper surface of the lower vertebra and travel upwards and medially, to the inferior surface of the vertebrae above. Towards the midline, the fibres interweave with corresponding fibres of the contralateral side. The deepest fibres repeat this pattern of interweaving, with individual fibres meshing together, with fibres originating closer to the midline of the vertebrae.

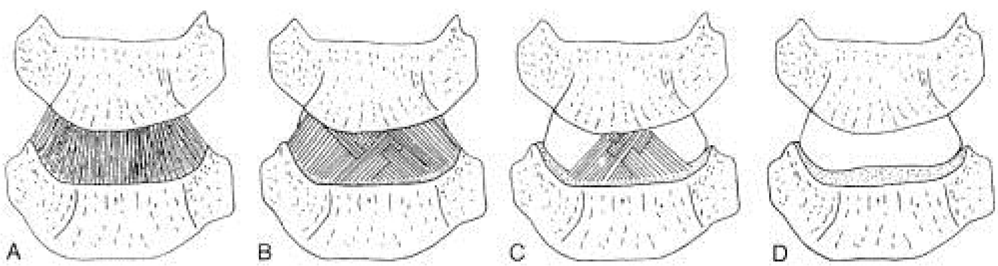


Figure 1.9. An illustrative diagram of the multiple, diverging annular fibres. A – perpendicular transitional fibres; B – superficial fibres; C – deeper fibres; D – fibrocartilaginous core. Image taken from (Mercer and Bogduk, 1999).

Beyond 2-3 cm from the surface of the anterior annulus, collagen fibres were found to be increasingly imbedded with what the authors presumed to be proteoglycans to form a homogenous fibrocartilaginous mass that had a pearly appearance and the consistency of soap (Mercer and Bogduk, 1999). Deeper still, the fibrocartilage became more homogenous and less laminated, forming what was interpreted to be the nucleus of the disc (Mercer and Bogduk, 1999).

1.6.2 Annulus fibrosis – posterior fibres

The posterior annulus extends between the base of the uncinate process on each side and consists of one set of vertically orientated collagen fibres that run between the facing surfaces of opposing vertebral bodies (see figure 1.10). This layer is no more than 1 cm thick, and deep to it lays the homogenous fibrocartilaginous core (Mercer and Bogduk, 1999).

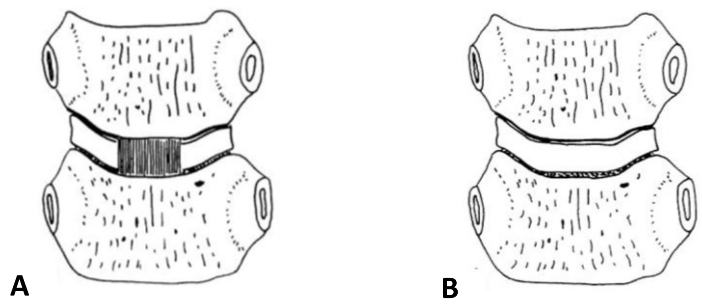


Figure 1.10. Longitudinal fibres of the posterior annulus fibrosus (A). Fibrocartilaginous core of the disc deep to the posterior annulus (B). Images taken from (Mercer and Bogduk, 1999).

1.6.3 Nucleus pulposus

The NP consists of a fibrocartilaginous core formed by proteoglycans, embedded in collagen fibres (Mercer and Bogduk, 1999). This fibrocartilaginous tissue develops in the early twenties and replaces cells from the notochord (cells located in the early embryo of vertebrates), found in their greatest abundance in the first decade of life (Oda et al., 1988). In the uncovertebral region, clefts extend into the fibrocartilaginous core. These clefts open under the periosteofascial tissue covering the uncovertebral region and penetrate the core at different extents, depending on age, with older spines demonstrating penetration of the clefts into the posterior two thirds of the disc (Mercer and Bogduk, 1999). A unique feature of the cervical nucleus is that the posterior annulus surrounds only the posteromedial aspect of the fibrocartilaginous core. The remaining areas are covered only by periosteofascial tissue (Mercer and Bogduk, 1999). In adulthood, the cartilaginous end plate of the vertebral body, adjacent to the nucleus pulposus, shows signs of calcification which, in turn, appears to reduce the ability of blood vessels to provide nutrition to the disc (Oda et al., 1988). Defects in the end plate, likely occurring through mechanical stresses and the degenerative process, appear to penetrate the disc and cause further degradation (Oda et al., 1988).

In summary, the cervical disc and its adjacent structures are inherently different to those of the lumbar disc. The cervical disc contains a NP that is approximately half the size of that found in the lumbar spine. Unlike the lumbar nucleus, it loses it gelatinous consistency by the early twenties, being replaced by a fibrocartilaginous core. Unique to the cervical spine are the uncovertebral processes aiding regulation of its range of movement. These uncovertebral processes give rise to clefts in the posterolateral aspect of the disc, causing a discontinuation of disc material in these areas. Furthermore, in contrast to an intact lumbar disc annulus which mostly consists of a continuous layer along the entire disc nucleus (Galante, 1967; Marchand and Ahmed, 1990), the posterolateral aspects of the cervical disc annulus are devoid of any annular tissue. The differences between cervical and lumbar disc anatomy may mean that their response to loading will vary. While the effects of various postural loads on position of the lumbar disc have been examined, no published studies have directly examined, with the use of MRI, the effects of postural load or exercise on position of the cervical disc.

1.7 Spinal level terminology

Throughout this study, reference will be made to specific spinal disc and segment levels that have been investigated in previous research, as well as by the Principal Investigator (PI). When describing the level of a disc, it is in reference to the vertebral bodies it lays between. For example, there are usually seven vertebral bodies in the cervical spine, and the disc located between the sixth and seventh vertebral bodies is termed the C6-7 disc. In other words, the C6-7 disc is located below the C6 vertebral body and above the C7 vertebral body (see figure 1.11). This process follows down the entire spine so that the most distal spinal disc located below the fifth lumbar vertebrae and above the first sacral body is termed the L5-S1 disc (Moore et al., 2010). A spinal segment refers to not only the disc, but the vertebral bodies directly above and below it. Therefore, the combination of the C6 vertebral body, the C6-7 disc and the C7 vertebral body, is referred to as the C6-C7 vertebral segment.

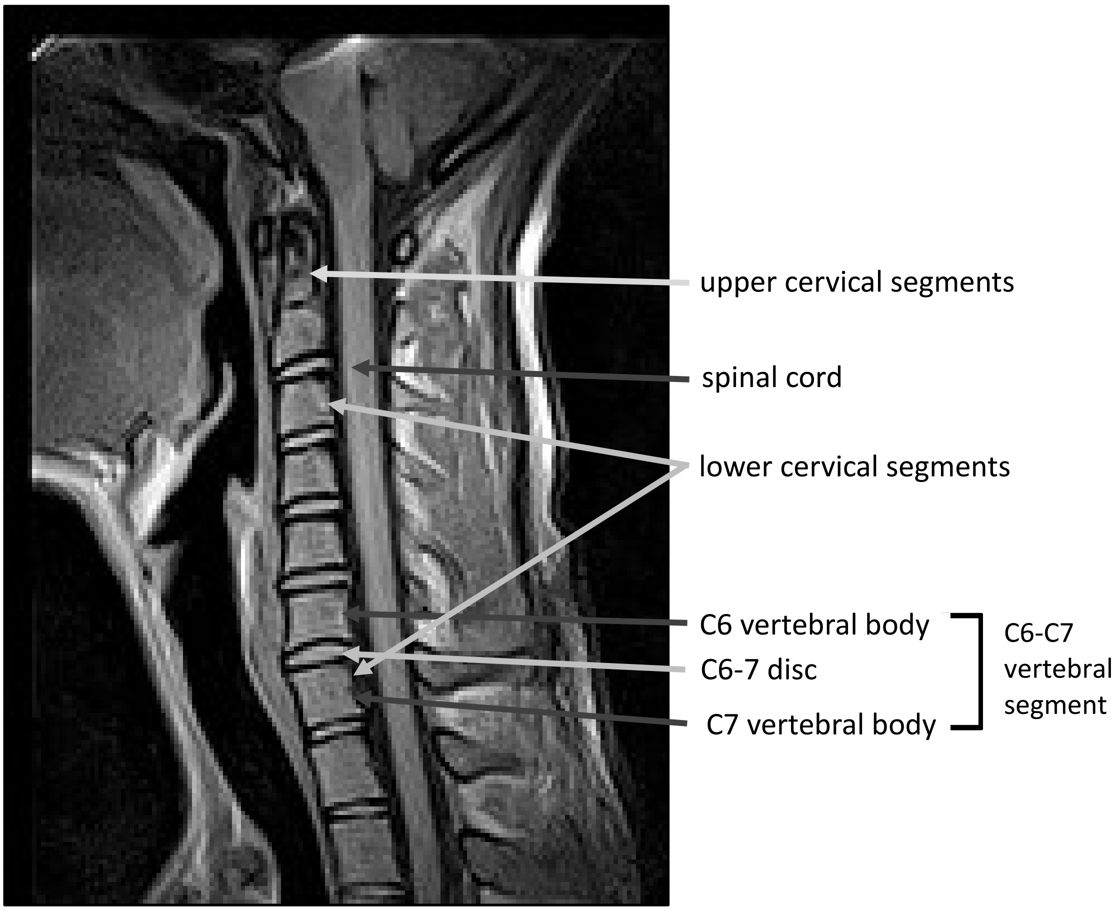


Figure 1.11. MRI of a sagittal view of the mid- section of the cervical spine in a neutral position with labelling of spinal structures.

1.8 Function of the cervical disc

The IVD's separate the vertebral bodies of the spine and allow the twisting and bending associated with spine mobility (Urban et al., 2000; Roughley et al., 2006). In conjunction with the adjacent spinal structures, they also dissipate energy and transfer loads applied to the spine from every conceivable combination of vectors (Modic et al., 1988; Smith et al., 2011). This ability to resist compressive loads is primarily achieved through a network of cross links composed of collagen fibres and proteoglycans (Urban et al., 2000).

Mechanically unfavourable loads placed on the disc can reduce its transport of nutrients by reducing tissue flexibility, transport efficiency and cellular capacity (Holm, 1993). This may lead to cell death, matrix degradation and disc degeneration (Urban et al., 2004). Therefore, reducing abnormal loads placed upon the disc is one way to help maintain its health (Handa et al., 1997). This will in turn reduce the incidence of spinal pain, as well as pressure on facet joints (Adams et al., 1996) and help maintain foraminal patency thereby reducing the risk of nerve compression (MacNab, 1971).

1.9 Forward head posture and neck pain

A high percentage of our daily lives, more so than any time in our past, is now spent sitting during commuting, in the work place, domestic environment and during leisure time (Owen et al., 2010). Activities we engage in while sitting may include reading and television viewing, as well as computer, laptop, tablet and mobile phone use. A common posture adopted by people performing these activities is a forward head posture. This posture implies that the head is in an anterior position in relation to an imaginary vertical line running through the centre of gravity of the body (Yip et al., 2008). A forward head posture can refer to more than one position. It may either imply a protruded head posture which involves extension of the upper cervical segments and flexion of the lower cervical segments, or it may imply flexion of both upper and lower cervical segments (see figure 1.12). A protruded head posture is generally maintained while looking forward, such as during desktop use while a flexed head posture is maintained while looking downward, potentially while during reading or using a hand held device. The common theme in both these postures is flexion of the lower cervical segments.

A **B**

Figure 1.12 Photographs of protruded and forward head postures. In both these postures the head is forward of a line running through the centre of gravity of the body. A protruded head posture implies flexion of the lower cervical segments and extension of the upper cervical segments (A). A flexed head posture involves flexion of both the lower and upper cervical segments (B).

Published studies have found a significant correlation between a forward head posture and the incidence of neck and inter-scapular pain (Harman et al., 2005; Falla et al., 2007; Yip et al., 2008). Griegel-Morris et al. (1992) found that the incidence of pain increased in participants with more exaggerated postural abnormalities. Those with more severe forward head postures had significantly greater cervical spine pain ($p < 0.05$), headaches ($p < 0.025$) and interscapular pain ($p < 0.01$) compared with those with less severe or normal head postures. An analysis of 150 University academic staff in Hong Kong recorded a significant association between a self-reported forward head posture and neck pain (Chiu et al., 2002). Participants reported their working postures by selecting from diagrams of forward head postures, flexed neck postures and sitting postures drawn by the authors.

There was no correlation found between the duration of holding posture (p = 0.73) or duration of computer use (p = 0.44) and the incidence of neck pain. However, there was a significant association between position of the head and neck during computer use and incidence of neck pain (p = 0.02) with 60.5% of subjects with neck pain reporting a forward head posture. These finding were supported by Yip et al. (2008) who used a more objective measure of head posture involving the use of the Head Posture Spinal Curvature Instrument which has been shown to have high intra-rater reliability (Wilmarth and Hilliard, 2002). This instrument is very similar in function to an enlarged goniometer and technique involved measurement with the use of a bony landmark at the C7 spinous process and soft tissue landmarks at the tragus of the ear (see figure 1.13). A smaller measured angle was significantly correlated with an increased forward head posture.

Figure 1.13 Head Posture Spinal Curvature Instrument used to measure forward head posture. Image from (Yip et al., 2008).

They found that an increase in forward head posture was positively correlated with neck disability as measured by the Northwick Park Neck Pain Questionnaire (NPQ) (p < 0.015). The source of pain was suggested to arise from anterior loading of the non-contractile spinal structures (Yip et al., 2008). One such non-contractile structure is the cervical disc, however there have been no published *in vivo* studies assessing the effects of a forward head posture on cervical disc loading. As it has been conclusively determined that the cervical disc can be a source of neck pain (Cloward, 1959), it is important to understand the effect this common head posture may have on position of the cervical disc.

1.10 Effects of lumbar spine posture on disc positioning

In vivo studies looking at movement of the IVD in various postures have focused solely on the lumbar spine and have consistently used MRI to measure disc displacement. These studies have repeatedly shown that the disc is a moveable structure affected by body posture, with flexed postures producing greater posterior disc displacement than extended postures in healthy discs (Beattie et al., 1994; Fredericson et al., 2001; Alexander et al., 2007; Kolber and Hanney, 2009).

Two of these investigations by Beattie et al. (1994) and Fredricson et al. (2001) specifically assessed the effects of posture and loading on position of the lumbar disc. Beattie et al. (1994) recruited 20 healthy women between 20 and 30 years of age and used MRI to measure disc position in two supine lying positions. The first involved use of a lumbar roll aimed at extending the lumbar spine. The second involved supine lying with hips and knees flexed with a large cushion, aimed at increasing lumbar flexion. Measurement of disc position included a vertical line drawn connecting the postero-inferior point of the vertebral body above to the postero-superior point of the vertebral body below the disc in question. A second horizontal line was drawn connecting the most posterior section of the disc to the vertical line connecting its vertebral segment. One way ANOVA with Bonferonni adjustment indicated that at the L3-4, L4-5 and L5-S1 disc levels, the extended spinal posture produced less posterior disc displacement than the flexed postures with an average difference of 1.5 mm (mean $p < 0.0003$).

Fredricson et al. (2001) scanned three healthy participants between 27 and 31 years of age, this time in neutral, flexed and extended sitting. They were then scanned a second time after six hours of normal activity and a final time after four hours of a continuous hike in the adjacent foothills with a 30 pound upper body vest. Disc measurement technique was identical to that used by Beattie et al. (1994) (see figure 1.14). Their results suggested increased posterior disc bulging at L4-5 and L5-S1 when comparing flexion to extension of the lumbar spine in a seated posture. The largest change was a 1.6 mm (46.6%) increase in posterior displacement at L4-5 in flexed compared to neutral sitting after four hours of hiking. These postures also produced a 1.1 mm (9.3%) increase in posterior disc displacement at the L5-S1 disc in flexed compared to neutral sitting. An important limitation of their study was the lack of any inferential statistical analysis of their results, likely due to their small sample size. Results were reported in percentage change, averages and trends denoted by graphs only.

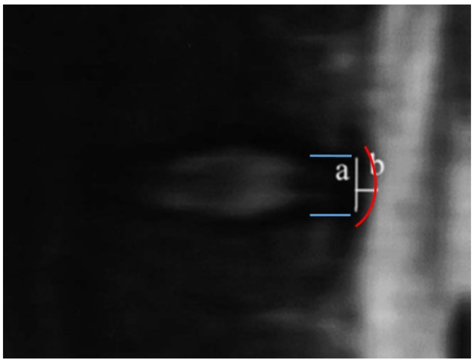
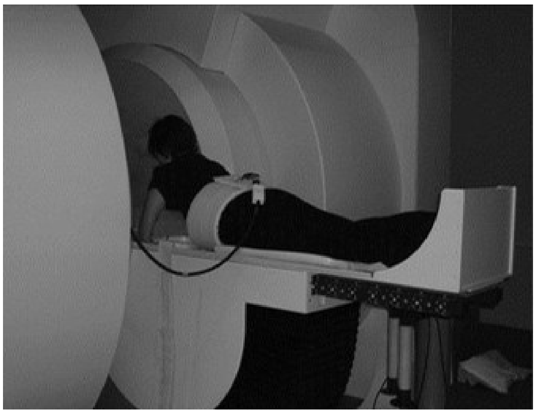


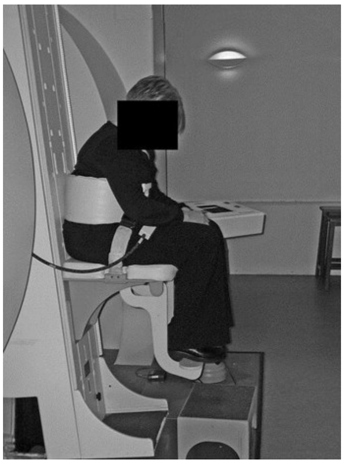
Figure 1.14. A perpendicular white line was drawn connecting the posterior edges of the vertebral bodies (a). A second horizontal line was drawn from the most posterior edge of the disc to the perpendicular line. Figure taken from (Fredericson et al., 2001). To allow for better visualisation of the vertebral structures the horizontal blue lines were added to indicate the posterior endplates of the vertebral bodies. A red line, semi-spherical line was drawn to indicate the posterior edge of the disc.

Further work by Alexander et al. (2007) found similar results after assessing the effects of different spinal postures on 11 healthy volunteers, between the ages of 18 and 60 years. One of the strengths of this study was their use of an upright scanner which allowed comparison of a variety of functional positions including: standing, sitting, (upright, flexed, extended), supine and prone extension (lying on your stomach while perched on your forearms), (see figure 1.15).

A



B



C

D

Figure 1.15. Photographs taken from Alexander et al.'s (2007) study demonstrating participants in various postures during MRI scanning. Postures in standing (A), prone extension (B), slouched sitting (C) and extended sitting (D). There was no photograph demonstrating upright sitting.

Position of the disc nucleus was measured from the centre of the nucleus determined by peak pixel intensity (i.e. the brightest pixel) on MRI to the anterior disc boundary. ANOVA and Friedman's analysis showed significant positional effects on the disc at all lumbar spinal levels (L1-2 to L5-S1). Flexed (slouched) sitting showed a 19.1% increase in posterior disc displacement at the L4-5 disc compared to standing, measured as a 6.1 mm difference. There was also a 22.8% difference in position at the L5-S1 disc, measured as 7.1 mm, between flexed sitting and supine lying. A flexed sitting posture increased posterior displacement of the lower lumbar discs significantly more than extended sitting with a 15.9% increase in posterior displacement in the former position, measured as a 5.1 mm difference. These findings have helped validate the clinical assumption that slouched sitting, associated with a loss of spinal lordosis, causes greater posterior displacement of the lumbar disc compared to upright sitting.

It is interesting to note the degree of disc movement recorded by Alexander et al. (2007) is noticeably greater than the movement recorded by both Beattie et al. (1994) and Fredericson et al. (2001). Alexander et al. (2007) reported moderate to high intra-class correlation coefficients (ICC) for the intra-rater reliability to locate the NP centre, with ICC results ranging from 0.71 to 0.97. Fredericson et al. (2001) also reported high inter-rater reliability in the measurement of posterior bulging of the discs (rho = 0.98). Beattie et al. (1994), did not perform an ICC, however demonstrated very good reliability after performing five repeated measures of disc displacement, with only a 0.1 mm difference reported between measurements. These reliability results reduce the possibility of measurement error as an explanation for the difference in measurement recorded.

As well, all participants were scanned in the same order with sitting upright performed prior to sitting in flexion, therefore it is unlikely that the order of scans impacted the degree of disc displacement. One possibility for the difference in measurement results is the differences in positions used. While Alexander et al. (2007) compared scans of participants in standing, sitting and lying postures, Beattie et al. (1994) compared scans in supine lying with only a lumbar roll and wedge to alter participant position. The greatest difference in disc position recorded by Alexander et al. (2007) was mostly found between sitting and lying postures. However, while Alexander et al. (2007) recorded a 5.1 mm difference in disc position between flexed and extended sitting, Fredericson et al. (2001) suggested findings of a 1.6 mm difference when comparing these same seated postures. This may have been due to their low sample size.

Another possibility for the difference in degree of movement between these studies may be due to the measurement technique used. Both Beattie et al. (1994) and Fredericson et al. (2001) measured disc displacement from the margins of the disc to the adjacent vertebral bodies. However, Alexander et al. (2007) measured disc displacement from the centre of the nucleus to the anterior disc boundary. The difference in magnitude of disc displacement between these studies may imply that there is greater movement that occurs within the disc itself as compared to movement of the outer disc boundary. This possibility may be a greater consideration for measurements of the lumbar disc which contain a more malleable gelatinous NP compared to a cervical disc which replaces its gelatinous core with fibrocartilaginous tissue as early as the mid-teens.

Kolber and Hanney (2009) completed a systematic review of the available research assessing the biomechanical concept of predictable disc migration in various spinal postures, referred to as the dynamic disc model (DDM). Articles were included for review if they (1) appeared in a peer review journal, (2) included human *in vitro* or *in vivo* investigations, (3) assessed migration of the NP in response to angular movement or position and (4) provided a conclusion as to the direction of, or lack thereof, NP migration. After searching the literature, they found 12 papers which supported the idea of the ability of various spinal postures to affect position of the lumbar disc in healthy participants. One such study found that the NP migrated away from the side of loading in healthy participants (Edmondston et al., 2000). Edmondston et al. (2000) reported that in 30% of cases there was anterior displacement of the NP in flexed spinal postures in healthy volunteers. They assessed nucleus position in a flexed and extended supine spinal posture with the use of MR imaging. There was however, no neutral position used as a baseline from which to compare nucleus displacement. As well, there was no mention of the order in which the scans were undertaken. As results from previous studies have shown, a flexed lumbar position causes greater posterior displacement of disc material compared to an extended position (Beattie et al., 1994; Fredericson et al., 2001; Alexander et al., 2007). Therefore, the initial scan will affect position of the disc prior to subsequent scans. This in turn may affect the degree of disc displacement recorded after the initial scan. Furthermore, their description of a flexed position included the use of pillows under the participants' knees and a wedge under the pelvis in order to maximise lumbar flexion. In their figures, however, it appears the extended position may have had a wedge placed under the mattress, producing a degree of lumbar flexion. In a figure meant to depict lumbar flexion there are pillows placed under the participants' knees and one under the buttocks and hamstrings, however the lumbar spine itself is in more of a neutral position. This may be an editorial error, however they do mention in their discussion that the ranges of motion they achieved were lower than those reported from conventional functional radiographic studies. They also note that the posterior displacement measured was generally small and greater than 6% in only four discs. Images of healthy volunteers showed that nine out of the ten participants demonstrated mild degeneration of the nucleus in at least one disc, with 26% of all discs demonstrating mild degeneration and two participants demonstrating frank posterior disc protrusions at the L4-5 disc. They report that in extension, five of the degenerative discs displaced posteriorly, however there is no mention as to whether it was the more degenerative discs which migrated anteriorly in the flexed position. They concluded that, as it was difficult to predict direction of disc displacement through change of spinal position, manual therapy treatment for lumbar spine pain should be based on symptomatic response rather than biomechanical theory aimed at repositioning displaced disc material. Although some of the images in their study lead to the question as to whether they were measuring lumbar flexion and extension accurately; evidence would agree that more degenerative discs respond to loaded postures in a less predictable manner (Schnebel et al., 1988; Beattie et al., 1994). When developing his conceptual model, McKenzie (1981) also felt that the disc was not always able to displace in a predictable manner. He predicted that the ability of the disc nucleus to move anteriorly in extension and posteriorly in flexion depended on the integrity of the annular wall. He felt that without an intact annulus fibrosis, the NP was less likely to be affected by spinal movement in this way, due to loss of its hydrostatic mechanism.

Of the 12 studies supporting the DDM, four were *in vitro* questioning the transferability of their results as cadaveric specimens do not accurately represent movement of the spine in a living human (Kolber and Hanney, 2009). Of the remaining eight studies, seven used MR imaging to assess disc position (Beattie et al., 1994; Fennell et al., 1996; Brault et al., 1997; Edmondston et al., 2000; Perie et al., 2001; Fazey et al., 2006; Alexander et al., 2007) while one used a combination of radiographs and discography (injection of contrast fluid into a disc using X-ray guidance) (Schnebel et al., 1988). Both MR imaging and discography have been shown to be excellent techniques for the imaging of the IVD (Modic et al., 1988; Beattie et al., 1994). These remaining eight studies found that the disc moved in the opposite direction to the load placed upon it, with flexed postures causing posterior disc displacement and extension causing anterior displacement. An interesting study by Perie et al. (2001) assessed the effects of chronic posture on disc displacement by assessing 14 children with scoliotic spines. In keeping with the DDM, they reported that the T11-L5 lumbar disc nucleus migrated to the side of convexity.

Although the findings in these studies produce the closest comparison to the cervical spine, lumbar and cervical discs are morphologically and biomechanically dissimilar and it may therefore be erroneous to extrapolate results from lumbar spine studies to predict cervical disc behaviour.

1.11 Biomechanics of disc movement

Most of the studies looking at disc movement in the lumbar spine have found that, in healthy participants, flexed postures result in a more posterior disc position while extended or neutral postures result in a more anterior position (Beattie et al., 1994; Alexander et al., 2007; Kolber and Hanney, 2009). This change in position is theorised to partly occur as a result of the compressive forces applied by the vertebral bodies on the anterior and posterior sections of the disc respectively. For example, in extended spinal postures, approximation of the postero-inferior section of the vertebral body above the disc to the postero-superior section of the vertebral body below potentially compresses the posterior section of the disc, causing it to migrate anteriorly. Equally, approximation of the antero-inferior section of the vertebral body above the disc with the antero-superior section of the vertebral body below - such as in flexion - is likely to cause compression of the anterior disc therefore encouraging posterior displacement (McKenzie, 1981) (see figure 1.16).

