Viewpoint

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Emerging Concepts in the Pathogenesis and Management of Degenerative Spinal Disease

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Abstract

The author discusses his personal concepts about the pathogenesis and treatment of degenerative spine. Vertical instability or telescoping of the spine as a result of long duration 'standing' human position is the point of genesis of degenerative spinal 'disease'. Muscle weakness, disuse or abuse and subsequent instability of the spinal segment generate a series of events that are collectively called 'spinal spondylotic disease'. All these changes are secondary and most probably protective in nature. Treatment lies in stabilization or fixation of the unstable spinal segment. Removal of bone, osteophytes, disc or ligaments can be avoided.

Introduction

For over a century, age-related disc degeneration, loss of disc water content and disc space reduction has been understood to be the initiating point for the process of degenerative spinal disease. The disc alterations are considered to be the primary issue and the rest of the spinal bony and ligamentous consequences are secondary effects. Osteophyte formation, ligamentous hypertrophy and secondary reduction in spinal and root canal dimensions are the events that result in cord and root compression and resultant symptoms of radiculopathy and myelopathy. Based on this premise, a number of decompressive surgical strategies have been described. A range of surgical techniques and elaborate technological tools has been in used for the surgical treatment. It may not be an over-exaggeration to say that there is no standard or gold standard understanding or treatment that has universal acceptance. Bone and disc preserving or saving methods have recently found favor. Although the issue of instability in degenerative cervical spondylosis has been discussed on several occasions, its role as the primary factor in the pathogenesis has not been appropriately addressed or therapeutically exploited. The aim of the surgical treatment is to surgically re-sect the spinal cord indenting osteophytes and hypertrophied ligaments and to widen the spinal canal and root canal dimensions. Spinal stabilization is usually considered to avoid instability that can possibly accrue after the decompressive surgical procedure. Some authors have discussed the issue of instability in association with or as a consequence of spinal degeneration.

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Alternative philosophy for spinal degeneration

The current focus on the understanding of subject is on the premise that vertical instability of the spinal segments may have a paramount influence on the pathogenesis of spinal degeneration. Goel recently speculated that instability of the spinal segments is the primary phenomenon and rest of the musculoskeletal and disc alterations are secondary processes[1, 2]. Spinal degeneration could be a price that is paid for standing human posture and life-long strain on the muscles of the spine that position the body in an erect posture.

The primary muscles that support the spine and assist in maintaining erect posture are the extensor muscles of the spine. Extensor muscles are long multi-segmental paraspinal muscles and small muscles that work at segmental spinal level. Each segment of the spine appears to be a discrete entity. The role of these muscles is to partake in the process of movements of the spine and the body and support the column in erect standing posture. Weakness of the muscles is related to abuse or disuse over a period of time. Weakness of the muscles is manifested by instability at the only true joints of the spine namely the facet joints. Goel's hypothesis proposes that instability manifested at the facets is the primary issue and all the spinal alterations are secondary and consequent [1–4].

It may even be that all the secondary spinal effects are protective and an attempt of nature to cushion or support the spine from the negative effects of instability.

The facets of the spine are laterally located and have an oblique profile and are relatively poorly visualized on conventional images. On the other hand inter-vertebral disc, osteophytes and cord changes are prominently and elegantly visualized on plain radiology and computer based imaging. This is probably the reason that the entire concept of spinal degeneration was earlier based on disc related issues and later on osteophytes, ligaments and structural alterations in the cord. Even on the basis of modern computer based imaging instability at the facets is difficult or impossible to decipher. Retrolisthesis of the facets of cervical spine and facetal over-riding of the lumbar spine are well-recognized entities. The facetal instability is relatively easily identified at the atlantoaxial facetal joint due to their relatively large size and their horizontal lie [5–8]. Goel first discussed the issue of facetal mal-alignment as it relates to cranio-vertebral instability [8]. Direct observation of the facets of the spine in general and craniovertebral junction in particular provides an opportunity to appreciate the status of stability of the joint and thus the stability of the spinal segment.

As our understanding of issues related to spinal degeneration mature, we realize that facetal instability; facet listhesis and vertical facetal instability are the prime issues in spinal degeneration. Vertical spinal instability is akin the telescoping of the spinal segments and an overall reduction in the height of the spinal segment or the spinal column. The muscle weakness is unable to sustain or retain the height of the spinal segment. It appears that the muscles of the spine have a role in spinal movements and also have a role in keeping the spinal segments apart. The facet joint has an oblique alignment in the cervical and dorsal spine and a near vertical alignment in the lumbar spine [9, 10]. As the weakness or instability progresses the rostral facet slips inferiorly over the inferior facet. The slipping or listhesis of the facets results in all the subsequent secondary and so called degenerative changes in the spinal segment. Reduction in the height of the neural foramina, circumferential buckling of all the inter-spinal ligaments, reduction in dimensions of the spinal canal and also reduction in the disc space height are all a part of secondary bodily response. Osteophyte formation is circumferential around the entire rim of the spinal canal and even around the facets and is related initially to ligamentous separation from the bone surface, periosteal reaction and subsequent osteophyte formation. The osteophytes are more prominently seen posterior to the disc and in relationship to the posterior longitudinal ligament. This is probably due to an increased response by the disc and the consequent disc space and height reduction. The osteophytes around the facets and around the other parts of the circumference of the spine are obvious only in the late phase of the disease process.

