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SYSTEMATIC REVIEW

The dynamic disc model: a systematic review of the literature

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Background: The intervertebral disc (IVD) has been implicated in the etiology and pathogenesis of spine pain. Examination and treatment approaches directed at the IVD often cite a biomechanical principle referred to as the dynamic disc model (DDM), which is hypothesised to account for positional changes of the nucleus pulposus (NP). The DDM proposes a predictable pattern of NP migration in response to movements and positioning; consequently, this model has served the basis for many clinical decisions.
Objectives: The purpose of this manuscript was to systematically review the available research pertaining to the DDM in human discs.
Methods: A literature review was conducted by two investigators independently using the MEDLINE, SPORTDiscus, EMBASE.com and CINAHL databases and the following key words independently and in combination: intervertebral disc, nucleus pulposus, nucleus migration, disc model, disc loading and dynamic disc model. Results from each researcher were pooled and studies were manually cross-referenced yielding 12 articles.
Results: A predictable *in vitro* and *in vivo* pattern of NP movement was identified with the NP migrating anterior during extension and posterior during flexion in the normal IVD. Limited and contradictory data were available to support this model in the symptomatic and degenerative IVD. No studies were identified in the cervical and thoracic spine above the T10 level.
Discussion: Available research supports the DDM of NP migration; however, an inconsistent pattern of migration may exist in patients with symptomatic and/or degenerative intervertebral discs. Future research is needed to evaluate the DDM in the cervical and thoracic spine and in abnormal discs.

Keywords: disc loading, disc model, nucleus migration, nucleus pulposus

Introduction

Disorders of the spine are a significant societal problem from both a medical and economic perspective. In particular, lumbar and cervical spine pain are among the most common conditions for which individuals seek outpatient physical therapy care.[1] From an epidemiological perspective up to 84% of adults will experience low back pain (LBP) and up to 70% report cervical pain at some point in their lifetime.[2–5] The problem of spinal pain is further highlighted by the recurrence rate. Reports indicate an 85% lifetime recurrence rate of LBP and 38% cervical spine pain for adults who have had a previous episode, suggesting prior history is a strong predictor for future episodes.[2,6] Given the prevalence of spine disorders and high recurrence rates, individuals will often seek therapeutic treatment. The interventions selected for these patients may be based on numerous variables such as impairments, clinical prediction rules and classification systems; however, in some cases, the underlying diagnosis may influence clinical decisions.

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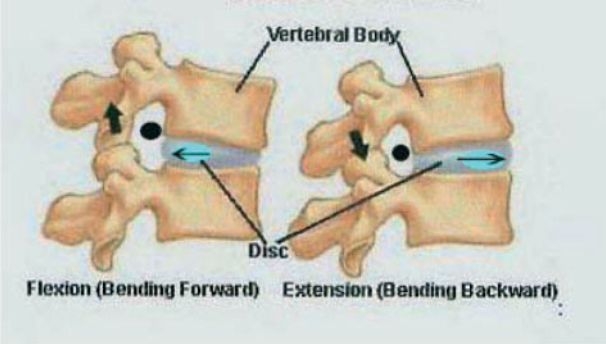

Figure 1 Lumbar spine intervertebral disc: horizontal arrow depicts migration of the nucleus pulposus according to the dynamic disc model (DDM)

While the precise etiology of spine pain is often obscure researchers and clinicians have implicated the intervertebral disc (IVD) as a more common source.[2,7–10] The IVD is primarily composed of two structures, namely the annulus fibrosus (AF) and the nucleus pulposus (NP).[11] The AF is composed of concentric layers of collagen fibres that enclose the NP.[9,11] The NP consists of a protoeglycan or semifluid gel that comprises 40–60% of the disc.[11] The effect of mechanical forces on the IVD has received much attention among clinicians and researchers particularly in regards to exercise. One of the controversies within the rehabilitation professions lies in whether patients with discogenic disorders should be instructed to maintain a neutral, flexed or extended spine. This controversy lies in positional changes of the NP postulated to occur within the IVD from positioning. McKenzie and Cyriax have specifically described displacement of the IVD and have advocated extension (lordosis) whereas others have advocated flexion.[9,12] Those who advocate extension have cited a biomechanical principle referred to as the dynamic disc model (DDM) which suggests that compression loading of the IVD during movements of the spine causes the NP to migrate within the AF opposite the direction of compression (Fig. 1).[9,13] The DDM concept suggests that the position of the NP may be altered in response to specific directions of loading. For example, anterior compression loading of the disc during flexion activities such as pulling one's knees to one's chest, performing a posterior pelvic tilt, sitting and bending would produce a predictable posterior migration of the NP, which may lead to a mechanical noxious stimulus to the posterior annulus.[8,9,13] A posterior displaced NP is one anatomical feature associated with LBP, thus this finding has potential clinical relevance.[8–10,14–16] Therefore, if the nucleus has migrated posterior as would be the case in a posterior directed disc herniation, specific extension forces such as maintaining a lordotic spine or bending backwards into extension may be applied in an attempt to restore the nucleus to its normal position. McKenzie has described a well-recognised approach for both the examination and intervention of patients with discogenic LBP which references the conceptual DDM as a potential explanation for changes in movement and symptom response to loading.[9,13,17] While the DDM is recognised as a potential explanation for a patient's response to movements, one must recognise both the merits and limitations of this principle.