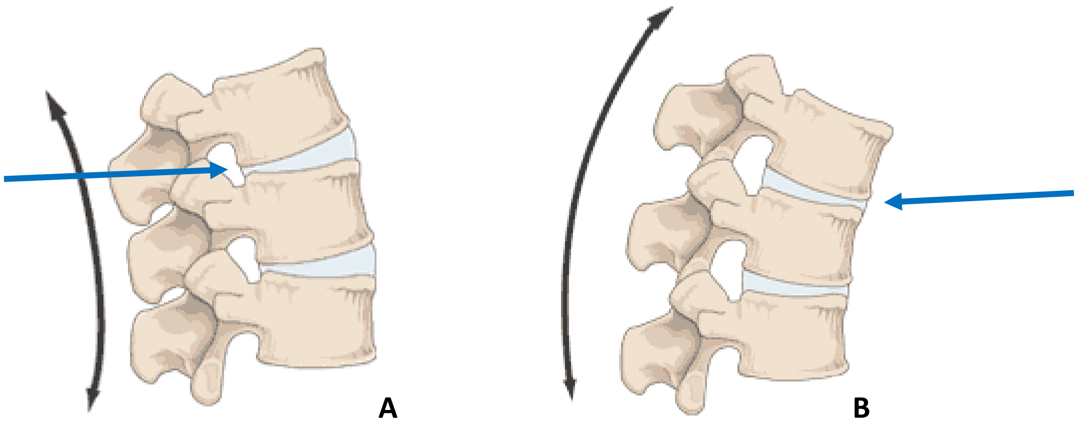


Figure 1.16. Lumbar spinal segments depicting an extended and flexed posture. Approximation of the posterior vertebral bodies in extension, indicated by the near horizontal blue arrow (A). Approximation of the anterior vertebral bodies in flexion, indicated by the near horizontal blue arrow. Figure taken from (Luklinski, 2015).

Other causes of disc displacement may include those similar to the causes of stenotic change in the spine. These include ligament hypertrophy, hypertrophic facets and degenerative spondylolisthesis. There is the potential for any of these changes to alter disc position through direct compression (Inufusa et al., 1996). Muscle forces and ligament tension in various spinal postures may also effect disc position by causing increased intradiscal pressure (Handa et al., 1997).

Regardless of the mechanisms of movement, a change in lumbar disc position in various spinal postures and under various loads has been repeatedly recorded in the literature

(Beattie et al., 1994; Fredericson et al., 2001; Alexander et al., 2007; Kolber and Hanney, 2009).

1.11.1 Hydrostatic pressure

The spinal disc is thought to be able to respond to the biomechanical loads placed upon it because it exhibits a hydrostatic pressure (McKenzie, 1981; Adams et al., 2009). A hydrostatic pressure refers to the pressure that any fluid in a confined space exerts. Pascal's principle states that any external pressure applied to a fluid is transmitted undiminished throughout the fluid and onto the walls of the containing vessel (Vawter, 2010). In terms of the spinal disc, 'external pressure' is applied by osseous and collagenous structures adjacent to the disc. The 'walls of the containing vessel' refer to the disc annulus while the 'fluid' refers to the high water and proteoglycan content in the central nucleus (Urban and McMullin, 1988; Iatridis et al., 2007). Spinal discs have been shown to exhibit a hydrostatic pressure, and this is explained by the discs' ability to migrate away from an area of compressive loading in order to equalise pressure within the disc space (Hutton et al., 2001; Skrzypiec et al., 2007; Adams et al., 2009).

Handa et al. (1997) has shown that the body's ability to maintain an appropriate hydrostatic pressure can affect the health of the IVD. They investigated the effects of hydrostatic pressures on 28 intervertebral lumbar discs obtained from cadavers as well as patients undergoing anterior interbody fusion, aged between 13 to 80 years of age. Examination of tissue cultures showed that a physiological level of hydrostatic pressure (3 atmospheres) acted as an anabolic factor for stimulation of proteoglycan synthesis and as a tissue inhibitor of metalloproteinases-1 production (protease enzyme involved in disc degeneration). They theorised that maintaining a physiological hydrostatic pressure within the disc was essential for maintaining the disc matrix. If the hydrostatic pressure was too high (30 atmospheres) or too low (1 atmosphere) a catabolic effect on the disc was demonstrated. Through these findings, they concluded that abnormal hydrostatic pressures may accelerate disc degeneration.

The theory of a hydrostatic pressure, whether at an optimal or suboptimal level, affecting the disc, might sound more applicable to lumbar discs that maintain a greater water content in a proportionally larger nucleus pulposus compared to cervical IVD’s. It was mentioned previously that in the third decade of life, the NP of the cervical disc rapidly undergoes fibrosis so that there is barely any distinguishable nuclear material remaining (Oda et al., 1988; Mercer and Bogduk, 1999). Furthermore, as the cervical disc contains clefts that pierce into the nucleus core, and no outer annulus layer in its posterolateral aspects, the gaps in its disc tissue may create a reduced potential for maintaining a hydrostatic pressure (Mercer and Jull, 1996; Mercer and Bogduk, 1999).

Despite these anatomical features, evidence of a hydrostatic pressure has been investigated in the cervical spine in two *in vitro* studies. The first was by Skrzypiec et al. (2007) who studied 25 cervical discs between the levels of C2-3 and C7-T1 from cadavers aged between 48 and 90 years. With the use of a miniature pressure transducer inserted along the sagittal midline diametre of the disc, and a computer controlled hydraulic device, they were able to measure pressure changes in the disc while applying angles of flexion and extension representing common neck and head postures. After correcting for the influences of disc degeneration and spinal level, posture was found to significantly influence stresses in the nucleus and anterior annulus. They found greater evidence of a hydrostatic pressure in discs showing no or minimally degenerative changes. Stress profiles from lower cervical levels (C5-T1) showed more conventional hydrostatic behaviour within the nucleus.

The second study, by Scannell et al. (2009), assessed whether posteriorly prolapsed cervical discs from 18 porcine specimens could be reversed with extension movements produced by a servohydraulic jig; a metallic device able to apply specific loads and pressures at various angles. The vertebral segments were repeatedly flexed under an axial load until a posterior/ lateral shift of the nucleus of at least 50% (2-3 mm) was achieved. Radiographic images were then used to assess position of the dissected discs, taken from C3-C6 segments, before and after application of repeated extension by the hydraulic device. They reported a reduction in prolapsed nucleuses in 5 of the 11 prolapsed specimens after reversal testing. They found the prolapsed discs that centralized had significantly less disc height loss which agreed with Skrzypiec et al.'s (2007) earlier findings of a greater hydrostatic region in the less degenerative discs. The findings of both these studies support the idea of the existence of a hydrostatic pressure within the cervical disc, as found in the lumbar spine, however, there are some limitations to the aforementioned studies. First, it cannot be assumed that dissected cervical segments behave in a similar fashion to ones *in vivo* due to the effects of muscle activity, spinal posture and body weight on disc dynamics (Sato et al., 1999; Wilke et al., 1999). Secondly, pressure applied to a disc at a single vertebral segment may produce exaggerated results compared to disc pressure occurring in living subjects. The eight cervical discs, in combination with the facet joints, vertebral bodies and the thoracic and lumbar spine, work as an extended unit to help reduce, transfer and off-load forces placed upon it (Jensen, 1980). Therefore, measuring movement at a single, dissected spinal level, without the ability of the disc to transfer pressure proximally or distally, cannot produce clinically transferable results. Furthermore, disc movement in a porcine cervical spine is unlikely to adequately mimic movement in a human spine. Quadrupedal animals have evolved with the ability to spend long hours grazing with their necks in a downward head posture, presumably without the production of pain, unlike bipedal humans who commonly report cervical pain if maintaining a prolonged forward head posture (Harman et al., 2005; Falla et al., 2007; Yip et al., 2008).

In vivo studies were found which assessed the impact of head posture and therapeutic exercise on cervical disc movement. The first, by Spanos et al. (2013), was a case study of a 34 year old sedentary, female teacher who attended a hospital out-patient orthopaedic clinic complaining of significant neck pain, stiffness and loss of function. An MRI scan was performed and found a large, left-sided, posterolateral disc protrusion at the C5-C6 level, compressing the dural sac and significantly narrowing the C5-C6 lateral foramen (the opening from which the corresponding nerve root emerges). She was immediately referred to an out-patient physiotherapy clinic and provided with postural advice and a variation of specific McKenzie based exercises which focused on end range cervical spine movements into retraction, extension and rotation, depending on symptom response. On her discharge, six weeks after her initial appointment, there was found to be a 56% reduction in the size of the disc herniation with less pressure on the adjacent nerve root. Subjectively, she reported near complete abolition of her symptoms and had regained full function. Clinically, one of the positive aspects of this case study was its use of symptom specific exercises to effectively reduce pain, thereby potentially sparing this patient the risks, and the National Health Service the cost of cervical surgery. From an experimental viewpoint, the six week gap between the initial and final scan makes it difficult to ascertain whether the reduction in disc protrusion was as a direct result of the biomechanical impact achieved through the provision of postural advice and various directional cervical exercises. There is the possibility that the reduction in disc material occurred through spontaneous regression which has been shown to occur during the 'acute' and 'healing' phase of disc injury (Ito et al., 1996). One theory behind this resorption includes neovascularisation around the periphery of displaced disc tissue, with the associated presence of macrophages (phagocytic cells that ingest dead or dying cells) (Ito et al., 1996; Mochida et al., 1998). Ito et al. (1996) concluded that cervical disc herniations, specifically migrating, lateral-type herniations, can frequently spontaneously regress in patients with radicular pain and upper limb atrophy.

The second *in vivo* study, by Abdulwahab and Sabbahi (2000), indirectly assessed potential disc displacement in the cervical spine by monitoring flexor carpi radialis (FCR) activity with electromyelography in participants complaining of a six month history of frequent neck, shoulder and scapular pain, associated with arm, forearm and hand paraesthesia and a pins and needles sensation. Their assumption was that the contractile impulse of the FCR muscle would be reduced if there was compression of the C7 nerve root by an adjacent posterolaterally herniated disc. This assertion does not appear to agree with findings by Gu (1997) who used nerve-stimulating electrodes in 15 patients undergoing C7 nerve root transfer, to assess which muscles are specifically innervated by roots C5 to T1. Results showed the C7 nerve root to innervate latissimus dorsi, triceps, extensor carpri radialis brevis, flexor carpi ulnaris and extensor digitorum. They reported the C5 and C6 nerve roots to innervate FCR. Nevertheless, there may be human variations in muscular innervation, as well as some overlay between adjacent nerve roots (Gu, 1997). Abdulwahab and Sabbahi

(2000) asked thirteen participants with a six month history of neck and arm pain and hand paraesthesia to read for a period of 20 minutes in whichever posture they chose, with observation of all participants showing consistent neck flexion in their chosen reading postures. Measurements of participants while reading showed reduced FCR activity using an electromyogram unit, and increased neck and radicular pain. Participants were then asked to perform a McKenzie based cervical retraction movement, presumably in sitting, and this produced an immediate increase in FCR activity ($p < 0.001$) and reduction of radicular pain ($p < 0.001$). These are very interesting findings, with the use of a relevant clinical population and the production as well as rapid, subsequent abolition of pain and improved neural function, after application of a simple exercise. The authors concluded that, as McKenzie (1981) had postulated, a forward head posture likely causes posterior displacement of the IVD towards the spinal root. They felt the reduction in pain and improvement in FCR activity was caused by anterior displacement of disc material achieved through McKenzie's (2006) neck retraction exercises. These findings may help validate the assumption that the cervical disc exhibits a hydrostatic pressure in a similar fashion as has been demonstrated in the lumbar spine. The use of an MR scanner in this study to measure actual disc position changes during reading and after the retraction exercise may have helped validate their assumptions.

1.12 Robin McKenzie's Extension principle

Flexed spinal postures have been shown to cause displacement of posterior lumbar disc material in a matter of minutes (Abdulwahab and Sabbahi, 2000; Alexander et al., 2007). This effect of flexed spinal loading on position of disc material was discussed by Robin McKenzie, a world renowned physiotherapist, who first developed an interest in treating spinal patients in 1953 (McKenzie and May, 2006). McKenzie developed an assessment and treatment approach for the management of MSK disorders which has been termed the McKenzie method of mechanical diagnosis and therapy (MDT). This MDT approach is used by MSK therapists throughout the UK and around the world (McKenzie and May, 2006) for the treatment of MSK spinal and peripheral complaints. An assessment approach in MDT for those presenting with spinal pain involves the performance of repeated end-range spinal movements with a monitoring of symptomatic and mechanical responses. According to the responses, patients are usually classified into one of three main mechanical syndromes – derangement, dysfunction or postural (McKenzie, 1981; McKenzie and May, 2006). The classification of interest in this thesis is that of a derangement syndrome. The conceptual model for the derangement syndrome in the spine involves the theory that pain can be caused by a change in position of the fluid nucleus of the IVD as it sits between two vertebral segments. This theory of internal derangement (displacement) of the IVD causing somatic cervical and lumbar spine pain has been supported by other research (Michelsen and Mixter, 1944; Yu et al., 1988; Ito et al., 1998). As mentioned previously, spinal discs, as a pain source, has been reported by Bogduk (1988) who identified innervation of the IVD by the sinuvertebral nerve. McKenzie (1981) hypothesised, partly through knowledge gained from research conducted at the time, that sustained flexed postures would result in excessive accumulation of disc material in the posterior compartment of the vertebral segment. As well as the posterior disc itself being a source of pain, over time, posterior disc displacement may cause mechanical compression of nerve roots, dorsal ganglion or the smaller nerves surrounding the disc (Luoma et al., 2000). Compression of these neural structures can, in turn, cause referral of pain as well as neurological symptoms such as paraesthesia, loss of sensation and reduction in myotomal function (Carette and Fehlings, 2005).

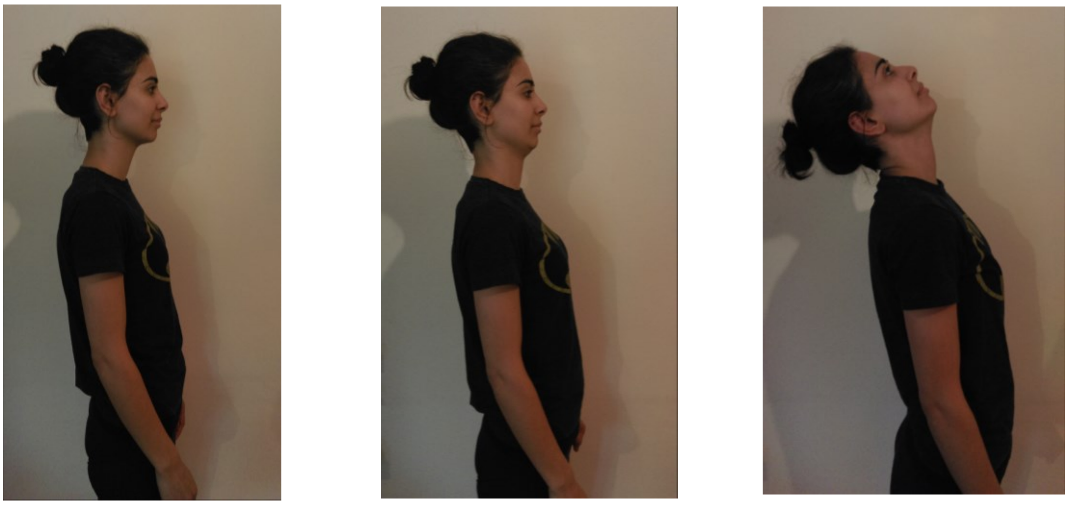
McKenzie's approach to managing those with a suspected derangement syndrome involves the application of a particular group of exercises aimed at reversing the derangement or displacement (McKenzie, 1981; McKenzie and May, 2006). This principle of treatment can be described succinctly by one of his quotes:

> If you adopt certain positions or perform certain movements that cause your back to 'go out', then if we understand the problem fully we can identify other movements and other positions that, if practised and adopted, can reverse that process. You put it out you put it back in (McKenzie, 1998…pamphlet).

In other words, if flexion of the spine (e.g. slouched sitting) can cause posterior displacement of IVD material, then extension of the same spinal segments should be able to reverse this displacement. Robin McKenzie's use of the phrase 'go out' in this context refers to displacement of disc material away from its centre. This concept of putting 'it back in' relates to the idea that the disc is a moveable structure that adapts to biomechanically applied stresses, with the ability to be repositioned. As mentioned previously, the assumed ability of a disc to change position in this way has been termed the dynamic disc model (Kolber and Hanney, 2009). In an attempt to manipulate position of a posteriorly migrated IVD, Robin McKenzie created a set of directionally based, end range spinal exercises grouped into a treatment method termed the 'Extension principle', (McKenzie, 1981). In the cervical spine, reversing posterior disc displacements using the Extension principle involves an exercise which creates extension of the upper and lower cervical segments aimed at reversing as much posterior displacement of disc material as possible. In

McKenzie's quote above, his description of 'certain positions', when relating to the cervical spine, refers to a protruded or forward head posture (McKenzie and May, 2006). This agrees with the findings of research reported earlier in this programme of studies, reporting a strong correlation between a forward head posture and the incidence of neck pain (Harman et al., 2005; Falla et al., 2007; Yip et al., 2008).

The exercise taken from his Extension principle to be used in this programme of studies is called 'retraction and extension in sitting'. This involves asking the participant to sit in an upright chair with a high back, with the sacrum in contact with the back of the chair. McKenzie and May (2006) describe the exercise as starting in a relaxed sitting posture. From this position, patients are instructed to retract their heads as far as possible, keeping the head facing forward and horizontal during the movement. Once maximum end range retraction is achieved, the patient is instructed to continue the movement by slowly and steadily tilting the head backwards as far as possible, as if to look at the ceiling (see figure 1.17). After a second, the patient then returns their head to a neutral position (McKenzie and May, 2006).



A B C

Figure 1.17. Cervical spine in a resting position (A), retraction (B) and end range extension (C).

1.13 Diagnostic imaging

MRI is the most commonly used diagnostic tool in the assessment of disc health and disc displacement in the lumbar spine (Beattie et al., 1994; Fennell et al., 1996; Fredericson et al., 2001; Parent et al., 2006; Alexander et al., 2007; Lurie et al., 2008). Although MRI has been shown to be an excellent modality for the assessment of disc displacement (Hickey et al., 1986; Beattie et al., 1994; Lurie et al., 2008), other imaging tools are also used in the assessment of this and other spinal structures.

1.13.1 Xray

Xrays are commonly used as a first line investigative tool by general practitioners for the assessment of spinal pain due to its accessibility and low cost. As the disc becomes more degenerative, loss of disc height and bone sclerosis of the adjacent vertebral bodies indicates manifestations of disc degeneration (Modic et al., 1988). The normal IVD, however, has no density on plain radiographs (Modic et al., 1988). This would make analysis of any disc herniations impossible as neither the NP nor the annulus fibrosis is visible on a radiographic image. Radiographs are more useful in the investigation of acute cervical spine injury, usually to detect for any variety of fractures (Kaiser and Holland, 1998).

1.13.2 Computed tomography (CT)

Spiral CT scans allow for quick performance of a complete cervical spine examination using thin sections, and improved computer software allows rapid reformatting into any appropriate plane (Kaiser and Holland, 1998). CT myelography has the advantage of better definition of osseous details, enabling the detection of uncinate joint spurs and overgrowths of posterior facet joints which can contribute to central and foraminal stenosis (Kaiser and Holland, 1998). CT, however, is relatively insensitive to initial degenerative displacements when the configuration of the disc itself has not changed and may result in underestimation of the severity of the changes within the NP and annulus fibrosis (Modic et al., 1988). This makes it less useful in the detection of subtle changes in disc displacement.

1.13.3 Discography

In combination with CT examination, discography can provide excellent figuration of the exact location of herniations. The procedure requires the use of fluoroscopy and involves insertion of a spinal needle into the spinal disc followed by injection of contrast fluid. It is a highly invasive procedure and its safe and effective application requires a highly experienced, procedural discographer (Schellhas et al., 1996). Despite its excellent ability to detect herniations, it is commonly felt that discography adds little when CT and MR imaging is available (Modic et al., 1988).

1.13.4 Magnetic resonance imaging

MR imaging overcomes almost all the limitations presented by the various alternative imaging tools described above. Its ability to detect subtle changes in disc displacement has been illustrated in numerous studies (Hickey et al., 1986; Beattie et al., 1994; Lurie et al., 2008). Tertti et al. (1991) were able to verify the sensitivity and specificity of MR imaging in detecting degenerative changes in lumbar discs by comparing MR findings to histological structure and biochemical composition of the discs post scanning. They found a positive correlation between histological detection of decreased water content in the disc and low signal intensity (black dots) on scanned images. They also reported that the amount of proteoglycans and chondroitin sulphate - keratan sulphate ratios differed significantly between the bright and dark discs on MRI scan. This agrees with findings by Hickey et al. (1986), Przybyla et al. (2006), Handa et al. (1997) and Adams et al. (2009) who concluded that water content, as well as the chemical environment of the NP, changes during aging and that this correlates with reduced demarcation between the NP and annulus fibrosis on MRI.

Reliability of MR readings for lumbar disc herniations has been demonstrated (Brant-Zawadzki et al., 1995; Lurie et al., 2008). Lurie et al. (2008) measured the sagittal extent of disc herniations from 60 spinal MR images and showed high reliability with an intra-rater summary kappa of 0.67 (95% CI 0.51, 0.79) and an inter-rater summary kappa of 0.63 (95% CI 0.54, 0.70). Lurie et al. (2008) did mention a potential lowered threshold for the reporting of disc displacement due to the knowledge by the radiologists that the scanned images were those of patients who either had a disc herniation or spinal stenosis severe enough to qualify them for surgery. Brant-Zawadzki et al. (1995) performed a double-blind prospective study measuring inter-rater and intra-rater reliability when evaluating reader consistency when interpreting disc extension beyond the interspace. They attempted to avoided potential reader bias by including the MR images of 98 healthy volunteers with those of 27 symptomatic participants. Intra-rater agreement was high at 80% with a kappa statistic of 0.58. Intra-rater agreement was also high 86% for each reader with a kappa statistic of 0.71 and 0.69 respectively.

One important advantage of the use of MRI as an investigative tool is that, unlike discography and CT myelography, it is a non-invasive procedure with no associated risks of injection or infiltration with dye. Furthermore, there is no exposure to potentially hazardous ionising radiation as in X-ray and CT diagnostics. In fact, other than those with known contraindications to MRI scan, such as those with pacemakers or certain types of aneurysm clips, there are no known adverse effects with the use of MRI scanners (Ellenberger, 1994).

One disadvantage of the use of MRI is the production of motion artefact as a consequence of even minor subject movement (Hickey et al., 1986). This is especially relevant when imaging the cervical spine due to the inevitable movement that occurs during breathing and swallowing.

Despite these disadvantage, Beattie et al. (1994) was able to successfully assess disc displacement in the lumbar spine using a very similar method to the one proposed in this thesis. With the use of MRI, 20 healthy young women had their lumbar spines scanned while in a flexed (knees and hips bent) and extended (supine with a lumbar roll) posture. The posterior and anterior margins of the nucleus pulposus relative to the posterior and anterior margins of the adjacent vertebral bodies were calculated from mid-sagittal T2-weighted images to determine position change of the NP between the two spinal postures.

1.14 Aims

The overall aim of this thesis was to determine whether McKenzie's conceptual model of vertebral approximation and disc displacement occurs in the IVD's in the cervical spine. It also aimed to assess whether his retraction-extension exercise in sitting causes measurable, acute changes in disc displacement, in an anterior direction, as described in his conceptual model. More specifically, the aims and objectives were:

1. To determine whether, as described in McKenzie's conceptual model, flexion and extension of the cervical spine cause anterior and posterior vertebral body approximation respectively at the C5-C6 to C7-T1 vertebral segments.
    a. Completion of a reliability study assessing intra-rater reliability in the measure of an adapted Cobb angle.
    b. Measure of anterior and posterior adapted Cobb angles at the C5-C6 to C7-T1 vertebral segments in cervical neutral, flexion and extension.
2. To determine whether a change in cervical posture, between neutral, flexion and extension, causes a predictable change in position of the posterior C5-6 and C6-7 NP.
    a. Completion of inter-rater, intra-rater and test-retest reliability in the measure of posterior NP position.
    b. Within participants measure of posterior NP position in three cervical postures.

3. To determine whether McKenzie’s retraction-extension exercise in sitting causes anterior migration of the C5-C6 and C6-C7 NP, according to his conceptual model.
    a. Within participants measure of posterior NP position before and after completion of 10 McKenzie retraction-extension exercises.

Chapter Two

The effects of cervical flexion and extension on position of the anterior and posterior C5-C6 to C7-T1 vertebral segments

Abstract

Introduction. It is often reported in the literature that spinal disc movement occurs through loading of the disc by the vertebral bodies. More specifically, it is thought that flexion of the spine causes approximation of the anterior portions of the vertebral bodies, resulting in loading on the anterior disc, causing its posterior displacement as disc material repositions to an area of lesser resistance. Conversely, it is thought that extension reverses this effect as approximation of the posterior vertebral bodies loads the posterior disc causing anterior disc displacement. Anterior and posterior vertebral approximation and separation has been measured with use of a Cobb angle, described as a measure of the amount of tilt of the edges of the vertebrae. This pattern of vertebral body movement and concomitant disc displacement has been shown to occur in the lumbar spine. There have been no studies assessing the effects of flexion and extension on vertebral movement in the cervical spine. This is a combined study firstly a) assessing intra-rater reliability in the measurement of an adapted Cobb angle of a single vertebral segment, and secondly b) measuring anterior and posterior adapted Cobb angles in a neutral, flexed and extended cervical posture at three cervical levels.

Methods. Intra-rater reliability testing was performed involving measurement of adapted Cobb angles of the C5-C6 vertebral segment, from the sagittal plane MR images of 22 participants. Measurements were taken on two separate days. Bland Altman plots and ICC measurements were used to compare the first and second set of measurements. Following this, experimental testing was performed, involving measurement of the C5-C6, C6-C7 and C7-T1 adapted Cobb angles in a neutral, flexed and extended cervical posture from the images of these same 22 asymptomatic participants. Adapted Cobb angle was determined

by the selection of three points along the vertebral segment. An OsiriX Imaging Software program was used for all measurement testing.

Results. Comparisons between the PI's two repeated measurements taken on the first (24.23° ± 4.00°) and second (24.11° ± 4.18) day showed high reliability (ICC 0.987). Bland Altman plots indicated acceptable levels of repeatability with the 95% limits of agreement ranging from −1.76° to 1.96°. Change in neck postures resulted in significant changes in adapted Cobb angle measurements at the C5-C6 segment only, with a decrease in anterior adapted Cobb angle in flexion compared to neutral (p=0.001) as well as an increase in posterior adapted Cobb angle in flexion compared to neutral (p=0.01). Counterintuitively, there was a significant decrease in the anterior Cobb angle in extension compare to neutral (p = 0.01) at the C7-T1 segment. Spearman's test found no significant correlation between anterior and posterior adapted Cobb angles in any cervical position.