It may be possible that spondylotic disease process actually begins with facet instability and the discs are involved secondarily. Decrease in inter-facet height and retrolisthesis can result in reduction in inter-vertebral canal height that can cause radiculopathy symptoms. It appears that this retrolisthesis is a result of potential or manifest instability of the segment. The reversal of pathological events following facetal distraction provides support to such a hypothesis [11,12]. In general, presence of osteophytes signals instability of the spinal segment. Presence of altered cord intensities also point towards spinal instability related effects. Osteophyte related cord compression and altered cord signal are relatively easily visualized on magnetic resonance imaging. These signals are due to composite causes that include indentation by the osteophytes, by the buckled ligaments and an overall reduction in the spinal canal dimension. All these ligamentous, bone, disc and spinal cord structural alterations are a secondary spinal feature and signal the presence of instability at the level of facet join [13]. Essentially, it is not the neural compression or spinal cord deformation that is the primary issue in spinal degeneration or even the cause of symptoms but it is instability at the level of facets that is the prime mover [3]. The therapeutic implication of the proposed concept is that the surgery in cases with spinal degeneration should be focused on treatment of spinal instability. Spinal canal and root canal stenosis are secondary issues and will resolve after the stabilization of the segment. The focus of attention can be on the feature that is not obvious rather than the features that are more clearly visible on conventional imaging.

Facet distraction spacers

Goel first introduced facet distraction spacers in the treatment of single and multi-level cervical spondylotic radiculopathy and myelopathy and for the treatment of lumbar spondylotic spinal canal stenosis [11, 12]. The premise of treatment is the understanding that vertical facetal instability is the prime and initial point in the pathogenesis of the entire process of spinal degeneration and spondylotic radiculopathy and myelopathy and secondary spinal and root canal stenosis. The surgery that involves distraction of facets aims at immediate restoration of visible anatomical changes and stabilization of the facet joint. The prime aim of surgery is distraction arthrodesis of the spinal segment.

The surgery involves direct observation of the facets and assessing by manual manipulation the presence of instability and the need for surgical stabilization. Radiological findings and clinical evidences only assist in identification of the level of spinal instability. It may be that there is no radiological feature that could suggest presence of any direct evidence of segmental abnormality like presence of osteophyte or cord changes at the level, but the facets can be unstable dictating the need for surgical treatment. Surgery involves opening up of the facets, denuding the articular cartilage using sharp instruments or power driven drill, introduction of bone chips and Goel facet spacer. The introduction of a suitable size spacer after appropriate distraction of the facets restores the height of the spinal segment stabilizes the facets and prepares a ground for arthrodesis. The process of insertion of the facet distraction spacers results in reversal of all the known features of degenerative spine that include restoration of the disc space height, restoration of stretch over buckled spinal ligaments and in the normalization of spinal and root canal dimensions.

The proposed operation of facet distraction suggests that the disc can 'regenerate' and its height can be restored and there is a potential for reduction of the size of the osteophytes. It presents an alternative hypothesis that suggests that there may not be a need for removal of the disc and osteophytes during the surgery for spinal degeneration. It also suggests that the spinal and root canal can be decompressed without removal of any segment of bone or ligament. The surgery provides a fresh thought in the treatment strategy of spinal degeneration.

Traction of the neck has been used over the past century in the management of spondylotic disease. The effectiveness of such a treatment method can be gauzed by its lasting popularity and clinical success. Our success with facet distraction as the primary mode of surgical treatment suggest that distraction of the facets by manual implantation of metal spacers within the articular cavity results in sustained traction and fixation of the spinal segment and provides an opportunity for local arthrodesis.

Only fixation for spinal degeneration

On further evaluation of the subject it was realized that only fixation of the involved spinal segment may be sufficient for the treatment of spinal degeneration [14]. The distraction of facets and deployment of spacers is an added mode of spinal stabilization, assists in an immediate postoperative restoration of spinal and root canal dimensions, restores the abnormal crumpling and buckling of ligaments to normal stretch and even assists in increasing the disc fluid content. However, more than restoration of physically altered parameters, it is the stabilization of the spine that is more crucial and therapeutically important. It was hypothesized by Goel that instability is the more important cause of symptoms than physical deformation or neural compression that is radiologically observed.