The purpose of this manuscript is to systematically review the available research pertaining to the DDM and where possible draw conclusions regarding the pattern of NP migration in the asymptomatic and symptomatic population. Additionally, it was our aim to determine the relevance of disc degeneration on the DDM. To our knowledge, this is the first paper of its nature to condense all the relevant research pertaining to the DDM into a literature review.

Methods

Articles used in this review were retrieved by two independent researchers using MEDLINE, SPORTDiscus, EMBASE and CINAHL databases and the following key words independently and in combination: intervertebral disc, nucleus pulposus, nucleus migration, disc model, disc loading and dynamic disc model. Results from each researcher were pooled and then each article was cross referenced in a manual search for additional resources. Articles were retained for the review if they met the following inclusion criteria: (1) appeared in a peer review journal, (2) included humans either *in vivo* or *in vitro*, (3) addressed migration of the NP in response to an angular movement or position and (4) provided a conclusion as to the direction of migration or lack of migration for the NP. Based on the established criteria 12 articles were ultimately retained for use in the review.

Results

A total of 12 articles that yielded a direction of NP migration in response to movements and/or positioning were retained. Four studies used *in vitro* discs and eight were performed with *in vivo* experimental methods.[15,18–21] Eleven of the 12 articles evaluated the DDM in response to flexion and extension whereas 2 of 12 evaluated movements outside the

sagittal plane. Additionally, four studies that identified a change in the posterior contour of the disc in response to flexion and/or extension were included for discussion.[19,22–24] No studies investigating the DDM in the cervical or thoracic spine above T10 were identified. Tables 1 and 2 list the results and methods for *in vitro* and *in vivo* studies of the DDM respectively. A majority of the studies used fluoroscopy, discography or magnetic resonance imaging (MRI) to measure NP movement. Nine of the 11 studies that evaluated sagittal movements identified posterior migration of the nucleus in response to lumbar flexion, whereas one study did not evaluate flexion and the other reported small insignificant migration patterns.[14,15,18,20,21,25–30] Nine of the 11 articles reported that the NP migrated anteriorly during extension, whereas one article reported posterior migration.[14,15,18,20,21,25–27,29,30] In regards to rotation the only study available identified NP migration away from the direction of rotation.[25] Similarly one study evaluated the NP response to a frontal plane deviation in scoliotic subjects and reported the NP migrated away from the concavity.[31] Four of the research studies reported an unpredictable pattern of NP migration when degeneration was present within the disc.[15,20,21,27]

Overall, a majority of the research studies have identified a predictable pattern of NP migration in response to loading and positioning. The NP when loaded in the sagittal and frontal planes appears to migrate opposite to the side of loading. Thus, flexion will induce posterior migration and extension will induce anterior migration. This concept has limitations particularly in the degenerative disc where patterns were not consistent.

Discussion

Early researchers used *in vitro* analysis to determine the movement of the NP during flexion and extension and produced results similar to the current *in vivo* studies that have used advanced imaging. Shah *et al.*[18] performed an *in vitro* technique on cadaveric lumbar spines using discography to determine nuclear displacement in healthy discs and found that during extension the NP moves anterior and during flexion the NP moves posterior. Shah *et al.*[18] also reported that degeneration may limit the normal movement of the NP.