Conclusion. This study assessed the PI's intra-rater reliability in the measurement of vertebral segment adapted Cobb angles, and involved measurement of the anterior and posterior adapted Cobb angles of the C5-C6 to C7-T1 vertebral segments in a neutral, flexed and extended posture. The PI demonstrated very good intra-rater reliability when measuring a single vertebral segment angle using an adapted Cobb angle measure. Adapted Cobb angle measures at the C5-C6 segment appear to support the biomechanical rational that flexion causes approximation of the anterior vertebral segments and separation of the posterior vertebral segments in the cervical spine when compared to neutral.

2.1 Introduction

The dynamic disc model describes discs as moveable structures that respond in a predictable manner to loads applied upon them (McKenzie, 1981). These loads are postulated to come from the edges of the vertebral body segments during movement of the spine. For example, during flexion of the spine, the anterior vertebral segment angle decreases (Parent et al., 2006; Alexander et al., 2007) causing associated approximation of the anterior borders of the vertebral bodies. This flexed angling of the vertebral bodies potentially causes loading on the anterior portion of the disc. In consequence, disc material displaces posteriorly, away from the source of pressure to an area of lesser resistance (Beattie et al., 1994; Callaghan and McGill, 2001; Parent et al., 2006; Kolber and Hanney, 2009). This idea that flexion of the spine causes a reduced anterior vertebral segmental angle, resulting in posterior disc displacement, and conversely extension causing anterior displacement, was described as early as the 1950's by James Cyriax (Cyriax, 1953). Robin McKenzie agreed with this concept and hypothesised that this was the basis by which his specific spinal exercises affect the spinal IVD's (McKenzie, 1981). With the use of sagittal view MR images, this pattern of bony movement, and correspondent disc migration, has been shown to occur in the lumbar spine (Fennell et al., 1996; Alexander et al., 2007).

Cobb angle measurements have often been used to assess the degree of vertebral approximation in flexed and extended spinal postures (Beattie et al., 1994; Parent et al., 2006; Alexander et al., 2007). The Cobb angle was first created as a measurement tool to assess the degree of lateral bend on radiographs in patients with a scoliosis. It is recognised as being the measure of the amount of tilt of the edges of the vertebrae above and below the scoliotic deformity (Morrissy et al., 1990) (see figure 2.1). It has been measured with both an antero-posterior (Morrissy et al., 1990) as well as a sagittal view of the spine (Mac-Thiong et al., 2003).

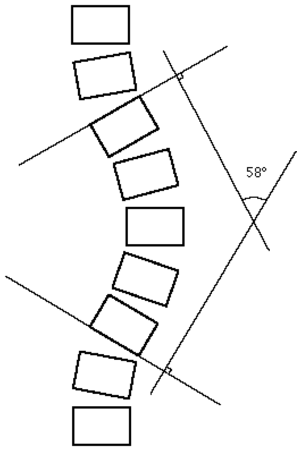


Figure 2.1. Demonstration of a Cobb angle measurement to assess the degree of scoliosis. Figure taken from McNeeley (2015).

Parent et al. (2006) used a Cobb angle measurement to calculate vertebral angles at the L1-2 through to the L5-S1 vertebral segments of 26 healthy male participants between the ages of 24 and 74 years of age (median age of 40 years). They used the angle between the line connecting the corners of the endplates above and below a disc to represent the segmental angle (see figure 2.2). They then correlated these measurements with anterior and posterior disc contours at all five lumbar disc segments in flexed, neutral and extended lying postures.

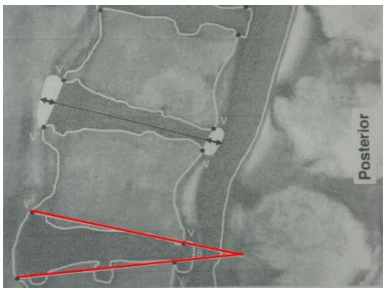


Figure 2.2. Image of an anterior vertebral segmental angle shown in red. Figure taken from Parent et al. (2006).

Flexion of the lumbar spine was achieved with participants in supine with a rounded wedge placed under their sacrum and a larger wedge placed under their posterior thighs. Extension was achieved by placing a lumbar roll under their lumbar spines while a neutral spine was achieved with a long wedge placed under their posterior thighs and calves. Their findings exhibited a smaller ($p < 0.001$) anterior Cobb angle in flexed postures (7.4° ± 3.4°) compared to neutral (9.4° ± 9.6°) and extended postures (12.9° ± 3.7°). These angles support the theory that flexion causes approximation of the anterior corners of the vertebral bodies compared to neutral and extended postures. Further measurements assessed anterior and posterior disc contour abnormality in millimetres with a comparison of disc position between the flexed, neutral and extended postures in lying. Interestingly, their results demonstrated increased anterior disc contour abnormality with lumbar flexion compared to neutral and extension at all five lumbar segments ($p < 0.001$). Results also showed a greater posterior contour distance in a neutral posture compared to a flexed one in lying. These results demonstrate the opposite effect theorized by Cyriax (1953) and McKenzie (1981) with flexion appearing to cause anterior disc migration.

Alexander et al. (2007) found a similar pattern of lumbar movement when using a Cobb angle measurement to assess vertebral position in flexed, neutral and extended spinal postures, however, with significantly larger angles recorded compared to Parent et al. (2006). This is likely to be due to the use of an open MRI scanner by Alexander et al. (2007) with participants in functional, loaded positions such as various forms of sitting and upright standing. The mean Cobb angles recorded for three sitting postures were: 1.6° ± 7.2° in flexion, 21.5° ± 10.1° in upright and 50.2° ± 8.1° in extension. These findings once again support the theory that flexed postures cause approximation of the anterior vertebral borders. It also demonstrates separation of the anterior borders in extended postures.

With regards to disc displacement in relation to vertebral approximation, Alexander et al.'s (2007) results showed greater posterior disc migration with the more flexed postures compared to extended ones at the L3-4, L4-5 and L5-S1 discs. They did not indicate significance level, however, they did report that upright, flexed and extended sitting were associated with greater posterior disc position than prone extension and supine lying. They found that prone extension and supine lying produced larger anterior Cobb angles, 61.4° ± 7.1° and 51.4° ± 6.4° respectively when compared to upright, 21.5° ± 10.1, and flexed, 1.6° ± 7.2, sitting. This further supports the concept that, in healthy IVD's, a more lordotic spinal posture encourages greater anterior disc displacement while a more flexed posture will encourage greater posterior disc displacement. This pattern of vertebral movement and disc displacement supports the initial assertions of Cyriax (1953) and McKenzie (1981) with regards to the effects of flexed and extended spinal postures on position of the vertebral body segments and consequently on position of the spinal disc. The maximum degree of lordosis achieved was in prone extension; this supports McKenzie's use of a prone extension exercise to potentially relocate posteriorly herniated lumbar disc material (McKenzie, 1981; McKenzie and May, 2003).

The contrast between the findings of Alexander et al. (2007) and Parent et al. (2006) with regards to the direction of disc migration may be down to the age of the participants in each of the studies. Alexander et al. (2007) recruited a potentially younger sample with an age range of 18 to 60 years compared to Parent et al. (2006) whose participants' ages ranged from 24 to 74 years. Alexander et al. (2007) did not include a mean age range or SD while Parent et al. (2006) reported a median age range of 40 years. There is the possibility that the level of disc degeneration in this latter study, due to a potentially older sample, was significantly greater, affecting the disc's ability to respond to biomechanical loads in a predictable manner (Lee et al., 2009; Zou et al., 2009). Parent et al. (2006) did not report on the degree of degeneration of the imaged discs in their paper other than the mention that differences in magnitude of posterior disc contour abnormalities between positions was larger in discs exhibiting more severe degenerative changes.

Although research measuring Cobb angles in the cervical spine does exist (Hilibrand et al., 1995; Harrison et al., 2000; Harrison et al., 2004), none have measured movement of the bony segments in different cervical postures. As described in Chapter 1, lumbar and cervical vertebrae are distinctly dissimilar as the cervical spine contains an atlanto-occipital and an atlanto-axial joint, from which approximately 35% of flexion and extension occurs (Bogduk and Mercer, 2000; Knipe et al., 2015). Considering the fact a significant degree of sagittal cervical movement occurs at the two most proximal joints, this may imply that less movement occurs at the lower vertebral bodies and therefore changes in cervical posture may have less of an impact on bony position than has been found in the lumbar spine.

The initial aim of this current study was to assess reliability in measuring vertebral segment movement using an adapted Cobb angle technique, in order to ensure validity of future measurement results. Following this, measurements were taken of the anterior and posterior adapted Cobb angles at the three lowest cervical segments with the cervical spine in a neutral, flexed and extended posture. It was felt that an increased anterior adapted Cobb angle in extension as well as an increased posterior adapted Cobb angle in flexion would support the idea of approximation of vertebral bodies in the cervical spine as described by McKenzie (1981).

2.2 Methods

Participants

Twenty-two asymptomatic participants, including seven males and 15 females, between the ages of 21 and 49 years of age (32.9 years ± 8.7) were recruited for studies 1, 2 and 3 of this programme of studies. All participants were free from any history of neck pain lasting no more than 24 hours in the last 12 months, with no more than once incidence of neck pain in a one month period. All participants were given a patient information sheet (PIS) (see Appendix 4), provided their informed consent (see Appendix 1) and completed an MRI safety questionnaire (see Appendix 2) to ensure there were no health and safety reasons for their exclusion from the studies. This study conformed to the latest revision of the Declaration of Helsinki and the ethics committee at MMU.

Procedure

History taking and a physical examination, commonly used in most NHS MSK out-patient settings, was completed for each participant (see Appendix 3). This was undertaken by the PI who is a Chartered Physiotherapist and Extended Scope Practitioner, holding a Diploma in Mechanical Diagnosis and Therapy, with over 10 years of MSK clinical experience. During history taking, questions were asked regarding any history of neck, shoulder and/ or arm pain. Participants were also asked about any current neck symptoms, as well as any medical history, current medication list, occupation and hobbies. Following this, a physical examination was performed where cervical range of movement (ROM) was assessed in three planes with a visual estimate of range recorded. Visual estimates of joint ROM are common practice in a physiotherapy clinical setting (Somers et al., 1997).

After completion of the physical examination, participants were assisted into a supine position on the MRI scanner. Participants were initially scanned in supine, with a thin mat placed underneath the participant's head for comfort. Following this, scans in cervical flexion and extension were performed (see figure 2.3). The aim was to standardize position between participants as much as possible by using the same size and number of wedges to position the cervical spine; however, each participant's body was different in shape and size, which inevitably affected the degree of flexion and extension achieved. Larger participants found it more difficult to produce as great a degree of flexion due to approximation of their necks and shoulders with the cervical coil. Various wedges were placed under the participants' legs, and in some cases lower back, to reduce discomfort during scanning.

MR imaging protocol

MR scans were performed using an Esaote 0.2 T MR imaging scanner. An initial scout scan was performed lasting approximately 1 minute and 38 seconds. This was followed by a coronal scan lasting approximately 30 seconds. The purpose of these two scans was to ensure imaging of the correct section of the cervical spine. Finally, conventional spin echo sagittal images were obtained using the following settings: T1:TR/TE/Nex: 650 ms/24 ms/ 3; slice thickness 4 mm, 0.4 mm spacing, FOV 260 x 260, image matrix 256 x 256, 75% phase field of view. This final scan lasted approximately 6 minutes and 30 seconds and provided the images from which measurements were taken. The MR imaging protocol remained unchanged throughout this thesis. A number of MR images from the same participants were used for studies 1, 2 and 3 of this programme of studies. An Osirix imaging software program was used for all measurements taken throughout this programme of studies.

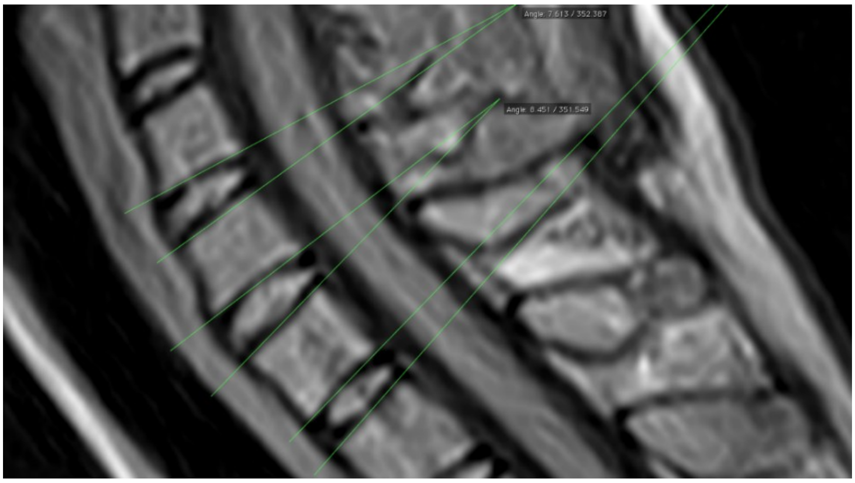
A B C

Figure 2.3. Participants positioned in supine with their cervical spines placed in neutral (A), flexion (B) and extension (C) on the MRI scanner.

Adapted Cobb angle measurements

Vertebral distance was measured using a similar technique to that of Parent et al. (2006), however, rather than use the entire length of the vertebral end plates to create an angular measurement, the corners of the end plates were used, connecting to a line at the mid-point between the opposite end of the segment. This is because, when using the same technique as demonstrated by Parent et al. (2006) to produce Cobb angles in the cervical spine, significantly acute angles were produced. This meant that, anatomically, in order to produce the complete angle, the measurement extended outside the MR image of the cervical spine (see figure 2.4). It was felt this would reduce repeatability of measures due to the length of the angle. This also did not allow for a sufficient level of magnification of the image to ensure the same anatomical starting points were used for each measure. It was decided that the next best alternative was to choose a specific, measurable end point, and this was chosen as the mid-point between the inferior vertebral end plate above and the superior vertebral end plate below the segment in question (see figure 2.5). The posterior vertebral segments were measured for the purposes of reliability testing (see figure 2.6).

The same measurement technique was use for both reliability and experimental testing. Reliability testing measured segment position at the C5-C6 vertebral segment in a neutral position only, while experimental testing measured vertebral segment position at the C5-C6 to C7-T1 vertebral segments in a neutral, flexed and extended posture.



A

B

Figure 2.4. Magnified (A) and full view (B) Cobb angles of the C5-C6 to C7-T1 segments in extension.

Figure 2.5. Adapted anterior Cobb angle measure of the C5-C6 to C7-T1 segments in extension.

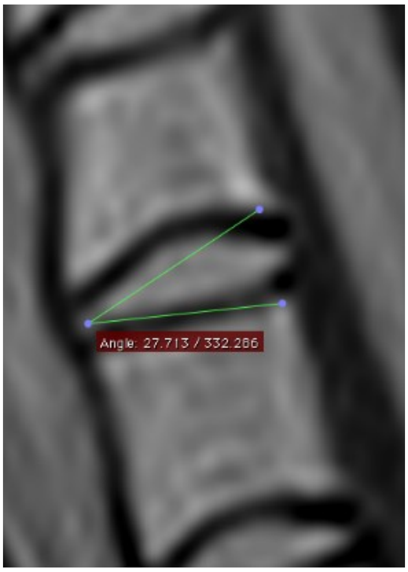


Figure 2.6. Adapted posterior Cobb angle measure of the C6-C7 segment in flexion.

Throughout measurement testing, the PI was blinded to participants' MR scans. This involved removal of participant's names from the data sheet, with only a seven digit ID reference number visible during data collection. A simple randomisation technique was used for selection of images for measurement (Suresh, 2011). This involved writing each participant's identifying 7 digit code on a piece of paper that was then folded several times and placed in a hat. The papers were then selected at random, without visually inspecting the hat during selection. This process of blinding and randomisation was repeated for all image selection throughout this thesis. For reliability testing, measurements of the C5-C6 vertebral segment were taken, on two separate days. For experimental testing, each angle was measured three times, in each position, with the mean taken as the final measurement in order to reduce the chance of erroneous outliers.

Statistical analysis

a) Intra-rater reliability testing

An ICC is helpful in determining whether a correlation exists between two sets of measurements (Bland and Altman, 1986). An ICC was used to determine whether there were any significant differences between the two sets of reliability measurements. Bland Altman plots help to demonstrate the level of agreement between measurements and serves as an advantage over an ICC alone. This is because correlation does not necessarily infer agreement of the data points. Therefore Bland Altman plots were used to show the level of agreement between the first and second set of measurements taken. The measurements represent the angular distance between the two vertebral end plates of the C5-C6 vertebral segment. With reference to the Bland Altman plots, the mean of the first and second set of measurements is represented by the x axis and the difference between the two sets of angular measurements is represented by the y axis. The mean of these combined values is represented by the horizontal, continuous line and the 95% limits of agreement (LoA) are represented by two horizontal dashed lines. A combination of both Bland Altman plots and ICC are deemed appropriate for analysis of intra-rater reliability (Rankin and Stokes, 1998).

b) Adapted Cobb angle measurements in a neutral, flexed and extended cervical posture.

As there was no information on the likely effect size in the literature, a *post hoc* power analysis was carried out on the initial results of the current study. This was conducted using Minitab (Minitab, 2010) to determine the sample size required to produce a power of 0.80

with an alpha of 0.05. These initial results produced a mean paired difference of 3.3 with a SD of 3.9. This gave a required sample size of 28 participants. Unfortunately, due to technical difficulties with the MRI scanner, no new participants could not be recruited and therefore the final sample size for this current study was 22, producing a power of 0.70.

A one-way repeated measures ANOVA was conducted between neutral, flexion and extension, at each cervical segment, to determine whether there were significant differences in adapted Cobb angle measurements in the three cervical postures. *Post hoc* analysis was completed using a Bonferroni adjustment. Shapiro Wilk's test indicated the data to be normally distributed at all vertebral levels and in all cervical positions. There were no significant outliers in the data as demonstrated by inspection of boxplot. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated for the data at any of the cervical segments.

As the data was deemed monotonic, as inspected by scatter plots, the Spearman's correlation coefficient was calculated to assess the relationship between the anterior and posterior adapted Cobb angles of the 22 participants, at all three cervical segments. Data are presented as means ± standard deviation (SD) and statistical significance was set at $p \leq 0.05$.

2.3 Results

a) Intra-rater reliability testing

The ICC results showed a strong correlation between the first and second set of measurements (see table 2.1).

	1st Cobb angle measurement	2nd Cobb angle measurement	ICC
C5-C6 segment	24.23° ± 4.00°	24.11° ± 4.18°	0.987

Table 2.1 Repeatability data for adapted Cobb angle measurements at the C5-C6 segment in a neutral position (n = 22).

Bland Altman plots show that the 95% LoA between the two measurements at the C5-C6 vertebral segment ranged from −1.76° to 1.96° (see figure 2.7). All differences were less than 3° in magnitude, with 18 of the 22 points having a difference of less than 1° (4.1% of the average mean). This was considered to represent an acceptable level of repeatability. In comparison, when measuring the L1-L2 to L5-S1 vertebral segments in supine, Parent et al. (2006) found a mean angle difference of 2.38° ± 0.59° between neutral and flexion and a mean angle difference of 3.12° ± 1.3° between neutral and extension.

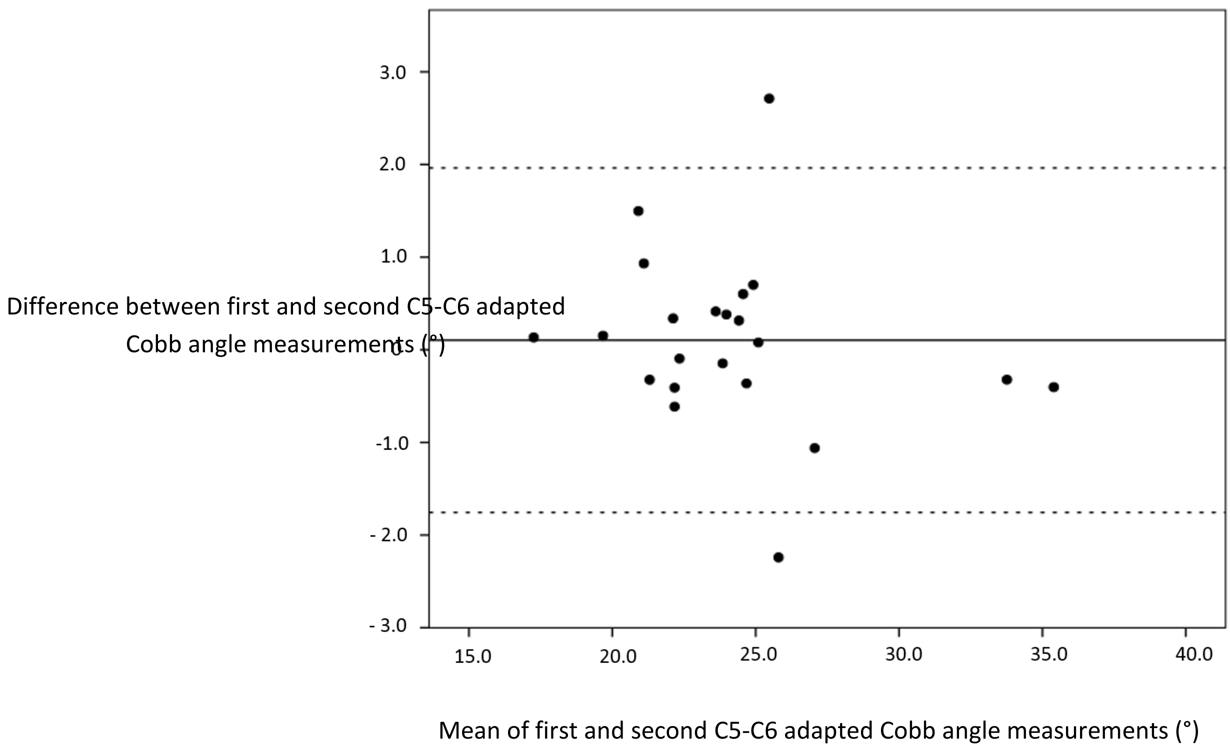


Figure 2.7. Bland Altman plot of the differences between the two measurements and the mean values.

b) Adapted Cobb angle measurements in a neutral, flexed and extended cervical posture.

At the C5-C6 segment, anterior adapted Cobb angle measurement results demonstrated a significant difference when comparing cervical postures in neutral, flexion and extension, $F(2, 44) = 8.822$, $p = 0.001$. *Post hoc* analysis revealed a significant decrease in the anterior adapted Cobb angle in cervical flexion compared to neutral ($p = 0.001$). Posterior adapted Cobb angle measurement results also demonstrated a significant difference in angle between the three postures, $F(2, 46) = 4.985$, $p = 0.01$. *Post hoc* analysis showed a significant increase in adapted Cobb angle in flexion compared to neutral ($p = 0.01$).

At the C6-C7 segment, anterior adapted Cobb angle measurements demonstrated no significant difference when comparing neutral, flexed and extended postures. Posterior adapted Cobb angle measurement results demonstrated a significant difference in angle between the three postures, $F(2, 46) = 3.301$, $p = 0.05$. However, *post hoc* analysis showed no significant change between the postures.

At the C7-T1 vertebral segments, anterior adapted Cobb angle measurements demonstrated a significant difference between the three postures, $F(2, 44) = 11.951$, $p < 0.001$). Counterintuitively, *post hoc* analysis showed that the only significant difference was a decrease in the anterior adapted Cobb angle in extension compared to neutral ($p = 0.001$). Posterior Cobb angle measurements showed no significant difference between postures.

Anterior adapted Cobb angle measurement data, at each vertebral segment, in all three cervical postures are denoted in table 2.2 Posterior measurement data is provided in table 2.3. Anterior and posterior adapted Cobb angles in flexion and extension, compared to neutral, are denoted in figure 2.8. Mean neck angulations achieved in neutral, flexion and extension are denoted in table 2.4.

Vertebral segment	Cervical position	Anterior adapted Cobb angle (°)	Difference from neutral (°)
C5 – C6	Neutral	25.2 ± 3.5	N vs F = -2.5 *; N vs E = 0.2
	Flexion	22.7 ± 4.4	
	Extension	25.4 ± 4.5	
C6 – C7	Neutral	25.6 ± 4.6	N vs F = - 0.8; N vs E = - 1.8
	Flexion	24.8 ± 4.9	
	Extension	23.8 ± 4.3	
C7 – T1	Neutral	24.6 ± 4.6	N vs F = - 1.1; N vs E = - 3.1 *
	Flexion	23.5 ± 4.2	
	Extension	21.5 ± 3.1	

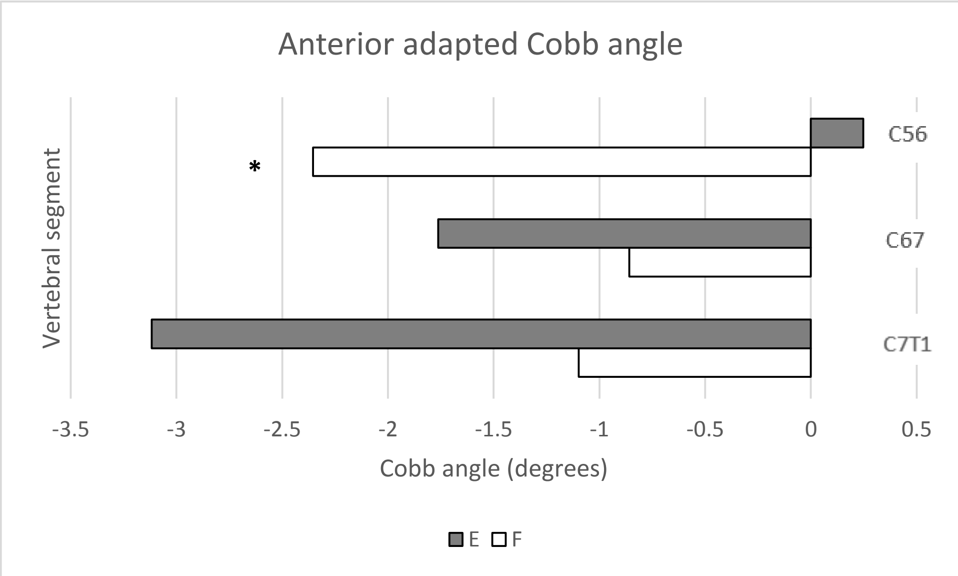
Table 2.2. Anterior adapted Cobb angle measurement data. * indicates a significant difference in position from neutral ($p < 0.05$). N = neutral; F = flexion; E = extension. (-) indicates that angle of the second position was less than that of the first.

Vertebral segment	Cervical position	Posterior adapted Cobb angle (°)	Difference from neutral (°)
C5 – C6	Neutral	22.7 ± 5.2	N vs F = 2.7 * N vs E = 0.7
	Flexion	25.4 ± 4.4	
	Extension	23.4 ± 5.1	
C6 – C7	Neutral	20.8 ± 4.1	N vs F = 2.3 ; N vs E = 1.1
	Flexion	23.1 ± 4.2	
	Extension	21.9 ± 5.3	
C7 – T1	Neutral	20.5 ± 3.9	N vs F = 1.1; N vs E = 1.1
	Flexion	21.6 ± 2.8	
	Extension	21.6 ± 4.5	

Table 2.3. Posterior adapted Cobb angle measurement data. * indicates a significant difference in position from neutral ($p < 0.05$). N = neutral; F = flexion; E = extension.