Surgical techniques

Surgical position

For all the surgical procedures on the cervical spine that involve instrumentation, the author prefers a prone surgical position under cervical traction. The head end of the table is elevated by about 35 degrees. The head elevation provides counter traction and also reduces the venous congestion in the operative surgical field. The traction assists in keeping the head stable during the surgery and avoids pressure effects over the face and eyeballs.

Facetal distraction technique

The C2 spinous process is always exposed to identify the status of atlantoaxial stability and to confirm the level of surgery. Subperiosteal dissection exposes the facets widely on both sides. Visual assessment and mild manual pressure on the facets can give a clear impression about the status of stability of the facets. Open facetal articular cavity, loose articular capsule, presence of facetal osteophytes and facetal overriding can assist in identification of unstable levels. It is frequently observed that the level of spinal facetal instability that is identified during surgery may not be clearly evident or depicted on imaging. Direct and real-time observation of the instability at the facet articulation and fixation provides an additional security to avoid 'adjacent segment' delayed instability. The facet joints are then opened up and distracted using varying sizes of osteotomes. The osteotome is introduced in the articular cavity with its sharp edge and is then turned ninety degrees in a screwing motion. This maneuver distracts the facets and denudes the articular cartilage and end plate. Bone chips are then introduced and packed into the articular cavity. Keeping the osteotome in a corner of the articulation, a suitable sized Goel facet spacer is introduced and jammed in place under direct vision. The spacer size that is more commonly suitable is 1.5 to 2 mm in thickness and 8 mm in diameter. The interspinous and interlaminar ligaments are then widely removed. The spinous process is cut from its base. The surface of laminae is drilled to make the host bone suitable for bone graft placement. The patient is advised cervical collar for a period of 6 weeks and is subsequently permitted all normal activities.

The anatomical subtleties, significance of the oblique anatomical profile of the facets, and the overall movements that occur in facet joints have been discussed in the literature. The firm consistency and mechanical strength of the facets and the pedicles has only infrequently been therapeutically used. A number of techniques of fixation of facets with screws have been described in the literature. The proximity of the facets to the nerve roots, vertebral artery, and spinal cord and the possible danger to these structures during screw implantation into the relatively thin and obliquely angled pedicles are probably the reasons that these techniques have not been universally accepted or popularly used.

The oblique profile, relatively large size, firmness and biomechanical strength of the facets and pedicles can be used effectively and safely for distraction of the spinal segments and fixation. Distraction of the facets was done by surgically implanting specially designed spacers. Impaction of spacers in the facets caused several structural changes, resulting in reversal of the pathological effects of cervical spondylosis. Stability of the treated spinal segment, increase in interlaminar and interspinous process distances, and restoration of buckled ligaments of the region were obvious after distraction of the facets. The results of MR imaging demonstrated that insertion of the spacer resulted in an increase in spinal canal diameter. The exit space of the nerve root was remarkably enlarged, as evident by an increase in spinal canal diameter and by an increase in height of the intervertebral foramen. The process resulted in an increase in the intervertebral disc space and interspinous process height that resulted in reduction of the buckling of the posterior longitudinal ligament and ligamentum flavum.

Goel cervical facet spacers are made of medical-grade titanium metal. The spikes on both sides of the spacers assist in fixation of the implant. The spacer has multiple holes that allow bone arthrodesis across the implant. The rounded circumference edge of the spacer avoids any inadvertent injury to the adjoining structure. Various sizes of the spacers are available to suit the circumstances at the time of implantation. The spacer impactor holds the spacer firmly because of its screw-thread design. The base of the impactor has a flat space for impaction and gentle hammering. The spacer is impacted after wide removal of the articular cartilage. Such a wide cartilage removal assists in making an otherwise smooth and slippery surface rough for firm fixation of the implant and provides an enhanced opportunity for bone fusion. The spacer holder prevents over-insertion of the implant. The inferior edge of the transverse process of the rostral vertebra provides a natural anterior barrier and blocks the movement of the spacer beyond the confines of the facet, avoiding injury to the root and vertebral artery.

We observed that 2 facets joint spacers were stronger and firmer than a single intervertebral body spacer. Biomechanical studies have confirmed the potential of the deployment of the spacers and its physical strength due to the implantation at the site of fulcrum of spinal movements. [15] The mineral density of the bones of the facets and pedicles is significantly superior to that of any other part of the vertebral, imparting greater strength to the process of fixation. The facet spacers avoided the need for neck dissection and even the need for direct manipulation and resection of the posterior osteophytes or PLL. Essentially, the decompression was achieved without removal of any part of the disc, bone or soft tissues. The other advantage is that the technique can be performed by percutaneous and endoscopic methods. Although patients with extruded disc prolapse were not treated, it may be possible that even such patients can benefit from the increase in the spinal and root canal dimensions.