Krag *et al.*[28] and Seroussi *et al.*[26] used *in vitro* methods to determine the displacement of the nuclear material when the IVD was subjected to compression, flexion, extension or anterior shear. Krag[28] *et al.* used a 'Finite Element Model' to predict quantitative values for the NP migration within the disc. In a further *in vitro* study Seroussi *et al.*[26] digitised beads within the disc and used sagittal plane radiographs to monitor NP migration in order to provide comprehensive data of this displacement, in nucleated and denucleated discs. The conclusions of both studies were in agreement with the findings of Shah *et al.*[18] in that the NP migrated anterior in response to extension and posterior in response to flexion. Gill *et al.*[29] reported posterior extravasation of injected dye during extension in pathological cadaveric discs, however leakage was not identified in normal discs.

While *in vitro* studies have provided baseline data for interpretation of the DDM this approach does have limitations when attempting to extrapolate these findings to living people. Studies performed *in vitro* do not give an accurate measurement of live human response to movement.[11,20] For instance, *in vitro* studies do not take into account the force or loads applied on the spine during active muscle contractions. Muscle contractions in combination with gravitational forces place a considerable amount of axial loading on the spine. Also the use of cadavers in these controlled studies may not be compatible with those of live subjects because fluid changes within the cadaveric disc may have been negated.[15,11,32] Fennell *et al.*[20] described two problems that may arise when comparing previous studies in cadaveric spines to living spines. First, axial loading in a living disc increases as internal pressure increases in response to loading, whereas research using cadaveric specimens used motion segments that bisected the disc thus releasing this internal pressure.[20] Second, reproducing the correct bending angles in a motion segment may be difficult when compared to a living spine.

Schnebel *et al.*,[27] using *in vivo* methods and a technique developed to digitise and analyse discograms, studied the movement of intradiscal dye in response to flexion and extension movements.[27] This study was performed on both symptomatic and asymptomatic patients. In symptomatic patients, the prediction of nuclear movement was considered questionable because of the extravasations of dye due to annular tears.[27] In asymptomatic patients, there was a more predictable presentation of nuclear behaviour.[27] The researchers reported a significant difference in the posterior distance of L3–S1 spinal levels between flexion and extension for normal NPs with the dye migrating posterior during flexion and anterior during extension. When interpreting this study one must consider the possibility that invasive

Table 1 ***In vitro*** **investigations describing the dynamic disc model**

Study	Subject sample size *n*	Age (year)	Description of subjects	Assessment plane	Motions tested	Migration of NP	Spinal levels	Measurement instrument
Seroussi *et al.*[26]	10	Not provided	Cadaveric spines Intact and denucleated IVD	Sagittal plane	Flexion, Extension, compression	Flexion: posterior Extension: anterior	L4–L5	Radiographs (metal beads)
Krag *et al.*[28]	11	Not provided	Cadaveric spines with no significant structural abnormalities	Sagittal plane	Flexion with compression and anterior shear	Flexion: posterior	T10–L5	Radiograph with implanted metal markers
Shah *et al.*[18]	3	Not reported for this component of study	Cadaveric spines Died second to road accidents No evidence of spinal cord injury	Sagittal plane	Posterior offset loading (extension), anterior offset loading (flexion)	Flexion: posterior Extension: anterior	L4–L5	Discography
Gill *et al.*[29]	19	34–72	Cadaveric spines normal and degenerated	Sagittal plane	Repeated extension with compression	Extension: no effect in normal discs. Posterior dye extravasation in abnormal discs	Lumbar, specific levels not reported	Discography

Table 2 ***In vivo*** **investigations describing the dynamic disc model**

Study	Subject sample size *n*	Age (year)	Description of subjects	Testing position	Motions tested	Migration of NP	Spinal levels	Measurement instrument
Alexander *et al.*[14]	11	Mean 36	Asymptomatic	Standing, sitting, supine and prone extension	Flexion, neutral and extension	Flexion: posterior Extension: anterior* *Compared to flexion. Authors used various functional positions Flexed sitting induced greatest posterior migration and prone extension induced the most anterior migration	L1–S1	MRI
Edmondston *et al.*[30]	10	Mean 30	Asymptomatic No lifetime history of significant low back pain Some discs were degenerated	Supine hip/knee flexed for flexion and supine with lumbar roll for extension	Flexion, extension	Extension: a trend toward anterior displacement, however 30% migrated posterior	L1–S1	MRI, peak pixel intensity
Brault *et al.*[21]	10	21–38	Asymptomatic	Supine in flexion and extension using supportive pads	Flexion, extension	Flexion: posterior Extension: anterior Abnormal discs had a variable migration pattern	L1–S1	MRI, peak pixel intensity
Fennell *et al.*[20]	3	18–46	Subjects with and without low back pain	Side lying	Neutral, flexion, extension	Flexion: posterior Extension: anterior Two discs in symptomatic subjects presented with both anterior and posterior migration during flexion	L1–L5	MRI
Beattie *et al.*[15]	20	20–30	Asymptomatic, discs deemed to have an abnormality based on MRI not used for analysis	Supine hip/knee flexed for flexion and supine with lumbar roll for extension	Flexion Extension	Flexion: posterior Extension: anterior	L3–S1	MRI