Cervical position	Cervical angulation (°)
Neutral	72.7 ± 5.2
Flexion	82.1 ± 3.3
Extension	75.5 ± 4.5

Table 2.4. Cervical angle achieved in each supine posture. Angle measured from the T1-T2 disc to the centre of the C2 vertebral body.



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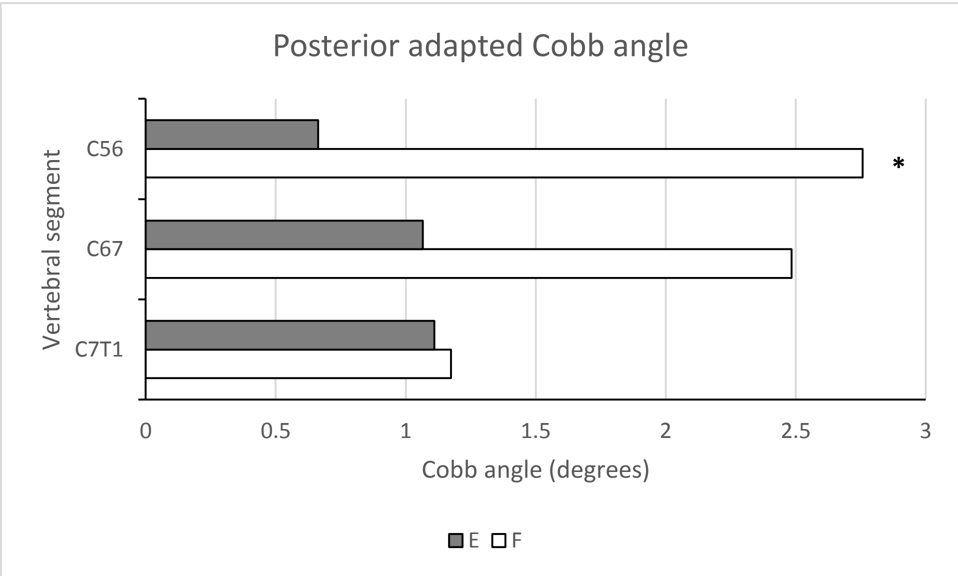

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Figure 2.8. Anterior (A) and posterior (B) adapted Cobb angle measurement data compared to neutral. * indicates a significant difference in position from neutral ($p < 0.05$). F = flexion; E = extension.

There was no significant correlation found between anterior and posterior adapted Cobb angles at any segmental level. However, visually it appears that in a flexed posture, as the anterior Cobb angle decreases, the posterior Cobb angle increases when compared to neutral.

2.4 Discussion

The results of the two repeated Cobb angle measurements of the C5-C6 vertebral segments in neutral, taken from the same image on two separate days, showed very good reliability. The mean difference between measurements was only 0.12°. The ICC results indicated high reliability and the Bland Altman plots indicated acceptable levels of repeatability. Unfortunately ICC results were not recorded by either Parent et al. (2006) or Alexander et al. (2007) for comparison.

Cervical angulation measurements demonstrate a 9.4° difference between the neutral and flexed cervical posture. Because the participants were unable to extend their heads beyond the scanner bed itself, this affected the degree of angulation achieved in cervical extension.

In McKenzie's Mechanical Diagnosis and Therapy teachings, he explains that cervical flexion causes approximation of the anterior edges of the vertebral bodies (McKenzie and May, 2006) which would presumably lead to separation of the posterior vertebral bodies. Results of this current study appear to agree with this description as there was a reduced anterior, as well as an increased posterior adapted Cobb angle in flexion compared to neutral at the C5-C6 segment. Although there was suggestion of a similar pattern of movement at both the anterior and posterior adapted Cobb angles at the C6-C7 and C7-T1 segments, the change in vertebral angle was not deemed significant.

Movement of the spine into extension produced much less consistent results. Anterior and posterior adapted Cobb angle measurements in extension compared to neutral showed no significant difference in position at the C5-C6 or C6-C7 vertebral segments. There was also no difference in posterior adapted Cobb angle at the C7-T1 segment. This result may be partly explained by the biomechanics of the cervical spine with a significant percentage of flexion and extension occurring at the atlanto-occiptal and atlanto-axial joints (see Chapter 1). When observing the sagittal MR images in full view, rather than at a magnified segmental level, it is apparent that most of the extension occurs at the C1-C2 to C4-C5 vertebral segments (see figure 2.9).

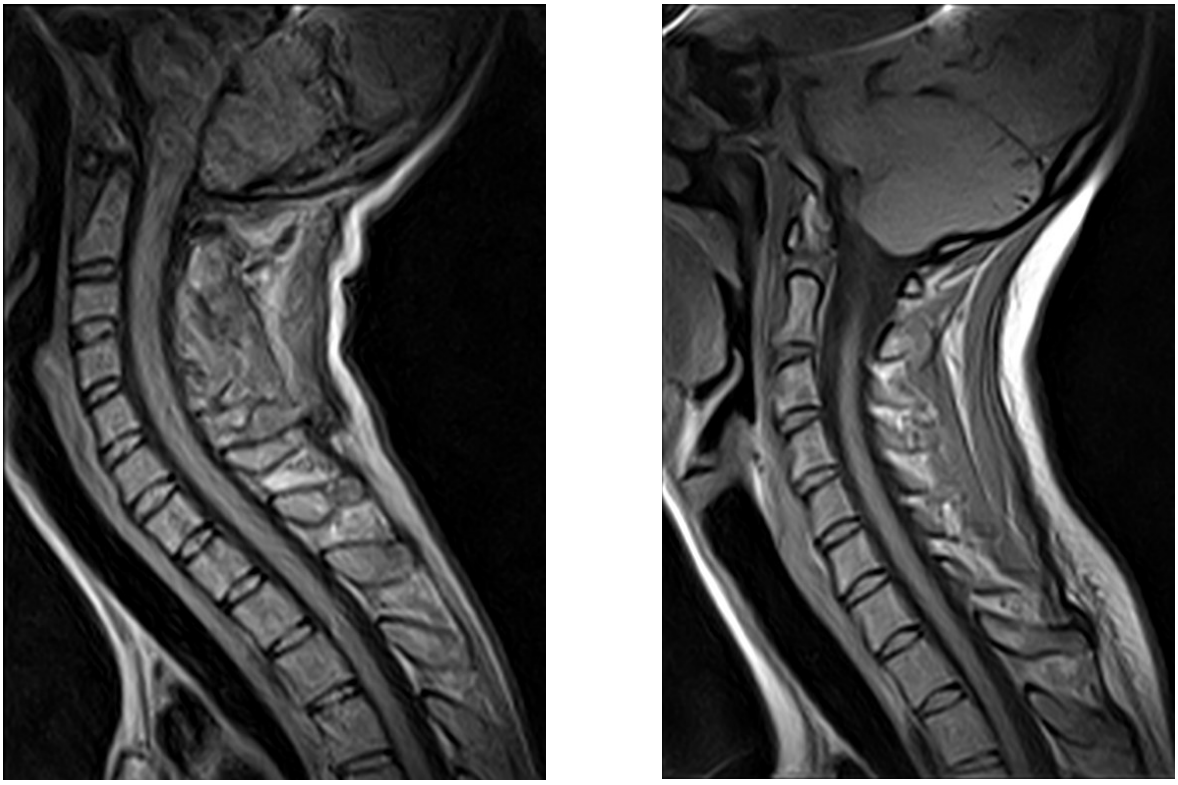


Figure 2.9. Sagittal MR images of the cervical spines of two participants in extension, indicating the greatest degree of extension occurring at the more proximal vertebral segments.

As well as the potential role of cervical biomechanics, lower cervical extension was also likely to have been affected by participant position on the scanner bed. As described previously, both the cervical coil as well as the scanner bed itself, limited the degree of lower cervical extension that was physically achievable. Unlike the results of this current study, and more in keeping with McKenzie's (1981) theory, an *in vitro* study by Inufusa et al. (1996), assessing lumbar vertebral movement, found that anterior vertebral distance increased with extension when compared to neutral at every lumbar vertebral segment, with a mean increase of 1 mm. This is likely to be due to a greater range of extension achieved with use of a loading frame.

Curiously, this current study suggested a significant reduction in anterior Cobb angle in extension compared to neutral at the C7-T1 segment. Interestingly, Inufusa et al. (1996) also reported counterintuitive findings with an increase in anterior vertebral distance of 0.87 mm in flexion compared to neutral at the L3-L4 and L5-S1 motion segments. There was no explanation as to the possible cause for this. There is the potential that, in terms of this current study, the reduced anterior adapted Cobb angle in extension was due to positioning of the wedge under the participants cervical spines, as it may have inadvertently caused a downward tilt of the lower cervical segments.

Other studies examining the effects of cervical flexion and extension on the spine have focused almost solely on measurements around the spinal canal in order to assess for stenotic changes (Penning and Wilmink, 1981; Wilmink et al., 1984; Schönström et al., 1989; Morishita et al., 2009). Although Morishita et al. (2009) did record measurements along the anterior vertebral bodies during flexion and extension of the cervical spine, the distance between these points was not recorded, with their discussion focused on the impact of cervical movement on spinal canal dimensions.

5.5 Conclusion

Very good reliability was demonstrated when measuring Cobb angles of the C5-C6 vertebral segments with a sagittal view MRI image of the cervical spine in neutral. Mean measurements, ICCs and Bland Altman plots all demonstrated very good agreement between the first and second set of measurements taken from the same image on two separate days. These combined results indicate very good reliability when measuring vertebral body position in the cervical spine using an adapted Cobb angle technique.

In terms of postural measurement, results at the C5-C6 segment indicate that, as McKenzie and May (2006) suggested, there appears to be evidence of approximation of the anterior vertebral bodies in flexion compared to neutral. Conversely, flexion appeared to cause separation of the posterior vertebral body ends compared to neutral.

There was no significant change in vertebral body position in extension of the spine when compared to neutral and this was probably due to the limited extension achieved.

Limitations

There was an initial attempt to perform the scans for this study, as well as study 3, in an upright sitting position; however this resulted in very poor image quality. Although the scans performed in supine allowed for more accurate data measurement, from a clinical viewpoint, supine lying does not represent the sustained sitting and standing postures adopted by most people during occupational and leisure activities.

Chapter Three

Inter-rater, intra-rater and test-retest reliability testing of posterior NP position at the C5-6 and C6-7 disc levels

Abstract

Introduction. Inter-rater and intra-rater reliability testing was performed to assess the PI's ability to measure the posterior C5-6 and C6-7 nucleus pulposus on sagittal view MR images with the cervical spine in a neutral position. The ability to reliably measure disc position is a crucial factor in subsequent studies aiming to measure potential changes in posterior disc position with the cervical spine in various positions and after performance of specific exercises.

Methods. Both the PI and a consultant head and neck radiologist separately recorded the position of the C5-6 and C6-7 posterior nucleus pulposus on the cervical MR images of 15 asymptomatic participants. The PI also recorded the position of the posterior C5-6 and C6-7 discs from the same images on two separate days in order to assess intra-rater reliability. In addition, test-retest reliability was completed with another group of 13 participants who were scanned on two occasions, approximately two weeks apart. Measurements from the separate scans were then compared. All scans were completed with the cervical spine placed in a neutral position. Both the PI and radiologist were blinded to the measurements until all measurement testing had been completed by both testers. The position of the mid-posterior section of the disc nucleus was measured relative to a line connecting the mid-section of the posterior end of the vertebral bodies superior and inferior to the disc.

Results. There were no statistically significant differences found between measurements at the C5-6 and C6-7 disc levels for the inter-rater, intra-rater and test-retest reliability studies. Combined ICC results between the two levels showed high agreement for the inter-rater ($p = 0.85$) and intra-rater testing ($p = 0.93$). The test-retest results showed moderate agreement ($p = 0.74$). Bland Altman plots showed good agreement between measurements

for the inter-rater and intra-rater reliability measurements. In the majority of cases, the distance between measurements was less than 0.5 mm in magnitude. The test-retest results were less favourable with a mean distance between measurements of approximately 4.2 mm in magnitude, as well as one outlier located approximately 8.0 mm from the mean.

Conclusion. There was high agreement demonstrated for the inter- and intra-rater testing, allowing for greater confidence when extrapolating results for the second and third studies assessing the effects of cervical position and neck exercises on disc position. The test-retest ICC results and Bland Altman figures suggest caution when investigating the feasibility of performing sub-acute or long term studies assessing disc migration.

3.1 Introduction

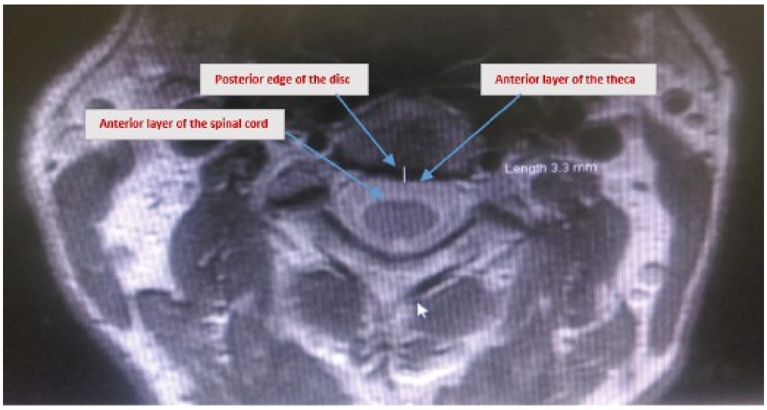
Research assessing spinal disc migration has involved various techniques to ensure appropriate and reliable measurements. Fennell et al. (1996) measured disc migration from print outs of MR images of the lumbar spine. They used tracings from the midline sagittal slice of the same vertebral segments in neutral, flexion and extension of the spine. To ensure reliable measurement, the selection of the image corresponding to the sagittal midline was repeated on six different days for each participant in the three positions. They did not specify any reliability testing, however, to confirm this repetition produced repeatable measurements. Alexander et al. (2007) measured disc displacement on MR images by locating the centre of the NP, identified as the area within the disc with peak pixel intensity, and measuring from this point to the anterior disc boundary. Scans were taken of the participants in slouched sitting, upright sitting, standing and in prone extension. The intra-rater reliability of locating the NP centre was assessed by measuring each mid-sagittal scan blind, for each participant, at all five spinal levels and in each position on three occasions. Results indicated moderate to high levels of intra-rater reliability with an ICC for each position ranging from 0.71 to 0.97 (0.89 ± 0.06). Both of these studies used one tester for all disc measurements with a consultant radiologist performing the measurements in the latter study.

Parent et al. (2006) also used MR imaging to measure disc migration with the lumbar spine in a neutral, flexed and extended position. The contours of the posterior longitudinal ligament, vertebral bodies and posterior disc annulus provided the points of interest from which the measurements were derived. Disc contour was measured using the vertebral corners above and below the disc of interest. The median intra-rater reliability coefficients for contour measurements were 0.84 for the anterior and 0.91 for the posterior disc. No specific details were provided as to the methodology used for reliability testing.

This current study performed reliability testing in the form of inter-rater, intra- rater and test-retest analyses. The aim was to assess the PI's ability to accurately measure posterior NP position on MR imaging and to assess any variation in measurements taken on repeated scans. Measurements were taken of the posterior section of the C5-6 and C6-7 NP with the cervical spine in a neutral position (see study 1). PI measurements for the inter-rater testing were compared with that of a consultant head and neck radiologist.

Axial spinal canal dimension measurements

In order to determine whether the potential degree of posterior NP migration recorded in studies 2, 3 and 4 were of clinical significance, the spinal canal dimensions from 25 anonymised MR images were selected at random from an open diagnostic imaging database (see study 1 for process of randomisation). Age range was 29 to 83 years of age (43 years ± 15.3), and included 11 women and 14 men. The distance between the posterior edge of the C5-6 disc to the anterior edge of the theca (outer layer of the spinal cord) as well as the spinal cord was measured using a Pukka-J imaging software program (see figure 3.1). Images were obtained from out-patient attendees complaining of cervical pain at a private MSK clinical assessment and treatment service. The distance from the posterior C5-6 disc to the anterior edge of the theca measured as 1.72 mm (SD ± 1.2). The maximum distance was measured as 4.3 mm while the minimum distance was measured as 0 mm as four images demonstrated contact with the theca by the posterior disc. The distance from the posterior disc to the spinal cord measured 4.59 mm (SD ± 1.69 mm) with a minimum distance of 1.8 mm and a maximum distance of 7.3 mm. There was no spinal cord compression noted on any of the scans.



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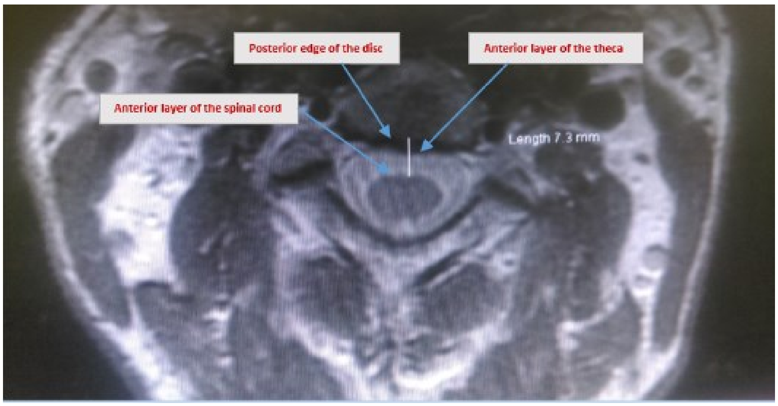

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Figure 3.1. Measurements taken from the posterior aspect of the C5-6 NP to the anterior aspect of the theca (A) and to the anterior aspect of the spinal cord (B).

These measurements indicate that disc movement as small as 0.1 mm may be enough to reduce neural pressure if the disc is already contacting a neural structure. However, 1 mm of anterior migration would allow the disc to increase its distance from the theca by approximately 58% and from the spinal cord by 22%. Two millimetres of movement would allow the disc to increase its distance from the theca by 116% and from the spinal cord by

44%. Conversely, posterior migration of the disc by 2 mm would be sufficient to cause contact with the theca in 36% of the images. The measurements taken from these cervical MR images indicate that a change in disc position of 1 mm could potentially make a clinical impact should the patient be presenting with symptomatic thecal compression.

2.2 Methods

Participants

Participants for all reliability testing were asymptomatic, having been free from any history of neck pain lasting more than 24 hours in the last 12 months with no more than one incidence of neck pain in a one month period. All participants were recruited by University email.

A total of 15 asymptomatic participants were recruited for the inter-rater and intra-rater reliability testing. This included seven males and eight females between 21 and 50 years of age (33.7 years ± 9.2). Of these, nine also provided the images used for the adapted Cobb angle measures recorded in study 1. A further 13 asymptomatic participants recruited by University email were used for the test-retest reliability study. This included nine females and four males between the ages of 25 and 49 years (35.9 years ± 7.7). Of these participants, eight also provided images used for adapted Cobb angle measurements in study 2.

An age group of 19 to 55 was chosen for this thesis. Although there may be evidence of fibrotic changes in the discs within this age range, there should not be a significant degree of degeneration. The demographic most likely to show significant degenerative changes in the cervical disc appears to be between 60 and 65 years of age and over (Lawrence, 1969;

Teresi et al., 1987). Nineteen was chosen as a starting age range as fibrotic changes have been shown to occur as early as the mid-teens (Oda et al., 1988) with children maintaining a gelatinous NP (Mercer and Bogduk, 1999).

All participants were given a PIS, provided their informed consent and completed an MRI safety questionnaire to ensure there were no health and safety reasons for their exclusion from the studies. This study conformed to the latest revision of the Declaration of Helsinki and the ethics committee at MMU.

Procedure

Inter-rater and intra-rater reliability

The procedure followed for reliability testing was identical to that followed in study 1, therefore a detailed description will not be repeated here.

Scans were completed with the participant's cervical spines firstly placed in a neutral, followed by a flexed and finally an extended position. Positioning of the participants cervical spine while on the scanner bed, and the MR imaging protocols were identical to those described in study 1. Images taken in flexion and extension were used for study 3, assessing the effects of cervical posture on disc displacement. The PI was blinded to all images, with images selected at random (see study 1).

Test-retest reliability

The procedure followed was the same as that for the inter-rater and intra-rater reliability studies with the only difference being the completion of a second scan for each participant completed on a second visit approximately two weeks apart. Whenever possible, participants were booked in for their follow up scan at the same time of day as their initial scan in order to reduce the impact of diurnal variation on disc hydration (Healey et al., 2008). The aim was to assess whether good agreement could be achieved in disc position between the first and second set of scans of the same individual. This would help ensure any change in disc position recorded in a sub-acute follow up study were due to the applied intervention rather than external variability such as participant positioning, equipment error or uncontrollable physiological effects.

Disc measurement

Inter-rater and intra-rater reliability

The C5-6 and C6-7 disc nucleus for each participant was measured, in a neutral cervical position, by both the PI and a consultant head and neck radiologist. The testers performed their measurements on separate days with neither tester having access to the other's measurements at any point until all measurements had been completed. The same images were used for both the inter-rater and intra-rater reliability study, with repeated measurements taken by the PI for test-retest measurements, after a two week lag. While taking the second set of measurements, the PI was once again blinded to the images with scans selected at random (see study 1). The C5-6 and C6-7 disc levels were chosen for measurements as spondylosis of IVD's occur most severely and frequently at lower cervical levels, with a higher incidence of disc degeneration and disc prolapse at the C5-7 disc levels (Matsumoto et al., 1998). The disc nucleus was identified by peak MRI signal intensity (Edmondston et al., 2000; Alexander et al., 2007). Measurements were taken from the mid-sagittal slice, located by visualising the entire length of the C2 vertebral body (see figure 3.2). In cases where the shape of the C2 body was similar between two slices, the slice demonstrating the greatest width of the upper spinal cord was used.

A B C

Figure 3.2. Three consecutive mid-sagittal slices of the cervical spine (A), (B) and (C). Slice (B) demonstrates the entire length of the C2 vertebral body (outlined in red). This identifies the mid-sagittal slice, and therefore the slice to be used for measurement.

The position of the mid-posterior section of the disc NP was measured relative to a line connecting the mid-section of the posterior ends of the vertebral bodies superior and inferior to the disc (see figure 3.3). If the mid-posterior section of the NP fell posterior to this line, the measurement was recorded as a positive number. If it fell anterior to this line, the measurement was recorded as a negative. If the posterior NP fell exactly on the line, the measurement was recorded as zero millimetres.

Figure 3.3. MR image of the cervical spine in a neutral position. The near horizontal line on the left of the image merely indicates the C6-7 disc level. The near vertical line connects the mid-section of the vertebral body above and below the C6-7 disc. The short, near horizontal line represents the distance from the posterior NP to the posterior vertebral bodies. The box in red reads a measurement of 0.185 cm distance between these two points.

Test-retest reliability

Test-retest reliability disc measurements were obtained in an identical manner to that described in the inter-rater and intra-rater reliability studies. To reduce the chance of a single measurement error skewing the results, each disc was measured three consecutive times with the mean value used in the data analysis.

Statistical analysis

Inter-rater and intra-rater reliability

Six images were unusable due to poor image quality caused by the cervical coil, which resulted in a reduction of three comparison measurements for the inter-rater and intra-rater reliability studies. This left a total of 13 participants for the C5-6 disc measurements. Histograms and Shapiro-Wilk Tests of normality showed that the measurements for the inter-rater reliability study taken by both the PI ($p = 0.16$) and consultant ($p = 0.49$) were normally distributed. The second set of C5-6 disc measures taken by the PI for the intra-rater reliability study were also normally distributed ($p = 0.49$). However, the second set of C6-7 disc measures taken by the PI were deemed not normally distributed ($p = 0.02$). There were no significant outliers as assessed through visual inspection of box plots.

Two tailed paired samples t-tests were used to compare the mean responses of the two raters, and the mean between the first and second set of C5-6 disc measurements for the intra-rater testing. The Related - Samples Wilcoxon Signed Rank Test was performed for the intra-rater testing at the C6-7 disc level. ICC results were used to determine whether paired measurements showed a strong correlation while Bland Altman plots were used to show agreement between the measurements taken. A combination of both Bland Altman plots and an ICC are deemed appropriate for analysis of inter- and intra-rater reliability (Rankin and Stokes, 1998).

Test-retest reliability

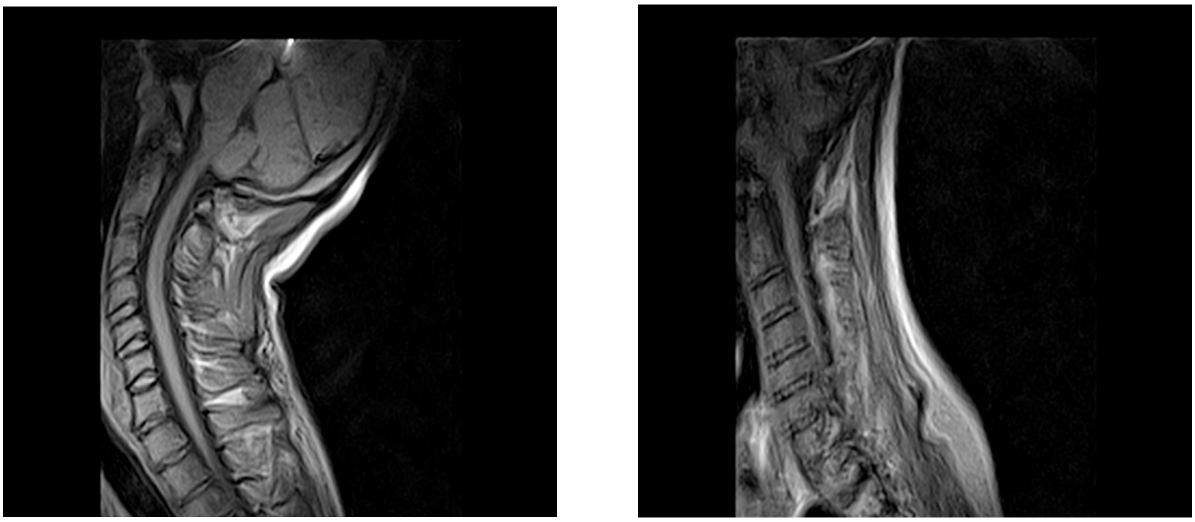
One image was unusable due to poor image quality caused by the cervical coil which resulted in a reduction of one disc comparisons at the C6-7 disc level. Shapiro-Wilk tests of normality showed that the second set of C5-6 disc measurements (p = 0.04), and the first and second set of C6-7 disc measurements (p = 0.01) were not normally distributed.

