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Biomechanics and Management of Lumbar Spinal Stenosis Neurodegenerative Disease: Mini-Review

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Abstract

Lumbar stenosis is an increasingly common pathology, which causes significant symptoms affecting quality of life, especially in the aging population. The mainstays of treatment employ both conservative and surgical management. Should surgery be required decompression of the lumbar spine via laminectomy or laminotomy has been shown to be effective. The addition of fusion may only benefit in cases with spinal instability. The treatment of lumbar stenosis should include a multifactorial and multidisciplinary approach. Lumbar fusion may lead to an adjacent segment disease as a result of endplate failure by promoting a lumbar alignment with parallel endplates. Upright MRI could be a useful adjunct objective diagnostic option in the future to differentiate symptomatic from asymptomatic patients by evaluating their foraminal geometry.

Keywords: Lumbar stenosis; Laminectomy; Orthopedic spine; Facet resection

Introduction

Lumbar spinal stenosis is an increasingly common pathology requiring evaluation and treatment by neurosurgeons, orthopedic spine surgeons, physical medicine physicians, and physical therapists alike. Absolute lumbar stenosis- defined as spinal canal diameter less than 10 mm has prevalence 2.6 to 7.3% of the general public, and is as high as 19.4% in the 60 to 69 age group [1]. The etiology can be congenital or acquired stenosis through degenerative changes [1], including degenerative disc disease resulting in lost disc height, segmental instability, or intervertebral disc protrusion. Lumbar stenosis becomes symptomatic when the intervertebral foramen or its contents impinge on the exiting nerve root, resulting in degenerative or compressive radiculopathy [2]. Symptomatic lumbar stenosis can be a life altering disability, greatly reducing quality of life and activity level for those suffering from significant stenosis [1]. Symptoms often present as low back pain and/or neurogenic claudication, or in other words unilateral or bilateral lower extremity pain, weakness, or paresthesias, usually brought on by activity such as walking [3,4]. Symptoms are relieved by lumbar flexion or the sitting position. Management for lumbar spinal stenosis can fall into the conservative, medical category or a surgical approach. The type of surgical management varies from decompression alone to decompression and fusion. With this review we hope to shed light on the biomechanics, treatment approaches, long-term outcomes, as well as the current state of affairs regarding the treatment of lumbar spinal stenosis.

Biomechanics and Etiology of Lumbar Stenosis

Foremost among the various forces acting upon the lumbar spine is compressive loading [5]. Under typical loading circumstances, the lumbar spine accommodates and withstands compressive loads primarily, through the action of the fibro-cartilaginous intervertebral disc. This is made possible by the impressive interplay between what are essentially three components, the centrally located, gel-like/hydrophilic nucleus pulposus, the peripherally located and radially-oriented annulus, and the horizontally oriented endplates that transmit the loads from the body to the disc [6,7]. Upon compression of the vertebral motion unit, the nucleus, behaving in accordance with Poisson's law, equitably transmits what initially was a vertically oriented load in an outward direction, the result of which is tensile load acting upon annular fibers [6].

Although the IVD and its individual components are the primary constituents of the lumbar spine's capacity to withstand compressive loading, the disc requires a stable structural environment to do so. To this end, the vertebral endplate must provide a solid foundation upon which the IVD is able to execute its role as a load-dissipating mechanism. Comprising the cranial and caudal vertebral body surface, osseo-cartilaginous endplates serve as the 0.75 mm interface between vertebral bodies and adjacent intervertebral discs [8]. Abnormal lumbar biomechanics result when the sensitive pressure balance that exists within the disc is disturbed [9,10]. This occurs, for example, following a breach of the vertebral endplate, the end result involving a decompressed nucleus. Our recent investigations, and others, have highlighted the relatively low mechanical tolerance of the endplates relative to the vertebral bodies [8,11,12]. Fracture of the endplate near the nucleus, the most common location, results in a change in the method of load transfer between the body and the disc [11]. As the now compromised nucleus loses its absorptive capacity due to endplate failure, the annulus and in particular the posterior portion of the annulus assumes increasingly greater loads [13]. This axial load shift allows bulk compressive forces to place non-physiologic stresses upon the otherwise resilient annular fibers. Internal disc disruption (IDD) and degenerative disc disease (DDD) can occur as consequences of the axial load-shift that occurs following a breach of the endplate. Both of those conditions can contribute to intervertebral stenosis through loss

of disc height and segmental instability. This described scenario takes on greater significance when a longer-term view of spinal health is considered [14]. Given the crucial relationship that exists between endplate and disc one can begin to appreciate the downstream negative consequence of endplate fracture with eventual clinical implications including accelerated disc degeneration and associated neurological structure compromise [15,16].

Significant research has gone into building the current wealth of knowledge surrounding disc and endplate, yet the biomechanical effects of segmental alignment relative to endplate tolerance had until recently not been addressed. A recent investigation seeking to address this concern, as well as to quantify spinal orientation on lumbar spine injuries during single-cycle compressive loads, has found vertebral endplates to be most susceptible to injury under alignment conditions involving parallel endplates [11]. Specifically, endplate failure occurred more frequently when the caudal endplate of the superior vertebrae was parallel to the cranial endplate of the inferior vertebrae, as is the case when the natural lordotic curvature is removed. Additionally, tolerance for endplate failure was substantially lower than cortical fracture tolerance, occurring at 41% of the axial force required for cortical fracture [11]. With these recent findings, it could be possible that in lumbar fusion patients, adjacent segment disease (ASD), a disease signified by the stenosis of levels above and/or below the fusion, may be the result of endplate failure introduced through lumbar alignment characterized by parallel endplates [11]. This finding has a significance clinical implication as lumbar fusion is often performed in patients with lumbar stenosis and with evidence of spinal instability. Therefore, during lumbar fusion, it is essential to maintain heightened awareness of the final endplate alignment, thereby minimizing the risk of developing ASD.