Table 2 Continued

Study	Subject sample size *n*	Age (year)	Description of subjects	Testing position	Motions tested	Migration of NP	Spinal levels	Measurement instrument
Schnebel *et al.*[27]	35	Mean 37	Symptomatic subjects	Supine in double knee to chest and prone in the press-up position	Flexion, extension	Flexion: posterior	L3–S1	Discography with lateral radiographs
			Normal & abnormal discs			Extension: anterior Abnormal discs unpredictable		
Frazey *et al.*[25]	3	Mean 27	No current symptoms or reported history of LBP	Supine	Flexion, extension, both combined with left rotation	Flexion: posterior	L1–L2, L4–L5	MRI
						Extension: anterior Flexion/left rotation: right Extension/left rotation: right		
Perie *et al.*[31]	14	Children age not reported	Scoliotic spine levels	Not reported	Measured in scoliotic posture	Nucleus migrates to side of convexity	T11–L5	MRI

techniques alter internal disc dynamics and dye patterns may not be representative of the NP.

Beattie *et al.*[15] measured movement of the NP in response to flexion and extension using MRI *in vivo* on subjects positioned supine. Subjects were positioned supine with a lumbar roll to maintain lordosis for the assessment of extension and supine with a bolster under the knees to maintain flexion. The posterior to anterior portions of the NP relative to the posterior to anterior portions of the adjacent vertebral bodies were measured to quantify movement.[15] The study found that the distance of the posterior margin of the NP from the posterior margin of the vertebral body was greater in extension when compared to flexion implying anterior migration of the NP in the extended position.[15] They also noted that abnormal disc behaviour is not the same as normal disc.[15]

Fennell *et al.*[20] measured *in vivo* migration of the NP with subjects using a seated MRI in an attempt to reproduce normal axial loads.[20] The results were consistent with previously established movements of the NP migrating posterior during flexion and anterior during extension. Brault *et al.*[21] and Edmondston *et al.*[30] studied displacement of the NP in response to non-weight bearing flexion and extension movements by measuring the peak pixel intensity on MRI in asymptomatic subjects.[21,30] Brault *et al.*[21] provided quantitative data using the peak pixel intensity to distinguish between NP and AF and concluded that during flexion the peak intensity shifts posteriorly and in extension the peak shifts anteriorly.[21] Edmonston *et al.*[30] used peak pixel intensity to measure the disc height and nucleus position during flexion/extension with similar results.

Alexander *et al.*[14] investigated the movement of the NP in response to sagittal plane movements in functionally loaded positions using pixel intensity and an upright position MRI unit. The use of the upright MRI allowed the researchers to measure sustained functional positions.[14] NP movement was measured by the distance from the anterior boundary of the IVD.[14] Six functional positions were tested and included standing, sitting upright, sitting flexed, sitting extended, supine and prone extension.[14] Interestingly in this study, there was no significant difference between standing and upright sitting which may explain why some patients with discogenic disorders feel symptom relief in upright sitting. Flexed sitting produced the greatest posterior migration whereas prone extension produced relative anterior migration which may also relate to clinical

Table 3 Studies investigating posterior disc contour in response to sagittal loading

Study	Subject sample size (*n*)	Age (year)	Description of subjects	Position in which the subject was tested	Motions tested	Posterior disc contour	Spinal levels	Measurement instrument
Fredericson *et al.*[19]	3	27–31	No history of low back pain Normal MRI's	Sitting	Flexion, extension	Flexion: posterior increased Extension: moved anterior	L4–S1	MRI
Parent *et al.*[22]	26	24–74	Subjects with and without LBP	Supine hip/knee flexed for flexion and supine with lumbar roll for extension	Neutral, maximal flexion and extension	Flexion: posterior contour less than neutral, similar or greater than extension Extension: posterior contour decreased compared to neutral and trend toward decreased posterior contour compared to flexion	L1–S1	MRI
Zamani *et al.*[24]	30	22–79	25 patients and 5 volunteers	Sitting	Flexion and extension	Extension: trend toward increased posterior disc bulge Flexion: trend toward decreased disc bulge	Lumbar spine, specific levels not cited	MRI
Weishaupt *et al.*[23]	30	20–50	Chronic low back pain	Sitting Supine	Flexion and extension	Extension: trend toward increased posterior disc bulge Flexion: trend toward decreased disc bulge	Lumbar	MRI

findings of patients with discogenic pain. This study supported previous results which demonstrated predictable migration of the NP in response to lumbar movements.[15,20,21,26–28]