The Related-Samples Wilcoxon Signed Rank Test was used to determine whether there were any statistically significant differences in the measurements taken of the posterior C5-6 and C6-7 disc nucleus on two separate days. ICC results and Bland Altman plots were again used to show reliability and agreement between the PI's measurements of posterior disc position at two cervical levels from two separate images taken of the same participant.

Inter-rater, intra-rater and test-retest reliability

For the Bland Altman plots, the mean of the two sets of measurements for each disc is represented by the x axis and the differences between the two sets of measurements at each disc is represented by the y axis. The mean of the differences is represented by a horizontal dashed line and the 95% limits of agreement (LoA) are represented by the solid lines. Agreement was a subjective determination according to position of the mean disc measurements as well as position of the values in relation to each other and to the upper and lower LoA. ICC results were used to determine the strength of the relationship between the two measurements.

A *post hoc* power analysis conducted using Minitab (Minitab, 2010) demonstrated that a sample size of 34 was required to produce a power of 0.80 with an alpha of 0.05. Intra-rater reliability measurements at the C5-6 disc and inter-rater reliability measurements at the C6-7 disc produced a combined mean difference of 0.2 with a standard deviation of the paired difference of 0.04. Further *post hoc* analysis calculated a power of 0.4 with a sample size of 15. Unfortunately, due to regular, intermittent failure of the cervical coil to produce a readable image, no further participants could be recruited within the time frame required to complete the reliability testing. Figure 3.4 demonstrates both a moderately and a significantly degraded image produced by the cervical coil.



A **B**

Figure 3.4. Sagittal MR images of the cervical spines of two participants. Figure A, taken in extension, produced a moderately degraded image. Figure B, taken in flexion, produced a significantly degraded image.

Data are presented as means and ± SD and statistical significance was set at $p \leq 0.05$.

2.3 Results

<u>Inter-rater reliability</u>

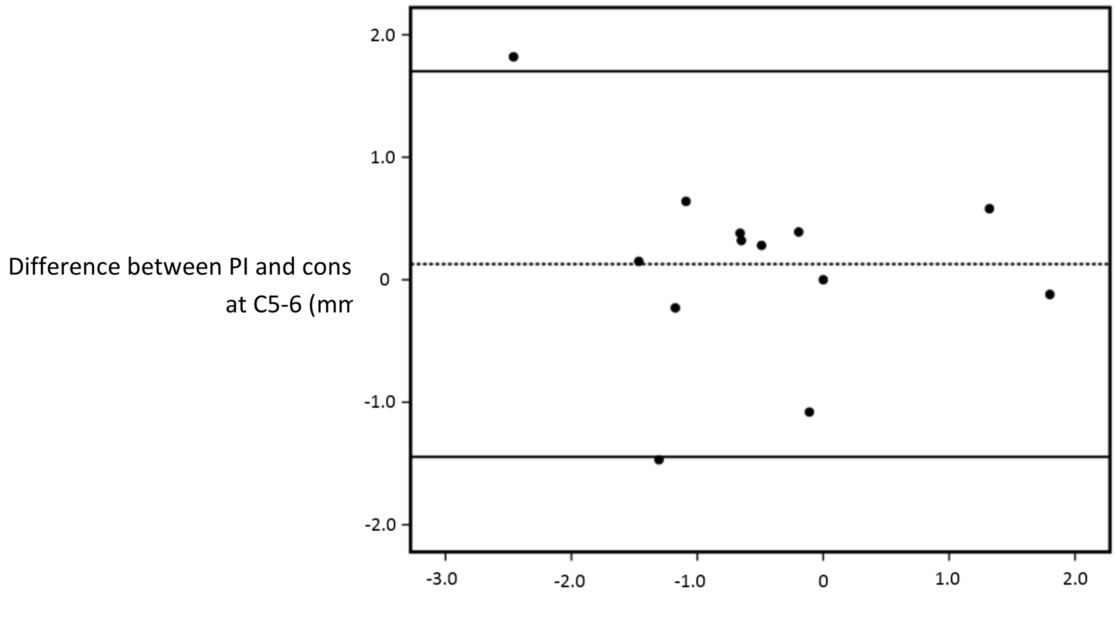
There were no statistically significant differences found between the PI's measurements and those of the consultant's at the C5-6 and C6-7 disc levels ($p = 0.35$). ICC results showed a strong correlation between the PI and the consultant radiologist with a mean value of 0.84 (see table 3.1).

At the C5-6 disc, Bland Altman plots show that the 95% LoA between the two measurements ranged from -1.5 mm to 1.7 mm (see figure 3.4). All differences were less than 2 mm in magnitude, with 10 of the 13 measurements having a difference of less than 0.5 mm. There was a mean difference between measurements of 0.13 mm.

At the C6-7 disc, Bland Altman plots show that the 95% LoA between the two measurements ranged from - 1.12 mm to 0.70 mm (see figure 3.4). All differences were less than 1.3 mm in magnitude, with 10 of the 14 measurements having a difference of less than 0.5 mm. There was a mean difference between measurements of - 0.21 mm.

Disc level	No. of images compared	Tester	Posterior disc nucleus position in relation to the posterior vertebral bodies	Mean difference	P value	ICC
C5-6	13	PI	-0.43 ± 0.11	0.13	0.58	0.79 95% CI (0.44 - 0.93)
		Consultant radiologist	-0.56 ± 0.13			
C6-7	14	PI	-1.08 ± 0.11	-0.21	0.11	0.90 95% CI (0.72 – 0.97)
		Consultant radiologist	-0.87 ± 0.11			

Table 3.1 Frequencies for consultant and PI posterior NP measurements at the C5-6 and C6-7 disc levels.



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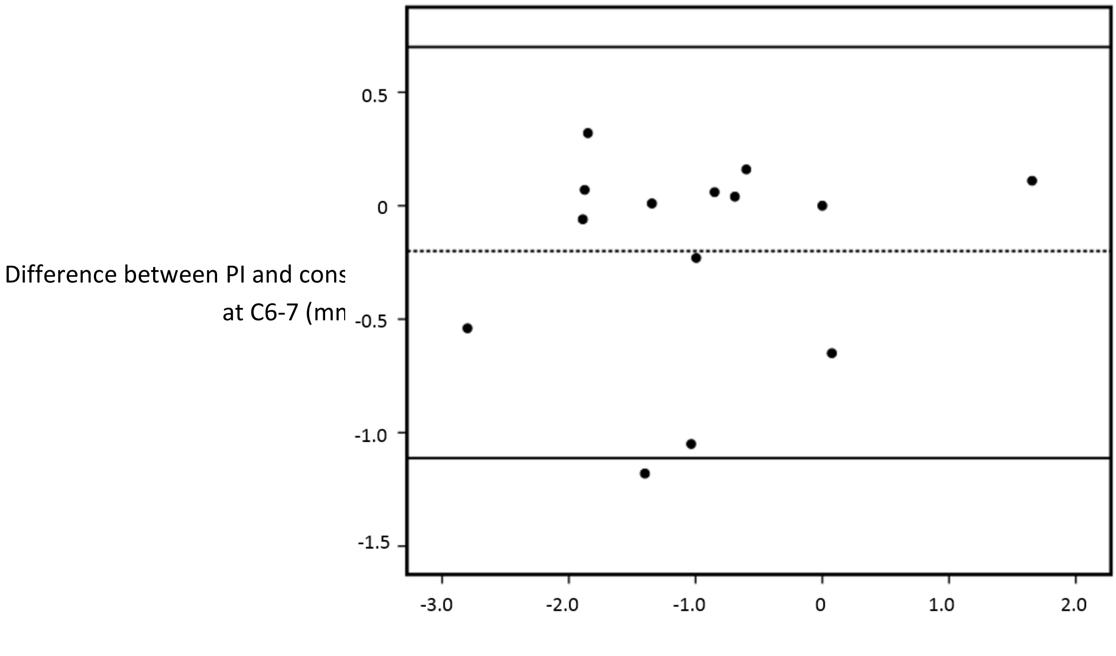


B

Figure 3.5. Bland Altman plots representing disc measurements of both the PI and consultant radiologists with 95% LoA at the C5-6 disc level (A) and C6-7 disc level (B).

Intra-rater reliability

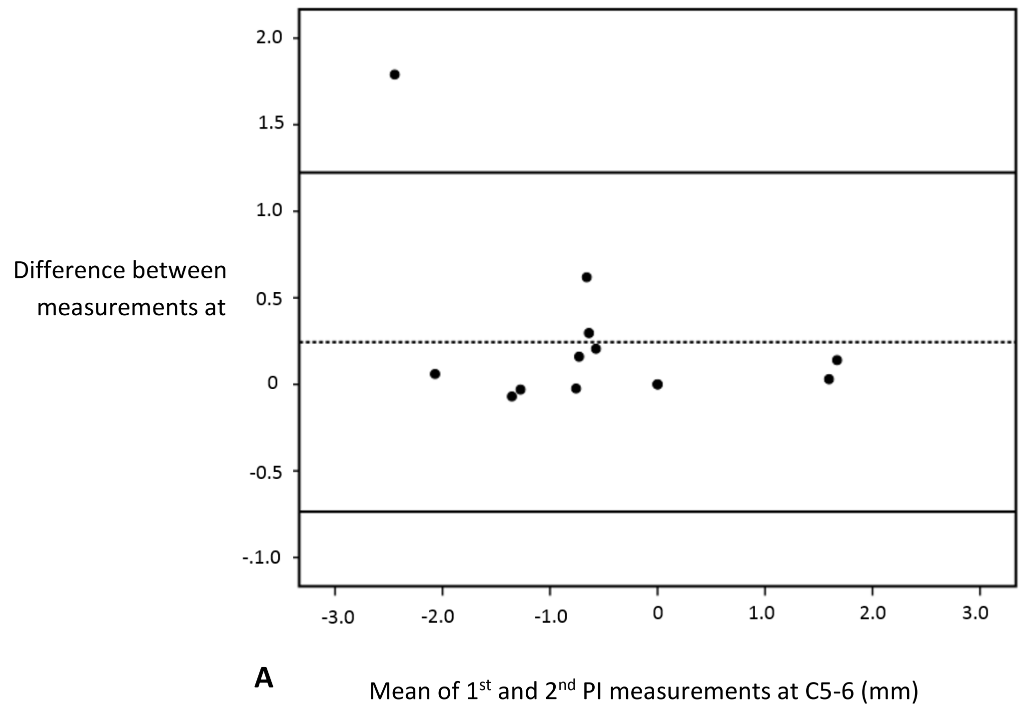
There were no significant differences found between the first and second set of C5-6 and C6-7 measurements taken of the same image on two separate days (mean p = 0.45) (see table 3.2). Correlation coefficient results showed a strong correlation between the first and second set of measurements taken by the PI with a mean ICC value of 0.92 mm (see table 3.2).

Bland Altman plots show that the 95% LoA between the two measurements at the C5-6 disc ranged from - 0.74 mm to 1.2 mm (see figure 3.5). All differences were less than 2 mm in magnitude, with 12 of the 13 measurements having a difference of less than 0.5 mm. There was a mean difference of 0.25 mm. Values for two of the participants were identical, with a position 0 mm recorded for both the first and second measurements. Because of this, the Bland Altman plots appear misleading with only 12 values visible.

At the C6-7 disc, 95% LoA ranged from - 0.08 mm to 0.07 mm (see figure 3.5). All differences (except for two outliers) were less than 0.5 mm in magnitude, with eight of these 12 measurements falling within 0.25 mm of the each other. There was a mean difference of - 0.03 mm.

Disc level	No. of images compared	Order of image taken	Posterior disc nucleus position in relation to the posterior vertebral bodies (mm)	Mean difference (mm)	P value	ICC
C5-6	12	1st	-0.43 ± 0.11	0.25	0.10	0.91 95% CI (0.71 - 0.97)
		2nd	-0.68 ± 0.13			
C6-7	14	1st	-1.08 ± 0.11	-0.03	0.79	0.94 95% CI (0.83 - 0.98)
		2nd	-1.05 ± 0.10			

Table 3.2. Frequencies for PI posterior NP measurements at the C5-6 and C6-7 disc levels taken from the same image on two separate days.



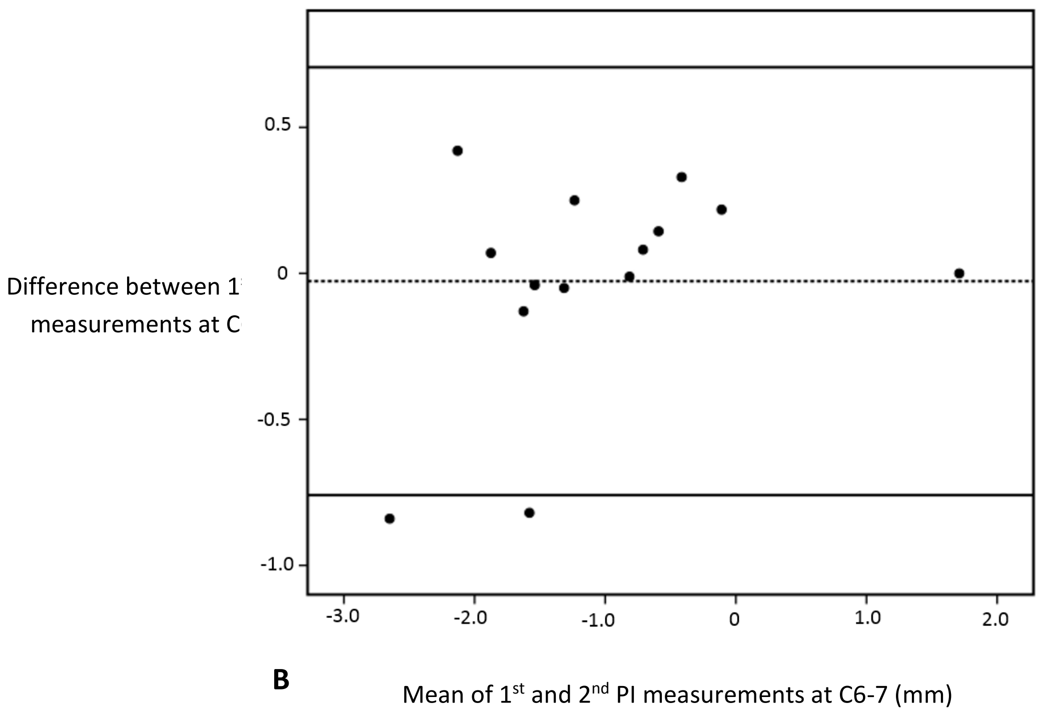


Figure 3.6. Bland Altman plots of the PI's repeated disc measurements, using the same image, with 95% LoA at the C5-6 disc level (A) and C6-7 disc level (B).

Test-retest reliability

There were no statistically significant differences found between measurements of the C5-6 and C6-7 disc in neutral (p = 0.3) (see table 3.3). ICC results however showed only a moderate correlation between the measurements taken on two separate days for the C6-7 disc.

Disc level	No. of images compared	Order of measurement taken	Posterior disc nucleus position in relation to the posterior vertebral bodies (mm)	Mean difference (mm)	P value	ICC
C5-6	13	1st	-0.24 ± 0.14	-0.65	0.39	0.83 95% CI (0.42 - 0.95)
		2nd	0.41 ± 0.16			
C6-7	12	1st	-0.22 ± 0.18	0.88	0.21	0.66 95% CI (-0.06 - 0.90)
		2nd	-1.10 ± 0.23			

Table 3.3. Frequencies for the first and second set of PI measurements taken from two separate images.

Bland Altman plots show that, at the C5-6 disc, the 95% LoA between the two measurements at the C5-6 disc ranged from - 4.87 to 3.58 (see figure 3.6). Eleven of the 12 measurements had a difference no greater than 2.5 mm, with one outlier approximately 6.5 mm from the mean. There was a mean difference of - 0.65 mm.

At the C6-7 disc, the 95% LoA between measurements was -3.10 to 4.87 (see figure 3.6). Eleven of the 12 measurements lay between 5.0 mm of each other, with one outlier approximately 7.5 mm from the mean. There was a mean difference of 0.88 mm.

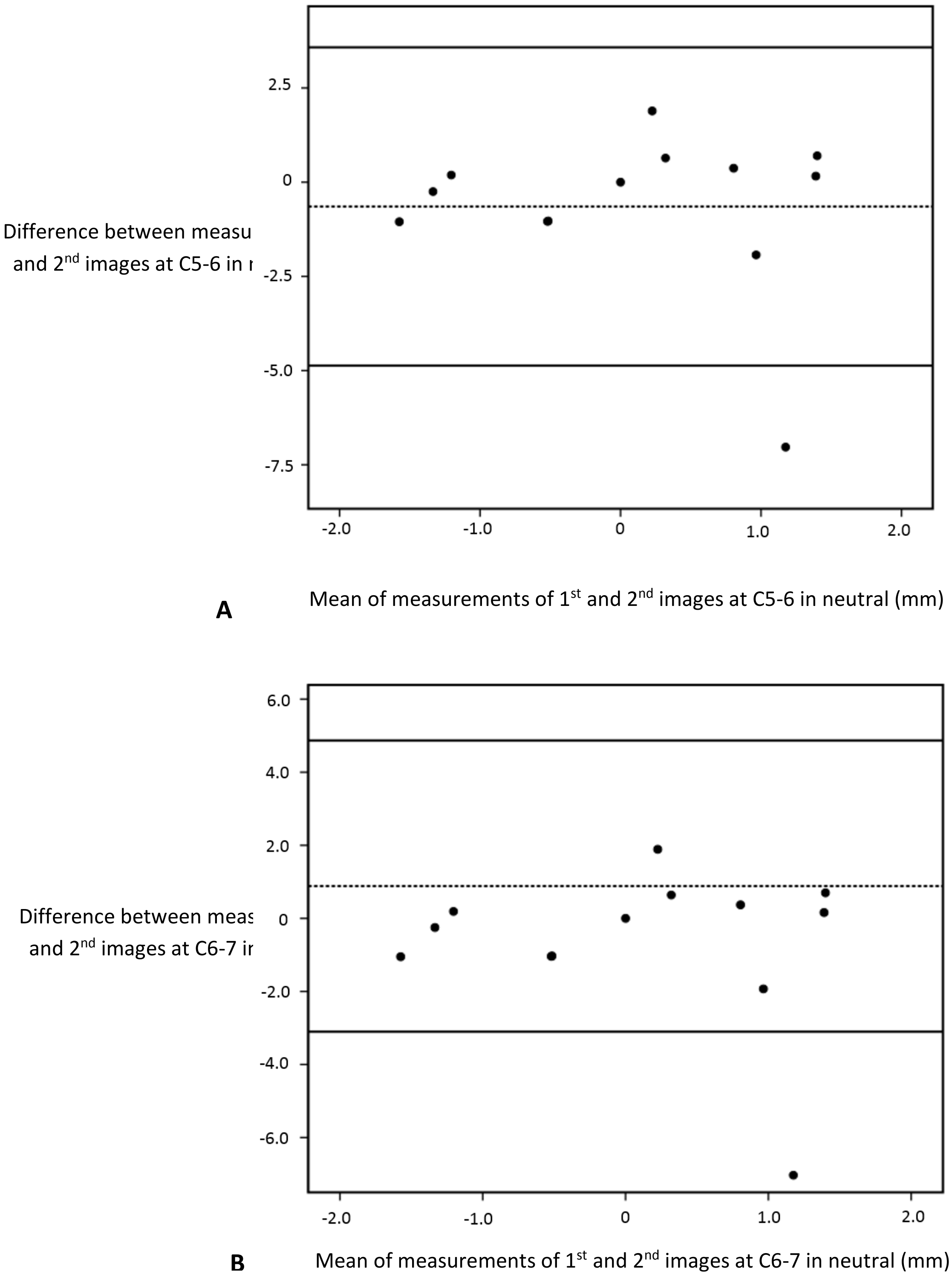


Figure 3.7. Bland Altman plots of the PI's disc measurements, using two separate images, with 95% LoA at the C5-6 disc level (A) and C6-7 disc level (B).

3.4 Discussion

The t-test and Related - Samples Wilcoxon Signed Rank Test results showed no significant difference between measurements for the inter-rater and intra-rater reliability studies. ICC results for these first two studies showed a strong correlation between measurements.

Bland Altman plots for the inter-rater reliability study showed good agreement, with 19 out of 26 disc measurements being no greater than 0.5 mm in magnitude. It appears the PI and radiologist likely used different reference points to measure the C5-6 and C6-7 posterior disc nucleus for one of the images. For this particular image, the PI recorded the C5-6 disc position as 2.0 mm and the C6-7 disc as 1.6 mm in relation to their posterior vertebral bodies. The radiologist recorded these same discs as 0.57 mm and 0.55 mm at the C5-6 and C6-7 levels respectively. If these measurements had been omitted, the mean difference in measures between the two testers would have been 0.15 mm. The SD between testers was less than ± 0.13 mm for all mean measurements at both disc levels.

Bland Altman plots also showed good agreement for the intra-rater measurements at the both disc levels, with 24 of the 27 measurements being no greater than 0.5 mm in magnitude. Of these 24 measurements, 17 were no greater than 0.25 mm in magnitude. The SD's from both sets of measurements was no greater than ± 0.13 mm.

As described at the beginning of this study, measurements taken of the distance between the cervical disc, theca and spinal cord in a symptomatic population produced a mean distance from the posterior C5-6 disc to the anterior edge of the theca of 1.72 mm ± 1.2. The mean distance between the posterior disc and spinal cord was measured as 4.59 mm ± 1.69. Considering these measurements, one may be inclined to assume that the mean variation in measurement values for the inter-rater and intra-rater studies is not great enough to be of clinical significance in terms of thecal or cord compression.

For the test-retest reliability study, each disc was measured three times with the mean value recorded in order to reduce the chance of measurement error skewing the results. Despite this, the results for the measurements taken provided lower reliability than the previous two studies. The Related-Samples Wilcoxon Signed Rank Test showed no significant difference between measurements at either disc levels, however the mean difference between the first and second set of measurements at both disc levels was disappointing. Bland Altman plots showed that for 11 of the 12 measurements taken from the C6-7 disc level (excluding the outlier), the greatest distance between them was just over 4 mm. This variation between measurements is significantly greater than that for both previous reliability studies and is almost as great as the distance between the posterior disc and the spinal cord measured as 4.59 mm ± 1.69. The SD for both disc measurements were higher than those in the previous two reliability studies, with that of the C6-7 disc being almost double that of earlier studies. The ICC at the C6-7 disc level also produced disappointing results with only moderate agreement achieved. The variability in measurements for this study throws doubt on the potential internal validity of the findings of future studies involving measurements of the same disc taken two weeks apart.

Considering the favourable results of the inter-rater and intra-rater reliability studies, it is reasonable to assume that the discrepancies in disc measurements for the test-retest study were due to actual changes in the disc position rather than from measurement error. Although an attempt was made to limit the effects of diurnal variation, not every participant was able to attend their second scan at the same time of day. It was also not practicably possible to control the activity levels of the participants directly prior to attending for their scan and this would have likely had an impact on cervical disc position. As mentioned previously, studies completed on the lumbar spine showed immediate changes in disc position by merely changing sitting or lying posture. It is therefore reasonable to assume that whatever activity the participant was engaged in prior to their scan would have impacted on their disc position.

No direct comparisons were found with similar research assessing inter-rater reliability of lumbar disc measurements. Unlike this current study, other research looking at reliability of MRI readings have at times used a classification system to describe disc herniation and used corresponding Kappa's coefficients (Brant-Zawadzki et al., 1995; Lurie et al., 2008). Fredericson et al. (2001) did mention use of Bland Altman plots to assess inter-reader variability in the measurement of posterior disc bulging with upper and lower LoA set at 95%. There were, however, no Bland Altman plots or descriptions provided within the paper to demonstrate the level of agreement achieved.

Alexander et al. (2007) performed intra-rater reliability testing involving direct measure of NP translation, however using only an ICC. It has been argued that it is inappropriate to use correlation coefficients alone to determine agreement as a strong correlation ignores the possibility of systematic bias between the measures (Bland and Altman, 1986). Nevertheless, a comparison of intra-rater ICC results between this current study and that of Alexander et al. (2007) showed a higher ICC for the former (0.93 and 0.89 respectively). Intra-rater measurement reliability was also assessed by Beattie et al. (1994) using comparison of mean values of disc position with two series of five repeated measures of the L4-5 IVD in flexion and extension. The mean difference between the first and second series of posterior disc position was 0.1 mm. In comparison, the first and second intra-rater measurement results of this current thesis were 0.25 mm at the C5-6 and 0.03 mm at the C6-7 level for 13 and 14 participants respectively.

3.5 Conclusion

There was high agreement between the majority of the repeated measures in the inter-rater and intra-rater reliability studies with most measurements being no greater than 0.5 mm in magnitude. The high reliability demonstrated enables greater confidence when extrapolating results for subsequent studies assessing the effects of cervical position and neck exercises on IVD position. The test-retest reliability study produced less favourable results and this will impact on sub-acute measurement testing of disc position, as it will be difficult to ascertain whether changes in IVD disc position are due to the intervention or whether they are significantly affected by confounding factors such as previous activity prior to scanning.

Further discussion

The test-retest reliability study was completed with the intention of performing an intervention study assessing the sub-acute effects of performing McKenzie's retraction-extension exercise in sitting on position of the posterior disc nucleus in a population with cervical or associated upper limb symptoms. The disc nucleus position was to be measured once before, and approximately two weeks after performance of this specific exercise, 3-4 times per day, over the two week period. The aim of this study was to assess whether performing this exercise over time had a more significant impact on position of the C5-6 and C6-7 disc compared to performing one set of the exercise. A positive finding would support the repeated nature of exercise prescription promoted in MDT. Unfortunately, the results for the C6-7 disc measurements in the test-retest reliability study provided disappointing results with greater variability than was demonstrated in the previous two studies. Although the C5-6 disc produced much more favourable ICC results, it demonstrated less favourable agreement as indicated by Bland Altman figures. After consideration, it was decided that even if the test-retest study had demonstrated higher agreement between measures, such a study would have little clinical significance. The McKenzie approach of treatment relies on the practitioner's assessment of symptom and mechanical response to repeated end range movements. This helps to determine the most appropriate loading strategy for the patient which can vary from session to session (McKenzie, 1981; McKenzie and May, 2006). Although extension loading exercises are the most commonly prescribed after initial assessment for those presenting with a derangement syndrome (see Chapter 1), it would be clinically counter-intuitive and potentially counter-productive to prescribe the same directional approach to each participant regardless of symptom and mechanical response. Furthermore, repeated visits to allow for reassessment of symptoms and, adjustment or progression of directional approach, is an important part of the treatment process. There is not the scope within this current thesis for assessment of the various loading strategies or for repeated visits to allow for appropriate progression or adjustment of prescribed exercises. For these reasons, a sub-acute intervention study assessing the effects of McKenzie's retraction extension exercises over a two week period was not commenced.