Furthermore, we recently showed that upright MRI could be a useful objective diagnostic option in the future to determine which patients are symptomatic from spinal stenosis by evaluating their foraminal geometry [4]. Upright MRI technology enables noninvasive scanning with subjects in upright seated or standing positions [17]. Supine orientation removes the load on the lumbar spine from supporting the structures of the body [18], which alters the lordotic curvature, changes the orientation of the segment, and can possibly remove intervertebral stenosis. For example, our study demonstrated disc bulge was 48% greater in symptomatic volunteers compared to asymptomatic volunteers. Foraminal cross-section area was also smaller in symptomatic volunteers compared to asymptomatic volunteers [4]. These differences imply greater stenosis, and associated symptoms for the patient, in the upright position that may not be evident during routine clinical exams that place the patient in the supine position.

Non-Operative Management of Lumbar Degenerative Disease

Prior to having the discussion regarding surgical correction of lumbar stenosis a trial of conservative management should be employed. Conservative management consists of non-steroidal anti-inflammatory, analgesic, and muscle relaxant, as well as exercise, physical therapy, spinal manipulation, and corticosteroid injection [19]. Although the epidural corticosteroid injection is often used to relieve the radicular component of lumbar stenosis, its efficacy remains controversial [20]. While responses tend to vary, Turner et al evaluated 21 baseline patient characteristics in those with lumbar stenosis to predict those that would benefit from injections; they concluded that not a single characteristic consistently predicted benefit from corticosteroid injections [20]. The Spine Patient Outcomes Research Trial (SPORT), studying the outcome of surgical vs nonoperative treatment for lumbar disk herniation, failed to establish the clear superiority of one treatment modality over another citing a high rate of crossover [21]. Similarly, Delitto et al, in their randomized study, found no significant differences in physical function between surgical and nonsurgical groups [22]. In an effort to better understand the benefit of various non-surgical modalities, Schneider et al initiated an ongoing prospective randomized controlled clinical trial that will be conducted from November 2013 through October 2016 evaluating three different regimens of non-surgical treatments for patients with lumbar spinal stenosis [23]. Results from this study when available will provide patients and providers with evidences about the clinical benefits of three non-surgical approaches to the management of lumbar spinal stenosis symptoms.

Operative Management of Lumbar Degenerative Disease

Should conservative management fail and symptoms are persistently reducing one's quality of life, or if there is a persistent neurological deficit surgical intervention is warranted. Different surgical approaches include decompression via a laminectomy or laminotomy, or fusion in addition to decompression [3]. Surgical planning is highly individualized and should focus on the pathology at hand. Minimally invasive (MIS) approaches continue to gain popularity with higher satisfaction rates, lower back pain Visual Analog Scale scores, less blood loss and shorter hospital stays as compared to traditional open techniques [24]. Fusion has historically been used as an adjunct to decompression in patients with spinal instability, where wide decompression took place such as >50% facet resection, or in cases of recurrent stenosis [25]. Indications and benefits to fusion within the literature are not clear. Recently, the New England Journal of Medicine (NEJM) published two articles comparing the different surgical techniques for lumbar stenosis and spondylolisthesis, namely decompression alone vs the addition of fusion [3,26]. In a randomized controlled trial it was shown that in patients with spinal stenosis, both with and without spondylolisthesis, the addition of fusion to decompression did not result in better clinical outcomes at both the 2 year and 5 year intervals [3]. To add to the controversy Ghogawala et al published results suggesting that the addition of fusion to laminectomy specifically in patients with lumbar stenosis and a low-grade spondylolisthesis only provides a slightly greater but clinically meaningful improvement in overall physical health-related quality of life than laminectomy alone [26]. The indication for fusion in patients with lumbar stenosis is limited, and great consideration should be taken into account whether or not fusion is truly indicated. Currently around 50% of patients undergoing surgery for lumbar stenosis are being fused, it remains to be seen whether this trend may slowly begin to decrease [27].

Long-Term Outcomes

When comparing long term outcomes for surgical versus nonsurgical management of lumbar stenosis, low back pain, predominant symptom improvement, and satisfaction of current state are similar between the two cohorts; however, leg pain relief and greater back-related functional status favor the cohort treated initially with surgery [19]. Almost 40% of those initially treated conservatively eventually require at least one lumbar spine operation [19]. For those

undergoing surgical correction of lumbar stenosis there is a risk of adjacent or same segment disease requiring additional operations with the risk for reoperation is 13-34% [3,19,26,28]. Pretreatment symptom duration lasting greater than 12 months is a significant risk factor for requiring additional surgery. In addition, significant preoperative disability is a positive predictor for good outcome in those undergoing surgical management, whereas body mass index and past history of psychiatric disease are negative predictors [29]. When comparing MIS verses open surgery or decompression alone versus fusion there is no difference in the reoperation rates [24,28].

Conclusion

Lumbar stenosis is an increasingly common pathology, especially in the aging population, which causes significant symptoms affecting quality of life. The mainstays of treatment employ both conservative and surgical management. Should surgery be required decompression of the lumbar spine via laminectomy or laminotomy has been shown to be effective [3]. The addition of fusion, however, remains a controversy and may only benefits in cases with spinal instability [3]. The treatment of lumbar stenosis should include a multifactorial and multidisciplinary approach.

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