Intrafacet joint spacers were significantly easier to implant and stabilize. Extension of the levels of fixation was relatively easy and remarkably quick. In contrast to other available midline fixation methods, the fixation is at the fulcrum of all cervical spine movements. This is probably the reason that stability imparted by such a spacer appears to be significantly more than the stability provided when implants are applied in other regions of the cervical vertebra. The highlight of the technique is that it is simple and significantly quicker than all other methods of decompression and fixation. The procedure can be done in isolation, or it can be used as a supplement to other techniques. It can be done when other midline methods of fixation/ decompression have failed. The implant is relatively small, and the use of large metal implants extending over multiple levels, which are used in some described stabilization techniques can be avoided.

Following the facet distraction surgery there can be an immediate postoperative relief from symptoms of radiculopathy and myelopathy as both neural foramina and spinal canal dimensions are increased both in their vertical and horizontal dimensions. The buckled ligamentum flavum gets stretched and relieves the dura of posterior compressive effect. The posterior longitudinal ligament and the related osteophyte also get stretched and there is a potential for regression in its size. The disc space height is increased and fluid in the disc space can be seen in the immediate postoperative imaging. The ultimate aim of the surgical procedure is to achieve distraction-arthrodesis of the spinal segment.

Only fixation for 'degenerative' spinal stenosis

We recently proposed only fixation as the form of treatment for degenerative cervical spondylotic myelopathy. [14, 16] The proposed treatment is based on the hypothesis that 'vertical spinal instability' results in telescoping of the facets and forms the basis of pathogenesis. As our understanding on the subject is maturing, we realize that subtle manifest instability of the spinal segment may be paramount in the pathogenesis of the entire structural deformation in spondylotic disease of the spine. Such instability is rather easily observed on direct visualization of the joint during surgery, even when preoperative dynamic radiographs do not depict such an event. It appears that the phenomenon of cervical canal stenosis is 'dynamic' in nature and local spinal instability plays a major role in its genesis. Standing human posture, ageing muscles, heavy body weight and sedentary life style may have contributory effects on pathogenesis of spondylotic spinal disease. It does appear that muscles have a role in keeping the spinal segments apart. Reduction of the articular cavity space and subsequent facetal overriding or telescoping and consequent ligamental laxity and buckling might occur on activity. Decrease in inter-facet height and retrolisthesis can result in reduction in intervertebral canal height that can cause radiculopathy and myelopathy symptoms. It appears that retrolistheis is a result of potential or manifest instability of the segment.

Surgery

The oblique profile, relatively large size, firmness and mechanical strength of the facets can be used effectively and safely for transarticular screw insertion. A number of biomechanical studies are available that suggest that transarticular screw provide satisfactory stability to the cervical spinal segment.

The operation aims at arthrodesis of the affected spinal segments. Sectioning of the spinous process at its base provided a possibility of insertion of transarticular screws with a wider angle. The screw could now travel in the lateral third of lamina and subsequently through the facets. Wider exposure of the facets following the spinous process resection and the relatively large size of the facets facilitated insertion of screws in a transarticular fashion. The operation involves transarticular screw insertion employing the technique described earlier by Roy-Camille and Saillant. [17] The screws measure 2.8 mm in diameter and 16-18 mm in length. Insertion of two screws provided 'double-insurance' stabilization. Although navigation provided accuracy to the procedure, even free-hand screw insertion under direct surgical vision seemed to be safe. The screws are inserted after wide removal of the articular cartilage. Such wide cartilage removal assists in making an otherwise smooth and slippery surface rough for firm fixation of the implant and provides enhanced opportunity for bone fusion. The remarkable strength of the transarticular screws, at the site of fulcrum of spinal movements, could be appreciated during the process of screw tightening and was also evident by the fact that none of the screws seemed to malfunction or changed its initial deployment position during the period of follow-up. Mineral density of the bones of the facets is significantly superior to that of any other part of the vertebra, imparting greater strength to the process of fixation. The large and bifid spinous process provided ample bone graft material. The technique of deployment of screws is simple and significantly quick when compared to most other methods of decompression and fixation. The procedure can be done in isolation or can be employed as a supplement to all other techniques.

Double insurance transarticular fixation

The large size of the facets of both lumbar and cervical spines allows the possibilities of inserting two screws in each facets. Insertion of two screws provides an added and reassuring stability to the fixation construct. [18]

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