Limitations

Pixel size for this current study was 1.02 x 1.35 mm, (reading resolution x encoding resolution). The increase in reading resolution from 0.78 mm to 1.35 mm was due to the reduced phase field of view (FOV) of 75%. Phase FOV was reduced partly to allow the scan to be undertaken in a shorter time. This in turn reduced the chance of lower image quality as a result of participant movement in the form of breathing and swallowing, as well as flow artefact caused by adjacent arteries. The less movement and artefact produced, the superior the image quality. Despite this pixel size, the images produced were of sufficient clarity to be able to identify the structural edges of interest. The closest structure adjacent to the posterior disc was the posterior longitudinal ligament. These images were of sufficient quality to be able to differentiate between the edges of these two structures. The high ICC results for both the inter-rater and intra-rater results also indicate that the images were of sufficient quality to produce repeatable measurements.

Chapter Four

The acute response of the nucleus pulposus of the cervical intervertebral disc to three supine postures in an asymptomatic population

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Abstract

Introduction. The term dynamic disc model refers to the ability of a spinal disc's position to be manipulated by body postures and movements. This theory was promoted by Robin McKenzie, a world renowned physiotherapist, and its biomechanical principles used for the treatment of patients presenting with a 'derangement syndrome'. Research conducted on the DDM has focused on discs in the lumbar spine. Results have shown that in lumbar discs that have retained their water content, there is movement of the anterior and posterior disc that correlates with posture of the spine. More specifically, flexion of the spine has been shown to cause posterior migration of disc material while extension of the spine causes anterior migration. Cervical discs have been shown to be morphologically dissimilar to lumbar discs, with loss of the gelatinous nucleus pulposus in early life, and a discontinuous outer annulus. The aim of this current study was to assess whether, despite its structural differences, the cervical disc responds to flexed and extended postures in a similar fashion to the lumbar disc.

Methods. Twenty five asymptomatic participants between the ages of 21 and 49 years of age (33.7 years ± 9.1) volunteered. Scans were performed in supine using an Esaote 0.2 T magnetic resonance imaging scanner. Participants lay with their cervical spine initially placed in neutral, followed by flexion and finally extension. The position of the C5-6 and C6-7 posterior disc nucleus pulposus was measured against a vertical line connecting the posterior vertebral bodies above and below each disc.

Results. Change in cervical spine position produced statistically significant changes in disc position for both the C5-6 and C6-7 discs (mean $p = 0.002$). *Post hoc* testing using a

Bonferroni correction showed a statistically significant difference in disc position at the C5-6 disc between neutral and flexion ($p = 0.03$) as well as flexion and extension ($p = 0.02$). There were statistically significant changes in disc position at the C6-7 level between neutral and flexion ($p < 0.001$) as well as flexion and extension ($p = 0.02$).

Conclusion. These results show that, despite the anatomical differences between lumbar and cervical discs, the cervical posterior NP is affected by spinal loading, in keeping with the concept of the DDM.

4. 1 Introduction

Robin McKenzie, a world renowned New Zealand born physiotherapist, spent over 55 years working in the treatment of those with spinal pain. He felt the spinal disc was often a source of pain for those presenting with what he classified as a presenting with a 'derangement syndrome' (see Chapter 1). In his first publication on the topic of spinal pain and treatment, written over 35 years ago, he described the IVD nucleus as a moveable structure that responded in a predictable manner to biomechanical forces. More specifically, he felt that flexion of the spine caused posterior displacement of disc material through compressive loading of the anterior disc, with extension of the spine causing anterior displacement through loading of the posterior disc. This conceptual model of disc displacement was used by him to devise an entire series of exercises for the treatment of those presenting with spinal pain, classified with a derangement syndrome. Shortly after the publication of his first book, his conceptual model and treatment principles became recognised and practised worldwide.

In this first publication, McKenzie (1981) explained that his conceptual model was hypothesised with the present knowledge available to him regarding the structure, function and behaviour of the IVD's, though he felt there was no absolute proof to substantiate his theory. Since then, studies have been conducted assessing movement of the IVD's in the lumbar spine in various spinal postures. Results appear to support McKenzie's description of the disc as a moveable structure with disc material altering position depending on posture of the spine (Beattie et al., 1994; Alexander et al., 2007). This phenomenon is termed in the more recent literature as the 'dynamic disc model'. To date however, these studies have focused on the lumbar spine (Kolber and Hanney, 2009).

McKenzie felt that spinal loading was able to cause predictable NP movement if the disc maintained an intact annular wall. He felt that a disruption in the outer annulus would in turn disrupt the hydrostatic mechanism that allowed the disc to migrate from an area of greater to lesser pressure. Cadaveric studies examining the anatomy of the cervical disc have shown that its outer annuls is discontinuous along the postero-lateral corners, with only periosteofascial tissue covering these areas (Mercer and Bogduk, 1999) (see Chapter 1).

To date, there have been no *in vivo,* randomised controlled trials (RCT) using MRI to assess whether, despite its anatomical differences, the DDM holds true for the IVD in the cervical spine.

4. 2 Methods

Participants

Participants recruited for studies 1 and 2, provided MR images for the purposes of the first objective of this current study, assessing the effects of cervical posture on potential disc displacement. In total, the images from twenty five asymptomatic participants (10 males and 15 females) between the ages of 21 and 49 years of age (33.7 years ± 9.1) were used for this current study.

All participants were given a PIS, provided their informed consent and completed an MRI safety questionnaire to ensure there were no health and safety reasons for their exclusion from the studies. This study conformed to the latest revision of the Declaration of Helsinki and the ethics committee at MMU.

Procedure

As the same group of participants provided from studies 1 and 2 provided the MR images for this current study, the procedure followed was identical to that described in the previous two studies.

Disc measurement

Measurement of posterior NP position was completed, for the MRI images of each participant, in cervical neutral, flexion and extension postures. The order of scanning remained the same for all participants. For a detailed description of posterior NP measurement, please refer to study 2. The only variation in technique was the recording of any NP located posterior to the vertebral bodies as a negative value with NP located anteriorly recorded as a positive. This is the opposite method to allocating positive and negative values that was used in study 2. This is because, after further analysis of the reliability data, the direction of NP migration, as visually represented through bar charts, appeared clearer with posterior disc displacement represented by a negative value. Disc material falling directly on the line was still recorded as 0 mm. The PI was blinded to all images, with images selected at random (see study 1).

Statistical analysis

For data collection of NP position in the three cervical postures, at least one positional image from nine participants was deemed unusable due to poor image quality caused by the cervical coil. Only participants with readable images in all three cervical positions were used in order to ensure a balanced design. This left images from 19 participants available for data analysis. A power analysis using G*Power (Franz Faul, Universitat Kiel, Germany) was conducted to determine the sample size required to produce a power of 0.80 with an alpha of 0.05. Data from the pilot study for the C5-6 disc measurements produced an effect size of 0.277 and a mean correlation between measures of 0.498. The total sample size required was calculated as 23 participants. For the C6-7 disc measurements, the pilot study produced an effect size of 0.421 and a mean correlation between measures of 0.695. This calculated a required sample size of eight participants.

A one-way repeated measures ANOVA was conducted to determine whether there were significant, within-participant differences in posterior NP position between supine cervical spine postures in neutral, flexion and extension. There were no outliers as assessed by boxplot and the data was normally distributed for the C6-7 disc measurements as assessed by Shapiro-Wilk test (neutral, $p = 0.39$; flexion, $p = 0.05$; extension, $p = 0.28$). There were no outliers for the C5-6 disc measurements. Measurements in neutral ($p = 0.74$) and flexion ($p = 0.49$) were both normally distributed while the measurements taken in extension were deemed not normally distributed ($p = 0.02$). The ANOVA assumes that the data is nearly normally distributed, however studies have reported no serious Type I errors introduced by non-normality on the significance levels of the F-test (Glass, 1972). Further analysis of the data in extension showed the results demonstrated a normal skewness score ($\beta1 = -0.066$) with a slight platykurtic ($\beta2 = -1.098$) trend. A distribution is generally deemed platykurtic at a value of -1.705 (Walker & Madden, 2013). Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated for either the C5-6, $\chi^2(2) = 2.57$, $p = 0.28$, or the C6-7 disc measurement data, $\chi^2(2) = 0.62$, $p = 0.73$. Data are presented as means and ± SD and statistical significance was set at $p \leq 0.05$.

4.3 Results

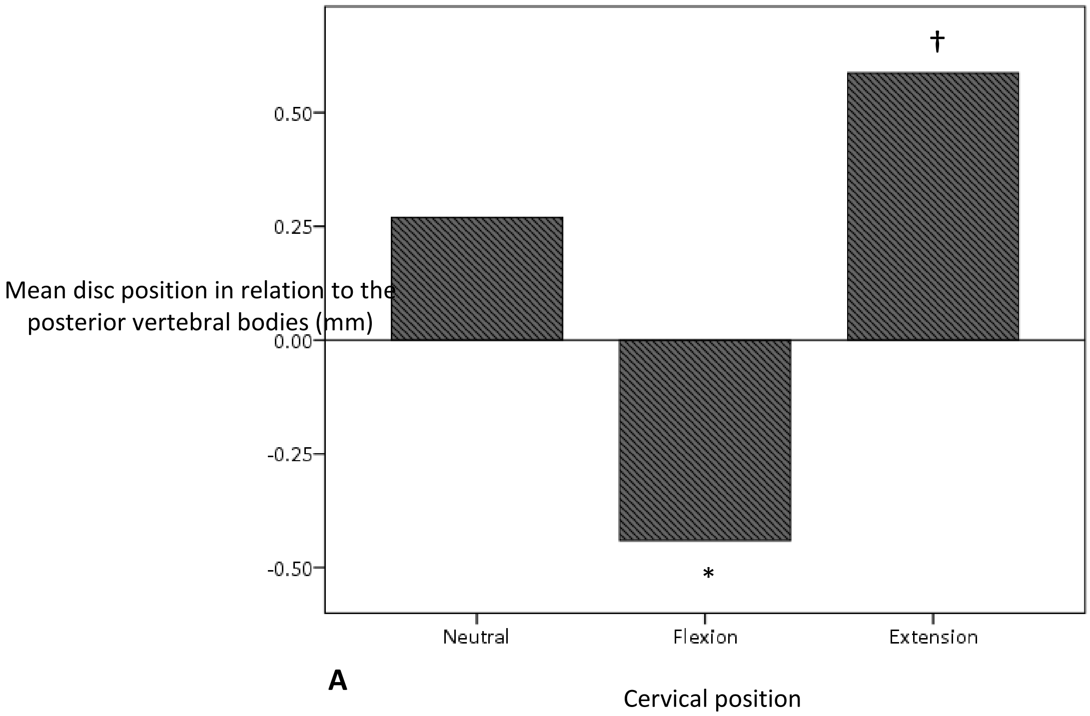
A change in cervical position elicited statistically significant changes in posterior NP position for both the C5-6 disc, $F(2, 36) = 6.88$, $p = 0.003$ and the C6-7 disc $F(2, 36) = 13.10$, $p < 0.001$. *Post hoc* tests using a Bonferroni correction showed significant differences in disc position between flexion and both neutral and extension at both disc levels. There was no significant difference found between neutral and extension at either level (see table 4.2). Table 4.1 shows IVD measurement in each position at both disc levels. Figures 4.1 illustrate posterior NP position in the neutral, flexed and extended cervical postures at both disc levels. Figure 4.2 demonstrates visual images of the posterior NP position in one participant in a neutral and flexed cervical posture respectively.

Disc level	Cervical position	Position of posterior NP ± SD
C5-6	Neutral	0.27 ± 0.13
	Flexion	-0.44 ± 0.11
	Extension	0.59 ± 0.13
C6-7	Neutral	0.75 ± 0.09
	Flexion	-0.29 ± 0.13
	Extension	0.29 ± 0.12

Table 4.1 Posterior NP position (mm) in relation to the posterior vertebral bodies at both disc levels in the three cervical postures.

Disc level	Comparison of cervical positions	Posterior NP position	% Difference	P value
C5-6	Neutral vs Flexion	-0.71	-263	0.03
	Neutral vs Extension	0.32	119	0.75
	Flexion vs Extension	1.03	234	0.02
C6-7	Neutral vs Flexion	-1.04	-139	< 0.001
	Neutral vs Extension	-0.46	-61	0.14
	Flexion vs Extension	0.58	200	0.02

Table 4.2. Measurement (mm) and % difference between NP position (mm) at both disc levels.



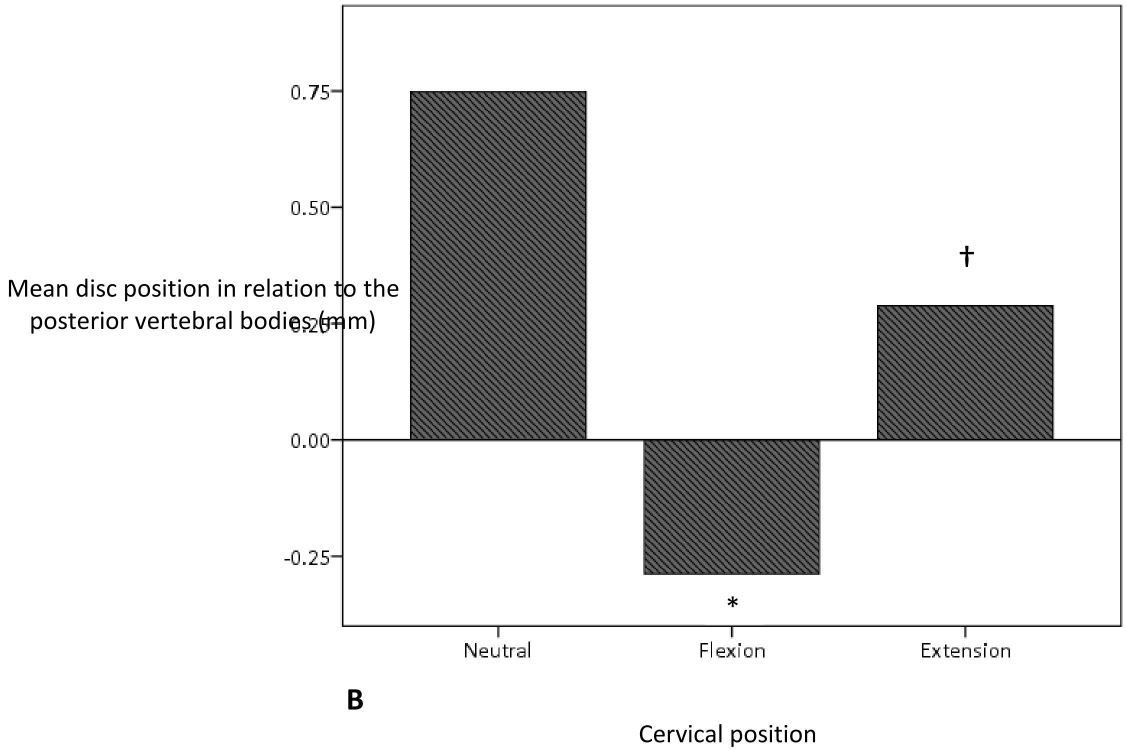
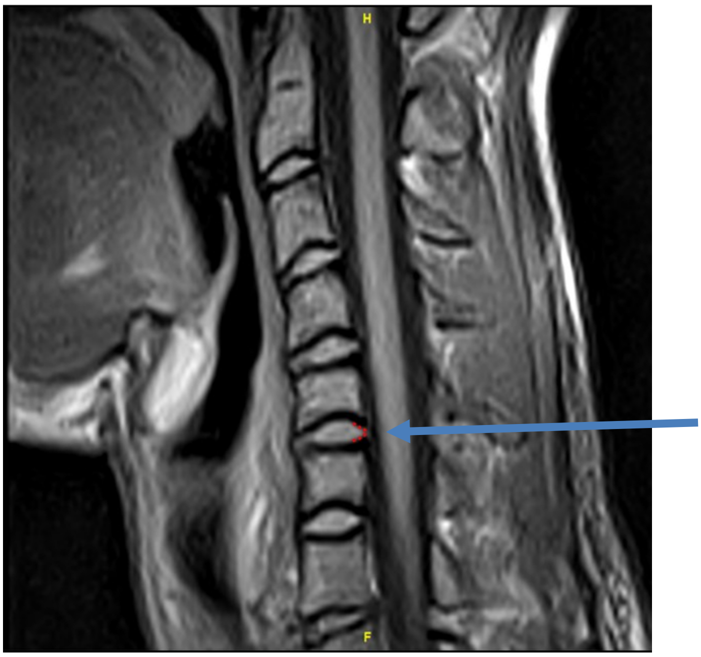
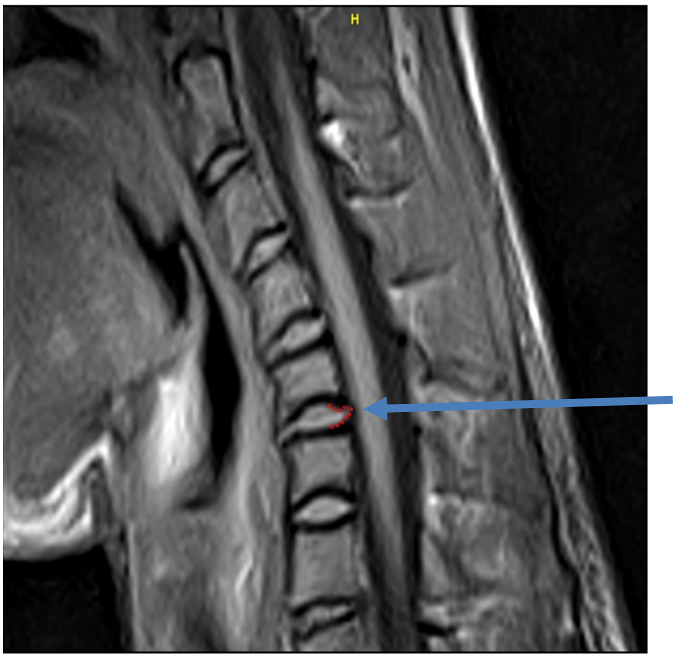


Figure 4.1. Posterior NP position in a neutral, flexed and extended cervical posture (mm) at the C5-6 (A) and C6-7 (B) disc levels. * denotes a significant difference from neutral ($p < 0.05$). † denotes a significant difference from flexion ($p < 0.05$).



A



B

Figure 4.2. MRI of the cervical spine in neutral (A) and flexion (B). The red dotted line indicates the outer border of the nucleus pulposus at the C5-6 disc level. Visually, these images indicate posterior migration of disc material in the flexed position when compared to neutral. The blue near horizontal arrow indicates the posterior NP.

4.4 Discussion

The findings from this study suggest that a flexed head posture causes posterior migration of the NP at the C5-6 and C6-7 disc levels compared to both a neutral and extended head posture. This supports the concept of the DDM in the cervical spine and shows that, despite the early fibrotic changes that occur in the disc and its discontinuous outer layer (Mercer and Jull, 1996; Mercer and Bogduk, 1999), the cervical disc may still retain a hydrostatic pressure allowing the NP to adjust its position according to the direction of pressure applied to it. This agrees with *in vitro* studies using human cadavers and porcine specimens, showing convential hydrostatic behaviour within healthy cervical discs, with flexion increasing stresses and, in some cases, causing prolapse of the posterior disc (Skrzypiec et al., 2007; Scannell and McGill, 2009). Measurements recorded by Scannell and McGill (2009) of anterior and posterior cervical disc displacement in 18 porcine specimins were 2 ± 2.2 mm and 2.6 ± 1.3 mm respectively. Their results show slightly greater movement of the disc than those of the current study which recorded measurements of 0.8 mm of anterior disc displacement and 0.9 mm of posterior disc displacement. Scannell and McGill (2009) may have achieved greater disc movement due to their use of a hydraulic jig which was able to apply various loads and angles to the vertebral segments. The cervical coil in this study, as well as patient body size, affected the degree of both flexion and extension achieved during the scans.

In neutral, the posterior C5-6 and C6-7 NP was measured as sitting anterior to the posterior vertebral bodies. There was no evidence of prolapse at either level overall. This is in contrast to flexion, in which the nucleus had displaced posteriorly in relation to the corresponding posterior vertebral segment. It was mentioned in previous chapters that the clinical implications of a posteriorly prolapsed disc is not only that increased pressure to this area has the potential to cause pain through stimulation of the disc's afferent nerve supply, but also that mild protrusions could eventually lead to extrusions and impingement of adjacent pain sensitive structures such as nerve roots and the spinal cord.

Extension of the cervical spine produced a significantly retracted posterior NP position compared to flexion at both disc levels. These findings are similar to those of Scannell and McGill (2009) and Skrzypiec (2007) who found cervical extension increased stresses in the anterior disc with redirection of displaced portions of the nucleus back to its centre. It is worth mentioning again that scans in cervical extension were taken after a flexed head position. This potentially means the disc had to begin its movement from a more posterior position compared to discs in a neutral position. Despite having to travel this further distance, the posteior NP in extension was still able to reposition itself into a more anterior position than neutral at the C5-6 disc level. This has strong clinical implications as there appears to be a basis for McKenzie's Extension prinicple in the cervical spine. This is investigated more specifically in the next study.

It is important to mention that measurements were performed with participants in supine which makes direct transfer of these findings to occupational postures difficult. Nevertheless, it is interesting to note that the change in disc position between cervical postures occurred in the space of a few minutes. Furthermore, one might assume that a flexed and extended head posture in sitting might produce greater changes in disc position compared to lying due to the effects of gravity on the head.

4.5 Conclusion

This study examined the effects of three cervical spine postures on position of the posterior NP at the C5-6 and C6-7 disc level. Studies assessing the lumbar discs have shown that the NP moves in a predictable manner when the lumbar spine is placed in various flexed and extended postures (Beattie et al., 1994; Fredericson et al., 2001; Alexander et al., 2007; Kolber and Hanney, 2009). The findings of this current study involving asymptomatic volunteers show that the cervical disc also moves in a predictable manner with the NP in flexion having a greater posterior position than in neutral and extension at both the C5-6 and C6-7 disc level. This would suggest that maintaining a neutral, and avoiding a flexed head posture, may help reduce the incidences of posterior disc prolapses which may in turn reduce the incidence of the more symptomatic disc extrusions. Finally, cervical extension was shown to cause anterior displacement of posterior NP material beyond its neutral position at the C5-6 disc level, despite having to travel from a posteriorly displaced position. This supports the validity of McKenzie's extension based therapeutic exercises.

Further discussion

In their most recent discussion regarding therapist clinical reasoning during the assessment of patients with cervical pain and dysfunction, McKenzie and May (2006) quoted Jones and Rivett (2004) stating:

> It is not satisfactory simply to identify structures involved, as this alone does not provide sufficient information to understand the problem and its effect on the patient, nor is it sufficient to justify the course of management chosen (p. 267).

This reflects the multi-faceted experience of spinal pain, with perception of symptoms and response to treatment affected by many social and psychological factors (Vranceanu et al., 2009). It is important to note that the majority of spinal pain experienced by people can be described as 'non-specific' in origin (Kent and Keating, 2004), implying that no anatomical structure can be identified as the cause of pain. Furthermore, it was previously mentioned that disc herniations on MRI are a common finding in an asymptomatic population (Ito et al., 1998; Videman et al., 2003). It is therefore not the intent of this current research to overstate the role of a herniated spinal disc as the source to a patient's spinal pain presentation. However, it is reasonable to assume clinically, that those presenting with clear signs of a radiculopathy are likely experiencing compression of a nerve by a structure in close proximity to it such as a spinal disc. In these cases, being able to manipulate the position of the disc with specific directionally based exercises may greatly impact a person's pain by reducing pressure on neural structures.

Chapter Five

The effects of McKenzie's 'retraction-extension exercise in sitting' on position of the C5-6 and C6-7 posterior nucleus pulposus in symptomatic participants

Abstract

Introduction. Disruption of the posterior disc can be a source of neck pain as it is innervated with an afferent nerve supply. The posterior disc also lies in very close proximity to pain sensitive neural structures such as the nerve roots and spinal cord. Compression of these structures by the disc is a common source of neck pain. McKenzie produced a set of exercises grouped into what he termed the 'Extension principle'. When used for those classified as presenting with a derangement syndrome, his conceptual model described these exercises as aiming to reverse displacement of posterior disc material, thereby redistributing the disc back to its original position and away from adjacent neural structures. To date, no published studies have directly assessed whether McKenzie's retraction-extension exercises cause immediate anterior disc displacement of the posterior nucleus pulposus. The aim of this study was to assess, with the use of MRI, whether McKenzie's 'retraction-extension exercise in sitting' resulted in immediate, measureable anterior displacement of the posterior disc nucleus at the C5-6 and C6-7 discs in a symptomatic population.

Methods. Twenty participants with neck pain were scanned in supine with their cervical spines in neutral, immediately before and after completion of 10 McKenzie retraction-extension exercises in sitting. Disc position pre- and post-exercise was measured at the C5-6 and C6-7 level for each participant.

Results. Following the McKenzie exercises, there was a significant degree of anterior displacement of 0.05 mm at the C5-6 level ($p = 0.04$); there was no significant displacement at the C6-7 level.

Conclusion. McKenzie's retraction-extension exercise in sitting produced a statistically significant degree of anterior disc displacement at the C5-6 level. Further studies are

needed to determine whether this pattern of displacement is consistent and can provide clinical changes in symptoms.

5.1 Introduction

McKenzie's (1981) first Mechanical Diagnosis and Therapy publication, focusing on the treatment of lumbar spine pain, described three mechanical syndromes diagnosed by their clinical presentations and responses following a structured assessment involving a sequence of loading strategies. These were termed the postural, dysfunction and derangement syndromes. The syndrome of interest for this study is that of a derangement. McKenzie (1981) described the derangement syndrome as originating from symptoms caused by mechanical deformation of soft tissue as a result of internal derangement. For those presenting with spinal pain, he felt this internal derangement was likely a result of deformation of spinal disc material. He felt that, because of our continuously flexed lifestyles, this derangement commonly presented as posterior disc protrusions (McKenzie, 1981). The assumption that most disc protrusions are posterior in direction is supported by Matsumoto et al. (1998) who, after scanning 497 asymptomatic participants, found posterior disc 'bulges' and 'prolapses' in 354 (71%) of cases. Of the posterior cervical protrusions, they found that 67% were displaced centrally, with 26% described as paramedian and 7% as lateral protrusions.

The posterior disc has been shown to be a source of spinal pain (Bogduk et al., 1988) and therefore posterior displacement of disc material has the potential to cause clinical symptoms. In his more recent Mechanical Diagnosis and Therapy publication focusing on the cervical and thoracic spine (McKenzie and May, 2006), the cervical disc was described as able to produce a herniated mass that can cause symptoms of radiculopathy and myelopathy through direct mechanical irritation of adjacent pain sensitive structures.