The response of the NP to sagittal plane movements in combination with left rotation was examined by Frazy *et al.*[25] The authors reported that when left rotation was added to both movements the tendency of deformation was to the side of less compression which in this case was migration to the right.[25] To our knowledge, no other researchers have measured the effect of rotational movement on NP migration.[25] The study results were consistent with previous studies which suggest translation of NP is opposite to the side of loading or compression. Perie *et al.*[31] studied the position of the NP in the lumbar spine among individuals with scoliosis. In this investigation, the NP was identified to be positioned toward the convexity, thus opposite the side of compression similar to previous investigations.

Other investigators have evaluated changes in the posterior contour or posterior bulge of the IVD in response to flexion and extension with contradictory results (Table 3). While these studies are not a direct investigation of the DDM they do contribute to the current knowledge of the effects of mechanical forces on the IVD. Fredericson *et al.*[19] investigated posterior IVD bulging and intervertebral foramina size in asymptomatic spines during flexion-extension movements with MRI.[19] Three healthy subjects were measured in the morning, 6 hours after normal activity, and after 4 additional hours of loaded activity.[19] In the loaded positions posterior disc bulging increased with flexion of the spine and decreased with extension of the spine.[19] This study was one of the first to measure the spine after it had been loaded in weight bearing. A limitation of this study is that the authors did not take into account the height, weight and muscular strength of subjects. While this was a limitation in a majority of the studies we have reviewed, this study specifically measured the spine after weight-bearing which may be affected by anthropometric data. Each of these aspects may affect the load placed on the subject's spine. Parent *et al.*[22] investigated posterior IVD contour among individuals with and without LBP. In this investigation, the neutral spine position produced the largest posterior contour in area and distance. Flexion had a decreased contour when compared to neutral and there was a trend toward extension producing the smallest posterior contour. Specific details were not provided for interpretation of degenerative or symptomatic discs from the sample. Zamani *et al.*[24] and Weishaupt *et al.*[23] reported a trend toward increased posterior disc bulging with extension compared to flexion which produced decreased posterior bulging using MRI in a seated position.

While there appears to be a consistent pattern of NP migration in the non-degenerated disc the direct correlation between clinical outcomes and the DDM has yet to be established. It may be reasonable to assume that clinical changes may take place in response to movement of a displaced NP back to its normal position; however, a paucity of evidence-based explanations exist to account for the sustainability of these changes, particularly in light of the various movements which individuals perform throughout the day.

Conclusion

Among the articles reviewed, there was agreement between research studies in that the non-degenerated disc has a predictable pattern of NP migration with flexion inducing posterior migration and extension inducing anterior migration consistent with the DDM. Based on the available research it appears that the annulus must be intact and the hydrostatic mechanism must be functioning for this model to act in a predictable pattern.[9,10,13]

These findings may be of clinical importance to the establishment of extension or flexion based interventions for the management of LBP if they are to be used specifically based on imaging findings. However, one must use caution when basing clinical decisions solely on a biomechanical model such as the DDM as the direct relationship between NP movement and clinical change has not been specifically investigated in the patient population. Future studies on disc behaviour in the symptomatic population should be conducted in order to determine whether or not a pattern of migration exists and to what extent it relates to clinical outcomes.

Additionally, only two of the studies measured movements other than flexion and extension thus further research to establish predictable patterns of movements in other planes of movement is necessary before one can consider the DDM in response to non-sagittal loading. Moreover, no studies were retrieved that evaluated spinal levels above T10, thus one may not generalise these findings to the cervical and thoracic spine.

The development of an advanced non-invasive imaging device that can map the NP migration during active or repeated end range motions in real-time

could provide relevant additions to the existing understanding of the DDM.[14] Lastly, clinicians and researchers must base interventions on patient responses such as centralisation or peripheralisation as advocated by McKenzie and other researchers,[9,13,17] not a biomechanical theory. While it is desirable to have an underlying biomechanical explanation for the effects of our interventions the patient's response should dictate the selection of interventions.

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