McKenzie (1981) also felt that the disc nucleus was a moveable structure that was able to migrate away from an area of compressive loading. For example, he felt that lumbar flexion would cause loading of the anterior disc resulting in posterior NP migration while extension would load the posterior disc causing anterior NP migration. This assertion has been shown to hold true for both lumbar (Kolber and Hanney, 2009) and cervical discs (see study 3). With this assertion, he felt adoption of extended lumbar postures and repeated lumbar movements into extension were able to reduce posterior disc herniations if enough time was allowed for the fluid nucleus to alter its position anteriorly. Through this reasoning, he devised a series of extension based exercises, grouped into his ‘Extension principle’ of treatment, aimed at reducing posterior disc herniations and their potential to compromise adjacent neural structures (McKenzie, 1981). In the cervical spine, one of these exercises is called ‘retraction and extension in sitting’. Conceptually, the aim of this exercise is to cause anterior displacement of posteriorly protruded disc material through loading of the posterior disc by the spine (see study 1).

McKenzie and May (2006) state that, during therapeutic intervention, exercises that can be independently performed by the patient should always be attempted first in order to reduce reliance on a therapist and promote independent symptom management. For this reason, the retraction-extension exercise in sitting was chosen for this current study. Although there are a plethora of treatment approaches that can be used to treat neck pain, the PI is not aware of any others that can be performed independently, and are aimed specifically at the disc, purporting to be able to change its position.

Once patients have been appropriately classified into McKenzie’s (1981) derangement syndrome and contraindications have been excluded, this treatment technique poses minimal risk to the patient and incurs the cost of the appointment session with the International McKenzie Institute trained therapist only. It takes only a few minutes to perform and can be completed independently by the patient allowing self-management for present and potential future incidences of pain.

The main risk involved with performance of this exercise is for those with vertebral artery damage who may experience symptoms in the extension phase of the exercise. However there is no manipulative movement involved in this technique and the controlled movement of the exercise should allow for early symptom detection of vertebral artery insufficiency (McKenzie and May, 2006). One of its disadvantages is that it is often, at first, painful to perform. It is also unsuitable for certain populations such as those with suspected spinal infection, moderate to severe rheumatoid arthritis due to potential upper cervical instability, extreme dizziness due to potential pathology of the central nervous system, those with osteoporosis, those with suspected cervical fractures and dislocations and those with central nervous system compromise (McKenzie and May, 2006). Nevertheless, this exercise is suitable for the vast majority of those who present with cervical pain and neurological upper limb symptoms who can be classified into a derangement syndrome.

To date there are no published RCT's that have used MRI to investigate whether McKenzie's retraction and extension in sitting exercise does indeed cause repositioning of disc material in the form of anterior displacement of the posterior disc nucleus. The aim of this study is, therefore, to assess whether this commonly used exercise does result in anterior displacement of posterior disc material at the C5-6 and C6-7 disc levels. These disc levels were chosen because spondylosis of IVD's occurs most severely and frequently at lower cervical levels, with a higher incidence of disc degeneration and disc prolapse at the C5-7 disc levels (Matsumoto et al., 1998).

5.2 Methods

Participants

A total of 20 participants with neck pain gave informed consent to participate in this study including thirteen females and seven males between 21 and 55 years of age (38.5 ± 9.3 years).

Occupation:		**Mode of onset:**	
Office workers	n = 7	Insidious	n = 11
Students	n = 2	Falling down the stairs	n = 1
University lecturers	n = 2	One to two hours of a sustained rotated head position	n = 2
Lab based researchers	n = 6	RTA	n = 2
Massage therapist	n = 1	Sneezing with the head rotated	n = 1
Allied health professionals	n = 2	Head injury during sport	n = 2
		Whiplash while horse riding	n = 1
Duration of symptoms:		**Frequency of pain:**	
1 – 6 months	n = 5	Daily pain	n = 9
6.5 months – 1 year	n = 3	Few times per week	n = 3
1.5 – 3 years	n = 3	Two or more times per month	n = 3
3.5 years – 7 years	n = 3	Could not specify	n = 5
7.5 years +	n = 6		
Aggravating factors:		**Easing factors:**	
Sedentary activities	n = 15	General movement	n = 9
Overhead upper limb activity	n = 2	Manual therapy	n = 6
Sleeping awkwardly	n = 1	Heat application	n = 4
Lifting the head from supine	n = 1	Self postural correction	n = 4
Sudden jolts to the body	n = 1	Analgesics and NSAID's	n = 7
Neurological symptoms:		**Previous surgery:**	
One month history of paraesthesia along C6, C7 and/ or C8 dermatomes	n = 5	Removal of the C5-6 disc with a cage fitted	n = 1

Table 5.1 Summary of participants' pain history as well as symptom presentation and behaviour.

Participants were asked regarding their age, occupation, mode of onset of their pain, its duration of onset, frequency of pain as well as any aggravating and easing factors. A Numeric Pain Rating scale was used to rate their pain when at its best and at its worst. They were also asked about any upper limb neurological symptoms and any previous cervical surgery. History taking also included questions regarding any previous or current medical conditions, any medication they may be taking as well as what hobbies they engaged in. Information was recorded on a standard physiotherapy assessment sheet (see appendix 4). A summary of the information obtained from history taking and symptom presentation is provided in table 5.1.

The greatest aggravating factor was sedentary activities, such as laptop and computer use, prolonged sitting, slouched sitting, ironing, driving and reading. These observations correlate with the results of larger scale studies that found, among women, sedentary occupations had the highest prevalence of neck pain (Palmer et al., 2001). The mean age of this participant population of 38.5 years ± 9.3 is consistent with previous research reporting those over the age of 37 to be more susceptible to developing chronic neck pain (Cassou et al., 2002). The mean duration of symptom presentation was 8.3 years ± 9.4. Although five participants reported experiencing paraesthesia in the upper limb, none presented with any upper limb symptoms during their assessment. Six participants had office based jobs as well as two physiotherapy students, two University lecturers, six primarily lab based researchers, one massage therapist and two nurses. Duration of pain varied from 3 months to 30 years, with nine participants recalling a specific event that brought on their symptoms (see table 5.1). Of the twenty participants, only one reported previous surgery, performed in 2012. Twelve participants reported sedentary activities such as laptop and computer use, prolonged sitting, slouched sitting, ironing, driving and reading as aggravating their pain. All participants were noted to have a mild to moderate forward head posture, as observed visually, except for one participant who habitually sat upright to avoid pain.

Exclusion criteria

Exclusion criteria included any participant involved in a current medicolegal claim regarding their cervical spine and those who had undergone cervical surgery in the last 12 months. Participants with any condition that contraindicated the use of manual therapy techniques were also excluded.

Physiotherapy assessment

Participants were given a PIS (see Appendix 4), provided their informed consent (see Appendix 1) and completed an MRI safety questionnaire (see Appendix 2) to ensure there were no health and safety reasons for their exclusion from the studies. Following this, history taking and a physical examination was completed with each participant (see Appendix 3). During history taking, detailed questions were asked regarding their current and any previous episodes of neck, shoulder and/ or arm pain, as well as any neurological and any other associated symptoms. They were also asked about their medical history, current medication list, occupation and hobbies. Following completion of history taking, their sitting posture in a relaxed position was observed. A physical examination was then performed with cervical ROM assessed in three planes with a visual estimate of range recorded. If any current symptoms were reported in the upper limb such as pain or paraesthesia, a neurological assessment was completed involving dermatomal, myotomal and reflex tests.

This study conformed to the latest revision of the Declaration of Helsinki and the ethics committee at MMU.

Procedure

Following history taking and a physical examination, participants were asked to position themselves in the scanner in supine. They were assisted in the positioning of their heads into a neutral position, ensuring no rotation or tilt of the skull. A thin mat was placed between their head and the cervical coil headrest for comfort. Cushions were placed under their heels, knees and lower back for comfort as required.

MRI protocol

Protocols used for scanning in this current study were identical to previous studies (see study 1).

Extension-retraction exercise in sitting

Following this scan, participants were assisted out of the scanner and into a chair where they observed the PI demonstrate McKenzie's retraction and extension in sitting exercise. Participants were then seated on an upright chair with a high back, in a relaxed position with their sacrum in contact with the back of the chair. From this posture, they were instructed to perform ten repetitions of this movement to the best of their ability. The PI corrected the participant's technique if required and encouraged as much retraction and extension as could be tolerated. This initial demonstration of the exercise by the PI, followed by performance of the exercise by the participant with appropriate correction and encouragement as required, replicates the manner in which the technique would be taught in a physiotherapy setting. In most cases, participants initially found extension of the cervical spine painful and this limited the range achieved during the first few repetitions. Towards the last four to five repetitions, most participants found the pain to have subsided allowing them to achieve near 90 degrees of cervical extension with their heads near parallel to the floor. After performance of this exercise they were asked to position themselves in the scanner once again with their head in neutral, while trying to avoid any overt movements of the cervical spine. The PI once again ensured the head was in a neutral position by correcting any tilt or rotation.

Disc measurement

The C5-6 posterior disc nucleus for each participant was measured relative to a line connecting the posterior ends of the vertebral bodies above and below the disc (see study 2). Measurements were taken with the spine in a neutral cervical position both pre- and post-exercise. The C6-7 posterior disc nucleus was also measured, although it was noted in Chapter 2 that only moderate agreement had been found for repeated measures at this level. Adams and Roughley (2006) discuss several markers of disc degeneration, including disc narrowing as a result of loss of nucleus pressure and collapse of annulus height. Therefore, disc height was also measured from the vertebral end plates above and below each disc and used as a potential indication of disc degeneration (see table 5.2) (Dabbs and Dabbs, 1990).

Statistical analysis

A *post hoc* power analysis was conducted using Minitab (Minitab, 2010) to determine the sample size required to produce a power of 0.80 with an alpha of 0.05. The initial results from this current study produced a mean paired difference of 0.047 with a SD of the difference of 0.096. This gave a required sample size of 35 participants. Unfortunately, due to persistent technical difficulties with the cervical coil, no further participants could be recruited. Further *post hoc* power analysis using Minitab calculated a power of 0.6 with the sample size of 20.

A Pearson's correlation coefficient was used to determine the strength of association between participant age and disc height at the C5-6 disc level as well as between disc height and disc movement at both levels. The data was deemed to have a linear relationship as determined by scatter plot with a normal distribution as assessed by Shapiro Wilks tests of normality ($p = 0.69$). The non-parametric Spearman's correlation coefficient was used to determine strength of association between age and C6-7 disc height. Spearman's correlation coefficient was also calculated to assess the relationship between the maximum NPRS score and disc height, the maximum NPRS score and duration of symptoms, as well as between disc height and duration of symptoms.

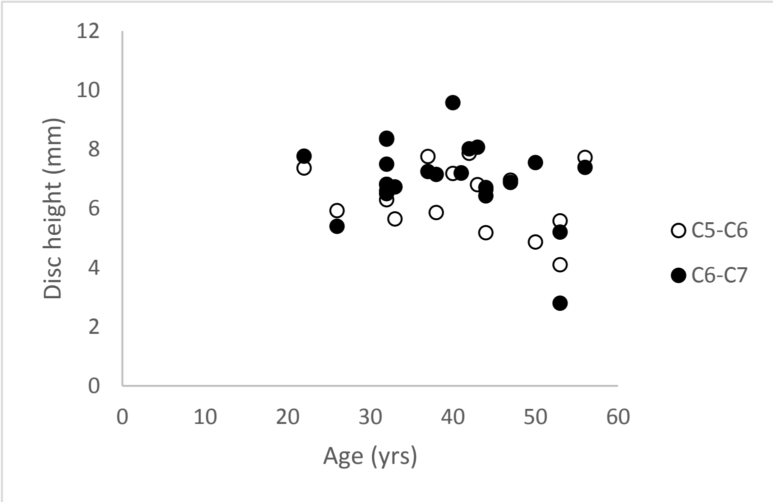
A paired-samples t-test was used to determine whether there was a statistically significant difference between posterior nucleus position at the C5-6 and C6-7 discs before and after application of 10 McKenzie retraction-extension exercises in sitting. There were no outliers as assessed by boxplot and the data was normally distributed for both the C5-6 and C6-7 disc measurements as assessed by the Shapiro-Wilk test (C5-6 disc, $p = 0.55$; C6-7 disc, $p = 0.74$). Data are presented as means and ± SD and statistical significance was set at $p \leq 0.05$.

5.3 Results

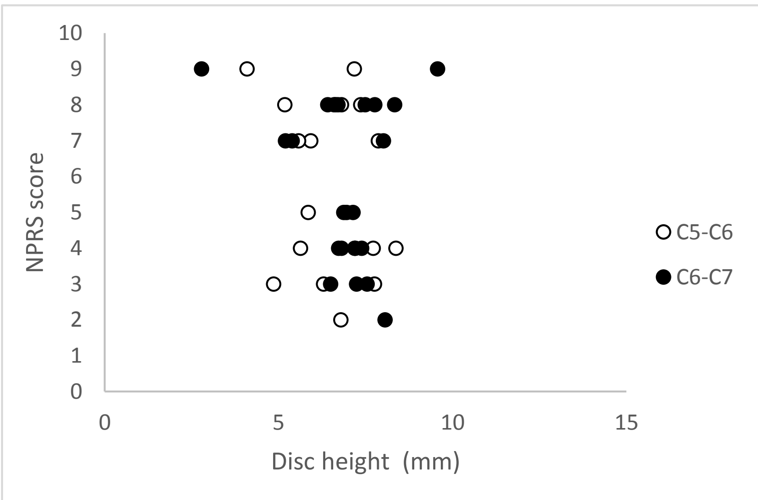
There were no significant correlations found between any of the baseline (pre-intervention) comparisons at either disc level. Scatter plots below demonstrate distribution of correlations between disc height and age and between NPRS score and disc height at both disc levels, as well as between disc height and disc migration at the C5-6 disc level (figure 5.1). Trend lines are not shown because the relationships are not significant. Disc height, NPRS scores and duration of symptoms are provided in table 5.2 below.

	Duration of symptoms Y/M	NPRS	Disc height C5-6 (mm)	Disc height C6-7 (mm)
Mean	8/10	5.8 ± 2.2	6.54 ± 1.1	6.96 ± 1.36
Minimum	0/3	9	4.10	2.79
Maximum	31/0	2	8.38	9.58

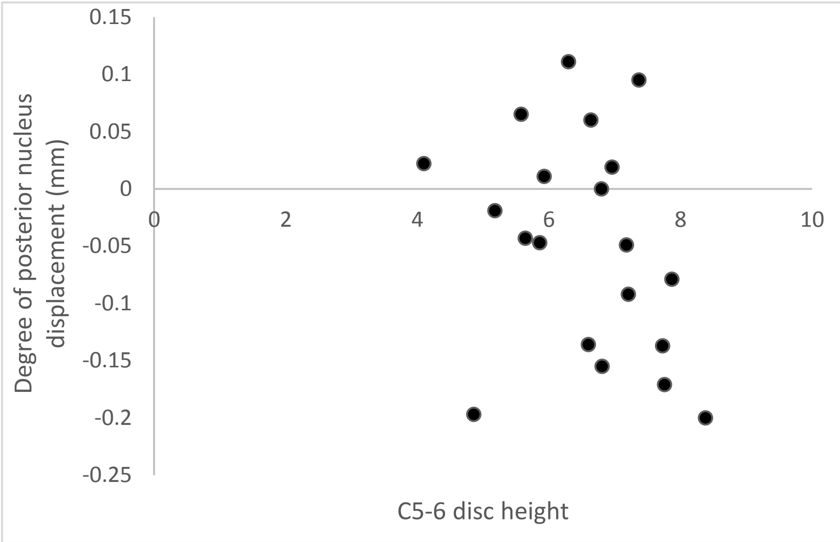
Table 5.2 Summary of frequencies for participant pain duration, pain levels and disc height measurements (n = 20).



A



B



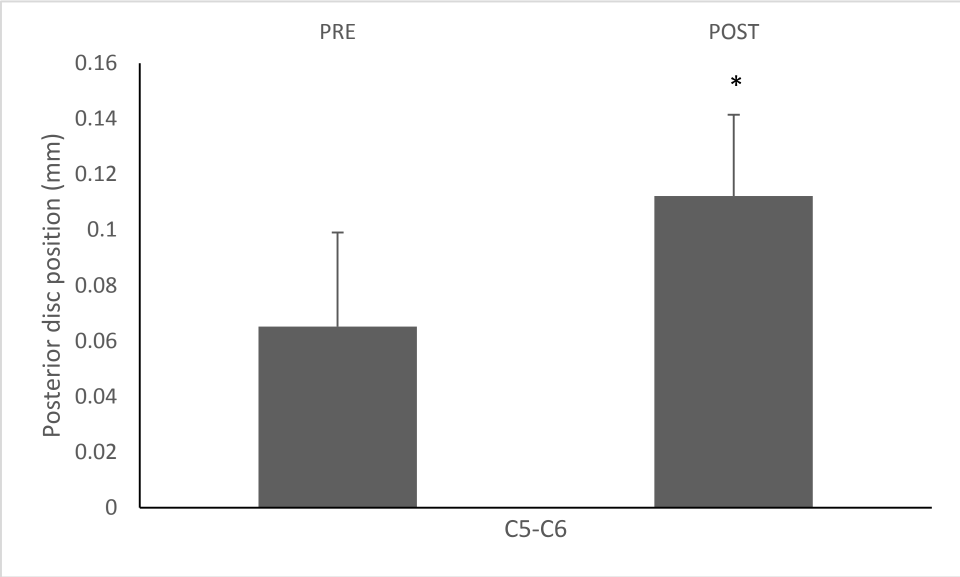
C

Figure 5.1. Scatterplots indicating correlations between disc height and age (A), disc height and NPRS score (B) and disc height and degree of posterior nucleus displacement (C).

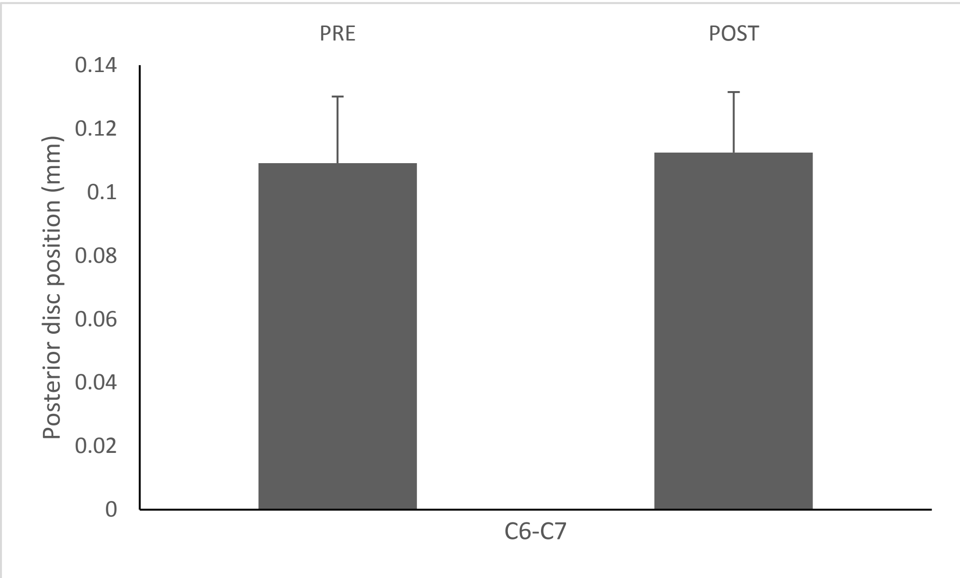
Following the McKenzie exercise there appeared to be a significant degree of anterior disc displacement at the C5-6 level of 0.05 mm ± 0.1 ($p < 0.05$, table 5.3). There was no significant change in disc position at the C6-7 level (table 5.3). Figure 5.2 illustrates posterior NP position pre- and post- exercise.

	Disc measurement (mm)	P value pre-post
C5-6 (pre-exercise)	0.07 ± 0.16	0.04
C5-6 (post exercise)	0.11 ± 0.13	
C6-7 (pre-exercise)	0.10 ± 0.1	0.84
C6-7 (post-exercise)	0.11 ± 0.09	

Table 5.3. Participant data prior to intervention.



A



B

Figure 5.2. Disc position (mm) and 95% CI error bars pre- and post-performance of McKenzie's extension exercise at the C5-6 (A) and C6-7 (B) disc level. * denotes a significant difference from pre-exercise position, p = 0.04.

5.4 Discussion

Previous RCT's looking at the DDM have only assessed the effects of various postures on position of the disc in the lumbar spine (Kolber and Hanney, 2009). Consistent with McKenzie's conceptual model of disc displacement, the data from this chapter suggests that anterior displacement of the posterior disc nucleus does occur with an extension based spinal exercise. Considering the limitations discussed in Chapter 3 regarding pixel size, there appeared to be a very small mean change in position of 0.05 mm. This is a change equivalent to 58% of the disc's mean starting position. Although the 0.05 mm of anterior disc displacement resulting from one set of the exercises is potentially only 3% of the mean distance between the posterior disc and the theca (see study 1), this would be sufficient to reduce pressure on neural structures if the posterior disc was in direct contact with the theca or the spinal cord. Furthermore, in a clinical setting, 5-6 repetitions of this exercise would likely be performed several times a day over several days. As these results indicate a change in C5-6 posterior disc nucleus position was achieved after only 10 repetitions, one may assume that repeated extensions would result in a greater degree of anterior disc movement at both disc levels. Further repetitions were not completed in order to reduce patient discomfort, as this exercise was not performed with the intention of reducing symptoms but rather only to assess its effect on disc position.

Based on the findings of this chapter, it appears that a single bout of the retraction-extension exercise was sufficient to induce changes in posterior disc NP position at the C5-6 level, however, further sets may be required to induce changes at other spinal levels.

Although the change in disc position at the C5-6 level was deemed significant, there was not as much disc movement created by this exercise as there was with change in position of the cervical spine (see study 3). Movement of the spine from neutral to flexion created a change of 0.71 mm in disc position while change in position between flexion and extension created a 1.03 mm change. This implies that sustained cervical postures of short duration have a greater impact on disc position than 10 repetitions of an exercise aimed at altering disc position. These findings help support the emphasis placed by Robin McKenzie on maintaining postures that encourage an upright spinal position as part of the therapeutic process (McKenzie, 1981; McKenzie and May, 2006).

Mercer and Jull (1996) questioned whether McKenzie's conceptual model for treatment of a derangement syndrome held true in the cervical spine. This was questioned firstly, because of the anatomical differences between the cervical and lumbar discs, with the cervical discs' gelatinous NP being replaced by fibrocartilage as early as the mid-teens, and secondly because of the discontinuous outer annulus of the cervical disc that McKenzie postulated was required in order for the NP to respond to loads in a predictable manner (McKenzie, 1981). Interestingly however, the results of this investigation show that despite both these anatomical features, the cervical disc did respond to extension loading at the C5-6 disc level.

Bearing in mind the results of the test-retest reliability study (see study 2), it is still interesting to note that anterior movement of the disc at the C6-7 level appeared significantly less than at the C5-6 disc level (difference of 0.04 mm). This is consistent with findings from study 3 that reported significantly less movement of the disc in cervical extension at the C6-7 disc (0.58 mm) compared to the C5-6 disc level (1.03 mm). One plausible explanation for this is the more distal location of the C6-C7 vertebral segment. At end range position of the retraction-extension exercise in sitting, the greatest amount of extension occurs at the more proximal joint levels and this is apparent from figure 1.17 (see Chapter 1). This may imply that the C5-6 joint segment achieved slightly greater extension during this exercise, thereby potentially allowing for great anterior disc displacement.

Robin McKenzie produced a series of progressions for this exercise, aimed at producing increasingly greater degrees of cervical extension, always aiming to reach the end of available range. One of these progressions includes lying in supine with the head, neck and shoulders placed unsupported over the edge of a bed. The patient supports their head with one hand under the occiput and performs the retraction-extension movement with the aid of gravity, slowly tilting the head as far back as possible into end range extension (McKenzie and May, 2006). It may be the case that in order to achieve a more significant degree of extension at the lowest cervical segments, this progression of retraction and extension in supine is required.

Pre-exercise correlations

The lack of any significant correlation between disc height and age in this participant group supports the age range chosen for this current study of 19 to 55 years. These findings also correlate with those of previous research reporting loss of disc height, as well as significant degenerative changes in the cervical spine, occurring between 60 to 65 years of age and over (Lawrence, 1969; Teresi et al., 1987). The lack of any significant correlation between disc height and disc migration reported in this study further supports the age range chosen, allowing for greater confidence that participant age was not a confounding factor affecting measurement results.

The association between disc height and spinal pain in the literature is variable. de Schepper et al. (2010) reported positive correlations between disc space narrowing and lower back pain while Videman et al. (2003) felt there was a poor correlation between these two variables. These opposing results may be due to the differences in sample type and size between the two studies. de Schepper et al. (2010) recruited a sample of over 1800 men and women while Videman et al. (2003) recruited 115 monozygotic male twin pairs as they felt this would control for the confounding effects of the combined role of genetics and early family influences. Another reason for the variation could be due to the differences in their analyses of the results. For example, Videman et al. (2003) concluded there to be a poor association between disc height and back pain after controlling for genotype and other familial influences. de Schepper et al. (2010) reported correlations between disc height and lower back pain after assessing disc space narrowing at two or more levels, and especially after excluding disc level L5–S1. The findings of this current investigation lean towards the assumption that disc narrowing and cervical pain are not correlated.

5.5 Conclusion

This study examined the effects of 10 repetitions of McKenzie 'retraction-extension exercise in sitting' on the position of the posterior NP at the C5-6 and C6-7 disc levels. There appeared to be a significant degree of anterior displacement of the posterior disc nucleus at the C5-6 level after completion of this exercise. These results may help support McKenzie's claim that discs are moveable structures that have the potential to respond in a predictable manner to specific directional forces. In light of these findings, therapists may have greater confidence in the use of McKenzie's retraction-extension exercise when aiming to reposition posteriorly displaced cervical disc material.

Although a significant change in disc position was not found at the C6-7 level following this exercise, this may be partly due to the low number of repetitions performed and the type of extension exercise used. In a clinical setting, this exercise would usually be performed in multiple sets, and given as an exercise to be performed over a several days (McKenzie and May, 2006). In addition, the performance of this exercise in supine, a known progression, may have allowed for greater extension at the lowest cervical segments, potentially producing greater anterior disc migration.

Limitations/ Further studies

It was not assumed that the symptoms experienced by the participants in this study were of a discogenic origin and there was no assumption that anterior disc displacement would reduce their pain. It was therefore not felt necessary to assess the NPRS score after completion of the exercise. Studies have shown that disc protrusions in both the cervical and lumbar spine are common findings in an asymptomatic population, with an increasing incidence of prolapse with increasing age (Teresi et al., 1987; Schwarzer et al., 1995; Matsumoto et al., 1998; Stadnik et al., 1998). The lack of any significant correlation reported in this current study between posterior disc position and NPRS score would agree with those findings. Consequentially, one may enquire as to whether the degree of anterior disc displacement achieved at the C5-6 disc level was of clinical benefit. With this question in mind, it may have been advantageous to use a population with confirmed disc protrusions and associated neural compromise. Neurosurgical waiting lists commonly include patients with confirmed cervical radiculopathy secondary to disc prolapse (Garvey et al., 2002). The use of this type of patient group for this study would have allowed for the direct assessment of any measurable reduction in nerve root compression as a result of anterior or antero-medial disc migration after performance of the retraction-extension exercise in sitting. If anterior displacement of disc material was achieved and was associated with a reduction in radicular symptoms, this may encourage greater use of McKenzie's exercises for surgical candidates that have failed with other conservative measures. Nevertheless, this current study provides a good starting point for future research.

A further potential limitation to this study was the convenience sample of participants recruited, mostly consisting of University staff and students with a few healthcare professionals and administrators. It would have been interesting to assess the behaviour of cervical discs in those with heavy manual jobs such as builders and road workers. Perhaps the cervical discs of those in more sedentary professions behave differently to the discs of those with occupations that involve greater loading of the spine.

Future research

Consideration for future research may be to assess the effects of McKenzie's retraction-extension exercise on the cervical discs in an elderly population, especially considering the increased incidence of spinal pain reported in the elderly (Manchikanti et al., 2008). Studies have shown that the more degenerative the disc, the less likely it is to respond in a predictable manner to the forces applied upon it (Schnebel et al., 1988). This implies that the McKenzie method of mechanical therapy may be less effective for an elderly population as the discs become more degenerative with age (Gore et al., 1986; Teresi et al., 1987; Boden et al., 1990). It would be interesting to assess whether this assertion is true. One point to consider however, is that the cause of nerve root compression in the elderly is often a result of bony changes rather than disc protrusion (McCormack and Weinstein, 1996).

Finally, lumbar spine pain is more common than cervical spine pain (Picavet and Schouten, 2003), with discs of the lower spine more frequently and more severely affected than discs in the upper spine (Holt and Yates, 1966). This is likely due, at least in part, to the increased loads placed upon the lower section of the spine. It may be useful for future research to assess the effects of McKenzie's extension exercises on participants with confirmed lumbar radiculopathy.

Chapter Six

General discussion

6. 1 Overview and main findings

The primary aim of this thesis was to establish whether the conceptual model of IVD displacement, promoted by the late Robin McKenzie, a world renowned and accredited physiotherapist, held true for discs in the cervical spine. His first publication, The Lumbar Spine, Mechanical Diagnosis and Therapy, describes the discs of the lumbar spine as retaining a hydrostatic pressure, and therefore able to alter their position according to the biomechanical loads placed upon them. He supported this assertion with research that had been conducted at the time using cadaveric lumbar spine specimens (McKenzie, 1981). More recent research conducted on the lumbar spine also supports the idea of the lumbar disc maintaining a hydrostatic mechanism, with flexed postures shown to cause anterior disc displacement and extended postures appearing to cause the reverse affect (Beattie et al., 1994; Alexander et al., 2007). McKenzie made reference to *in vitro* research conducted at the time demonstrating NP displacement accompanying alterations in position of the vertebral segments. Diagrams used to illustrate this demonstrated approximation of the posterior vertebral segments in extension with approximation of the anterior vertebral segments in flexion. It was thought the compressive loading of the segments were what created NP displacement. With this biomechanical reasoning, he developed an entire treatment therapy, now taught worldwide, aimed at improving the position of displaced spinal disc protrusions through various postures and with specific loaded exercises. In order to assess the effects of spinal loading on both vertebral segment position and posterior NP displacement, the following objectives were set:

1. To determine whether, as described in McKenzie's conceptual model, flexion and extension of the cervical spine cause anterior and posterior vertebral body approximation respectively at the C5-C6 to C7-T1 vertebral segments.

2. To determine whether a change in cervical posture, between neutral, flexion and extension, causes a predictable change in position of the posterior C5-6 and C6-7 NP.
3. To determine whether McKenzie's retraction-extension exercise in sitting causes anterior displacement of the C5-6 and C6-7 IVD, according to his conceptual model.

In brief, the main findings of this current thesis support the concept of the DDM in the cervical spine of asymptomatic participants, with flexed cervical postures appearing to cause posterior displacement of the cervical disc and extended postures causing anterior displacement. The posterior disc migration resulting from a forward head posture helps support the ergonomic advice of upright spinal postures during occupational activities. These results may also highlight the potential detrimental effects modern technology such as laptops, tablets and phones have on position of the cervical disc, as the natural posture during the use of such devices tends to be a forward head posture. The anterior migration caused by cervical extension appears to indicate a posture that, as McKenzie suggested, can reverse the effects on the disc of a forward head posture.

Furthermore, McKenzie's retraction-extension exercise in sitting, aimed at causing anterior disc displacement through loading of the posterior disc with end range cervical extension movements, did appear to cause a significant degree of anterior displacement of the posterior C5-6 NP. These findings suggest that the theoretical basis for McKenzie's extension principle holds true. For the therapists worldwide that use this technique, these results may provide greater confidence in the use of and explanation to patients as to their mechanism of action.

Finally, there were significant changes in Cobb angle measurements at the C5-C6 vertebral segment between neutral and flexed postures only, however this was not correlated with disc displacement. A more thorough explanation of these findings is described below.

6.1.1 The effects of three cervical postures on vertebral segment position, and correlation with disc displacement

McKenzie (1981) reported previous literature describing displacement of NP material occurring concomitantly with changes in vertebral segment angle. He therefore felt that by manipulating vertebral position, position of the IVD could also be manipulated. It was with this reasoning that he devised his series of spinal exercises aimed to load the NP through various spinal postures and movements.

Consistent with previous research on the lumbar spine (Fennell et al., 1996; Alexander et al., 2007), results from study 2 show a significant degree of approximation of the anterior vertebral segment in cervical flexion compared to neutral at the C5-C6 level. Although no significant association was found between vertebral segment movement and disc migration at any level, combined data from studies 2 and 4 illustrate similar patterns of movement between the vertebral bodies and the posterior NP. At the C5-C6 level, as the anterior Cobb angle reduces in flexion, the disc NP takes a more posterior position. Concomitantly, the posterior Cobb angle reduces in neutral and extension when compared to flexion (see figure 6.1). Figure 6.2 appears to show that this pattern of movement is repeated at the C6-C7 vertebral segment. As the anterior Cobb angle reduces in flexion, the disc NP takes a more posterior position. As the cervical spine moves into neutral and extension, the posterior Cobb angle reduces compared to flexion.

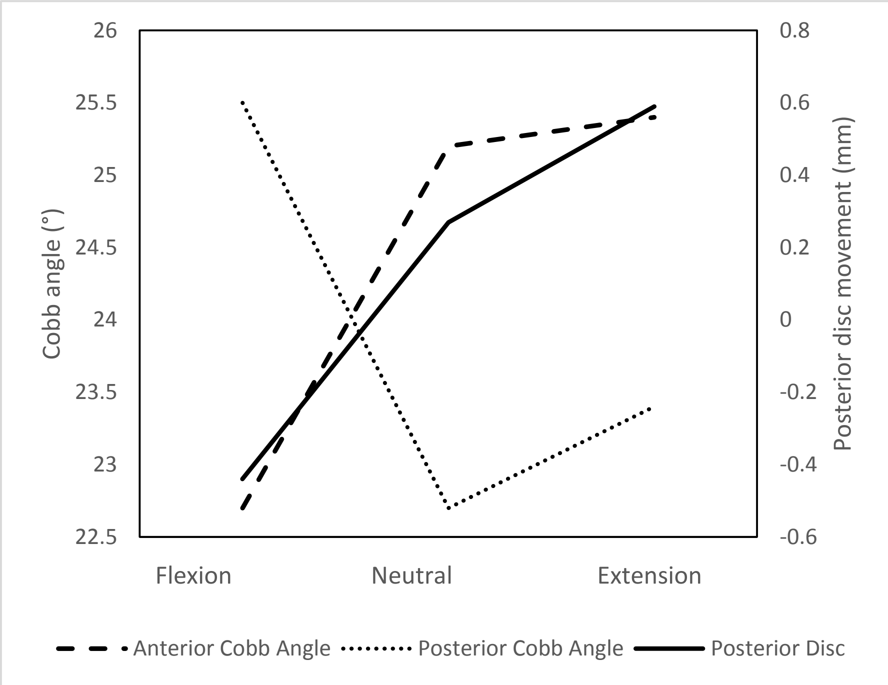


Figure 6.1. Adapted Cobb angle measurements at the C5-C6 vertebral segments. Position of the C6-7 posterior disc is represented by the solid line (n = 15).

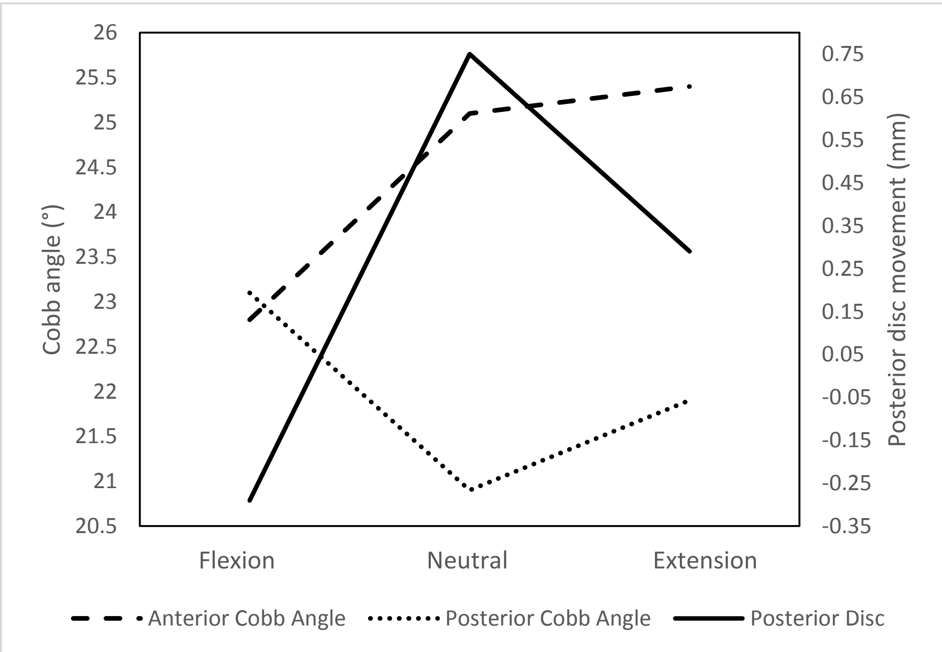


Figure 6.2. Adapted Cobb angle measurements at the C6-C7 vertebral segments. Position of the C6-7 posterior disc is represented by the solid line (n = 15).

As previous results demonstrated, no significant correlation was found between anterior and posterior adapted Cobb angles (see study 2). However, graphically the two vertebral angles appear to show opposing patterns of movement.

The lack of significant changes in Cobb angle at the other cervical segments is likely a result of an inability to achieve significant degrees of lower cervical flexion and extension as a result of the cervical coil and the scanner bed. As mentioned previously, there would be benefit in repeating these measurements in an upright MRI scanner with a larger bore as this would hopefully allow imaging of greater degrees of cervical movement, as well as better represent common occupation and leisure postures.

6.1.2. Effects of cervical posture on position of the posterior C5-6 and C6-7 NP

Results from study 4 indicate that flexed cervical postures cause posterior displacement of the posterior NP while extended postures cause anterior displacement. When describing his conceptual model in the lumbar spine, McKenzie felt that in order for the disc to be able to displace in this predictable pattern, the disc required an intact outer annulus. This would prevent extrusion of NP material, thereby maintaining its hydrostatic pressure. Anatomical dissection of the cervical disc by Mercer and Bogduk (1999) have shown that the cervical disc does not contain an intact annular wall along its posterolateral borders. Mercer and Jull (1996), in fact, questioned McKenzie's conceptual model of disc displacement in the cervical spine because of their anatomical finding. McKenzie and May (2006) make reference to their questioning, pointing out that their conclusions were based on anatomical studies, with their morphological models constructed from post mortem examinations. The findings of this thesis also appear to question the assumptions of Mercer and Jull (1996), with evidence of posterior and anterior NP displacement in flexed and extended cervical postures respectively.

Therapists commonly provide postural advice to those presenting with spinal pain, often dissuading patients from maintaining prolonged flexed sitting and standing postures. These results strengthen the evidence that this postural advice is appropriate when aiming to reduce posterior displacement of cervical disc material.

Significant changes in posterior NP position were obtained despite the scans being performed in a supine position, which not only limited the degree of flexion and extension achieved, but also reduced the effect of gravity on the cervical spine. Multiple attempts were made to perform the scans in an upright sitting position, however the images produced in seated postures were significantly degraded for a large number of the participants. Future studies using an alternative upright scanner could provide more specific information regarding the effects of common occupational and leisure postures on position of the cervical disc.

6.1.3 The effects of McKenzie's retraction-extension exercise in sitting on position of the posterior C5-6 and C6-7 nucleus pulposus

McKenzie's exercises, provided for those presenting with a derangement syndrome, are aimed at manipulating position of the spinal disc. He felt strongly that the disc could be a source of pain, and that protruded disc material could be returned back to its centre with the performance of specific end range spinal movements (McKenzie, 1981; McKenzie and May, 2003; McKenzie and May, 2006). He felt this repositioning of disc material back to its centre, thereby equalizing intradiscal pressure, could help relieve symptoms for a particular group of spinal pain presentations. His exercises, therefore, aimed to reduce multiple directions of disc herniations in the spine through the concept of disc loading described above. For example, if a patient presented with signs of a posterior disc herniation, end range loaded movements into extension were applied in order to reposition the disc into a more anterior position.

In study 3, a symptomatic population performed the retraction and extension exercise in sitting to assess whether the end range cervical extension movements caused anterior displacement of the posterior NP, as it is intended to do for those diagnosed with a posterior derangement syndrome (see Chapter 1). Results suggested that performance of 10 repetitions of this exercise did cause a significant degree of anterior displacement of the posterior NP at the C5-6 disc level. Although there was no significant change in disc position at the C6-7 disc level, there did appear to be a pattern of anterior displacement after performance of the exercise.

Further studies assessing the effects of multiple sets, alternate directions of loading, as well as various progressions would provide further support for the efficacy of these exercises. It was mentioned in study 4 that it would be misleading to overstate the role of the spinal disc in the production of spinal pain. However, in a population presenting with a confirmed radiculopathy secondary to disc herniation, being able to manipulate the disc away from the site of neural compression could provide significant symptom relief.

6.2 Conclusion

In conclusion, there is support for the DDM in the cervical spine at the C5-6 disc level. These findings, and those assessing the DDM in the lumbar spine, are a credit to Robin McKenzie, who developed an entire therapeutic treatment approach, based on what was at the time, mostly a conceptual model of disc migration. Although his techniques incorporate much more than treatment of spinal derangements, he felt this was the most common presentation presenting therapeutically. These results hopefully provide further evidence to the benefit of maintaining an upright posture during occupational as well as leisure activities. Therapists worldwide using McKenzie's technique for the cervical spine may also find these results of interest as they support the idea that his extension based cervical exercise causes anterior disc migration.

6.3 Future research

Throughout this thesis, specific areas for future research have already been highlighted. In summary, the main areas that would be of therapeutic benefit, include an investigation of the effects of further repetitions on position of the disc, with an assessment of whether this correlated with increased degrees of disc displacement. This would support the basis of repeated repetitions provided by the therapist. This future work should aim to secure a more powerful, upright MRI scanner able to produce higher quality images so that disc position can be measured with greater confidence. A larger sample size should also be obtained in order to reduce the potential for Type II errors.

It would also be useful to assess the effects of various progressions of the exercises to assess whether certain postures are more effective than others at altering disc position. Assessment of various sitting postures on disc position would provide information regarding common occupational and leisure postures on posterior disc displacement. As lumbar spine presentations outnumber those of the cervical spine, the assessment of McKenzie's exercises on position of the disc in the lumbar spine would also be of benefit. From a clinical view point, the assessment of the effects of McKenzie's exercises on position of the disc with those with confirmed radiculopathy secondary to disc displacement may provide stronger evidence for the use of this treatment technique prior to consideration of neurosurgery.

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Appendices

Informed consent, MRI safety questionnaire and assessment form

Department of Exercise and Sport Science

Manchester Metropolitan University — Cheshire —

Informed Consent Form

(Both the investigator and participant should retain a copy of this form)

Name of Participant:

Principal Investigator: **Areej Elmaazi**

Project Title: **The dynamic disc model in the cervical spine.**

Ethics Committee Approval Number: 30.01.13 (i)

Participant Statement

I have read the participant information sheet for this study and understand what is involved in taking part. Any questions I have about the study, or my participation in it, have been answered to my satisfaction. I understand that I do not have to take part and that I may decide to withdraw from the study at any point without giving a reason. Any concerns I have raised regarding this study have been answered and I understand that any further concerns that arise during the time of the study will be addressed by the investigator. I therefore agree to participate in the study.

It has been made clear to me that, should I feel that my rights are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform the Registrar and Clerk to the Board of Governors, head of Governance and Secretariat Team, Manchester Metropolitan University, All Saints Building, All Saints, Manchester, M15 6BH. Tel: 0161 247 1390, who will undertake to investigate my complaint.

Signed (Participant)

Signed (Investigator)

Please provide a contact number in case we need to get in touch with you.

I confirm that the details of this study have been fully explained and described in writing to (insert name) and have been understood by him/her and I therefore consent to his/her participation in this study.

Telephone :

MANCHESTER METROPOLITAN UNIVERSITY MRI UNIT

SCREENING & CONSENT FORM FOR MAGNETIC RESONANCE IMAGING (MRI)

Patient ID……………………………………………………

It is important that you read and understand the questions below since we cannot scan you until they are all answered. Please do not sign the form unless you are happy with the information you have given.

Delete as appropriate

1. Have you ever had an MRI scan before? Yes/no
   If so, where?...
2. Do you have a cardiac pacemaker or have you ever had heart surgery? Yes/no
3. Had you ever had any operations on your heart, head, neck or back? Yes/no
   Please give details………………………………………………………………….
4. Have you ever had any other operations?
   Please give details………………………………………………………………….
5. Have any of these operations involved the insertion of metal pins/plates/implants? Yes/No. Please give details including type, location and date of surgery.

   ………………………………………………………………………………………………

   ………………………………………………………………………………………………
6. Is there any possibility that you may have metal from a previous injury, e.g.
   a) have you ever had metallic fragments in your eyes? Yes/no
   b) have you ever had a shrapnel or bullet injury? Yes/no
7. Have you ever suffered from epilepsy? Yes/no
8. Have you removed the following – jewellery, hair clips, keys, watches, hearing aids, coins, spectacles, false teeth, other metal objects, credit cards, memory sticks? Yes/no
9. Do you have any tattoos? Yes/no

   FEMALES ONLY

10. Is there a possibility that you may be pregnant? Yes/no
    Date of last period……………………
11. Do you have a contraceptive diaphragm in situ? Yes/no

SIGNATURE……………………………………………………………………. DATE………………………….

MRI OPERATIVE……………………………………………………………… DATE………………………….

SPORTS INJURY CLINIC PHYSIOTHERAPY

SA	P	MSS I	No. of authorised Rx's No. of authorised Rx's

FULL NAME:

D.O.B:

ADDRESS:

EMAIL:

TELEPHONE NUMBER:

UNIVERSITY TEAM SPORT (if applicable):

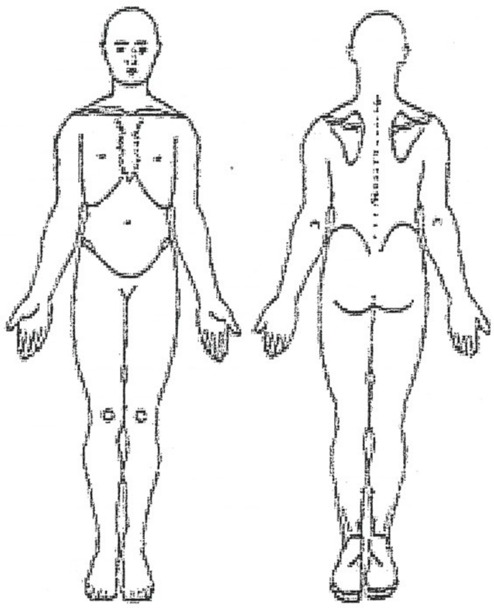
Date:

Physiotherapist:

Informed consent:

Constant/ Intermittent

VAS:



Aggs

Eases

Red Flags Lx

Severe/ progressive LL neurological deficit
Saddle anaesthesia
Night Sweats
Unremitting pain
Sudden, unexplainable weight loss
Recent onset of bladder & bowel dysfunction
H/o cancer
Thoracic pain
Morning stiffnes > 1 hour

Red Flags Cx

Drop attacks
Diplopia
Dysarthria
Dysphagia
Dizziness
Ataxia
Nauseous
Numbness
Nystagmus

MANCHESTER METROPOLITAN UNIVERSITY

MMU Cheshire

Department of Exercise and Sport Science

Information Sheet for Participants

Title of Study:

The role of McKenzie based mechanical therapy in the management of cervical spine disc dysfunction

Ethics Committee Reference Number: 30.01.13 (i)

Participant Information Sheet

1) This is an invitation to take part in a piece of research.

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Please take time to decide whether or not you wish to take part.

2) What is the purpose of the research?

i. To determine if there is any movement of the discs in the cervical spine (neck) when placed in different positions

ii. To determine whether certain neck exercises cause movement of the discs within the neck

3) Why is the study being performed?

Between each vertebra (bone) in our spines there is a disc, shaped somewhat like a half flattened balloon and filled mostly with water. In some of us these discs can prolapse (bulge). The term prolapsed disc usually refers to a posterior (backward) or posterolateral (back and sideward) movement of the disc away from its natural centre. There are certain postures and exercises which are meant to return the disc from a prolapsed position back to a central (**non-bulging**) one. Studies have been done looking at whether certain spinal positions cause movement of the disc further away or closer to its natural centre, however, to date all these studies have been performed on the lumbar spine. There are no current published studies that have assessed movement of the disc in the cervical spine. There are also no published studies that have looked at the effects of certain exercises on movement of the spinal disc with the use of MRI.

The aim of this study is to determine, with the use of an MRI scanner, whether discs in the neck move in the same way that has been found in the lumbar spine. It also aims to determine whether certain **neck stretching** exercises can help to improve the position of a prolapsed disc.

4) Why am I being asked to take part?

This study requires both healthy volunteers and those with at least a **four-week** history of neck, upper arm and/ or shoulder pain. If you do not have neck pain, you will have your neck scanned in a **forward (chin to chest), neutral and extended (look up to the ceiling) position**. Some of you will be asked to come back and have these three scans repeated on a separate day.

If you have neck pain you will have your neck scanned in **only a neutral position both before and after a set of exercises** and you will be asked to return for one further visit within a three week period for one final scan to be taken. There will be a maximum of two scans during each visit with each scan taking no more than 10 minutes.

All participants will receive a CD copy of all the scans taken of their necks during their involvement in the study.

5) Do I have to take part?

You are under no obligation to take part in this study. If, after reading this information sheet and asking any additional questions, you do not feel comfortable taking part in the study you do not have to. If you do decide to take part you are free to withdraw from the study at any point, without having to give a reason. If you do withdraw from the study you are free to take any personal data with you and this will not be included when the research is reported. If you decide not to take part or withdraw from the study this will not affect your relationship with any of the staff at Manchester Metropolitan University.

If you do decide to take part you will be asked to sign an informed consent form stating your agreement to take part and, if you request this, you will be given a copy together with this information sheet to keep.

6) What will happen to me if I agree to take part?

If you do not have any previous history of neck, shoulder and/or arm pain you will be asked to attend the Manchester Metropolitan University John Dalton building in Manchester **where you will first be asked a few questions followed by a quick check of the movements of your neck**. **You will complete a safety questionnaire to ensure there is no reason why you should not undergo an MRI scan (pregnant women and people with certain types of metal implants will not be able to participate in this study). If safe to do so**, you will then have an MRI scan taken of your neck which will involve you lying still, on your back, for no more than 20 minutes **with a half dome-shaped device centered above your head**. During this time **you will have your neck scanned in a neutral position**. A second scan will then be completed this time with your neck in a **slightly forward position supported by a pillow**. This process will be repeated one more time with your neck **slightly tilted backwards in a supported position**. You will be asked to re-attend within seven days to have this process repeated.

If you have neck pain, you will be asked to attend this same location where more **extensive questions will be asked about your pain** and some general **measurements of your neck range of movement** will be taken. You will then be asked to **lie on your back** in the scanner where **one scan of your neck lasting approximately eight minutes** will be taken. You will then be asked to come out of the scanner and will **be shown how to perform a stretch exercise of your neck**. You will be asked to repeat this exercise **ten times** and immediately after you will undergo **one more scan** while lying on your back again. The entire visit should last approximately one and a half hours with each scan lasting **no more than 10 minutes**.

If you are in the neck pain group, you will then be invited to **return in three weeks with a final scan performed at this time**s. During these three weeks, some of you will be asked to continue these exercises and some of you will not. If you have been asked to continue with these exercises, you will also be asked to keep a mental note of the amount and times you complete them during this period.

7) Are there any disadvantages or risks in taking part?

There are no known disadvantages to taking part in this study. **Every measure will be taken to ensure your comfort while undergoing the scans.** You will be provided with the researcher's contact details should you encounter any problems within the three week period between scans.

8) What are the possible benefits of taking part?

For both the participants with neck pain and those without, you are helping to determine the way in which the cervical spinal disc moves as this information is currently lacking in the scientific literature.

Specifically for the participants with neck pain, you are helping to determine the benefits of specific exercises in the management of neck pain. The physiotherapist will also be happy to answer any specific questions on your symptoms throughout and on completion of the scans.

9) Who are the members of the research team?

Principal Investigator: Areej Elmaazi
Supervisor 1: Dr Islay McEwan
Supervisor 2: Dr Sandra Lewis
Supervisor 3: Dr Chris Morse

For any further information please use the following contact details: 07500848796; a.elmaazi@mmu.ac.uk

10) Who is funding the research?

This research is self-funded by the Principle Investigator

11) Who will have access to the data?

All information collected during the course of the research will be kept confidential and will only be used for the purposes of the study. The data will be stored anonymously in a locked cupboard and only the Principal Investigator **and supervisory team** will have access to this information. Participant data will be kept until 24 months following the end of the research project **after** which all the data will be destroyed. It is envisaged this project will be completed by December 2015.

The results of the study may be communicated at conferences or published in scientific journals at some point in the future but in a manner that does not allow an individual's identity to be determined. Each participant will have the opportunity to obtain a copy of any publication that results from the research.

You have the right to obtain a copy of any publication that results from this research. Please send requests in writing to Areej Elmaazi, Room 1-19, Seeley, Manchester Metropolitan University, Crewe Green Road, Crewe, CW1 5DU

12) Who do I contact if I feel my rights have been violated?

Registrar & Clerk to the Board of Governors
Head of Governance and Secretariat Team
Manchester Metropolitan University,
All Saints Building, All Saints,
Manchester, M15 6BH
Tel: 0161 247 1390

13) Finally, a thank you!

A sincere thank you for helping make this research project possible.

ESS Ethics Stage 1 ISP form. Use this ISP form for all Stage 1 reviews from September 2012 onwards.