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Spine

Anterior Spinal Column Surgery

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BIOMECHANICS OF THE ANTERIOR COLUMN

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The three-column theory of the spine was introduced by Denis[5] in 1984, after a retrospective review of 412 thoracolumbar spine injuries and observations on spinal instability. According to Denis, the posterior column consists of the neural arch, as described by Holdsworth.[10] The middle column consists of the posterior aspect of the posterior longitudinal ligament, posterior aspect of the anulus fibrosus, and the posterior wall of the vertebral body. The anterior column consists of the anterior vertebral body, anterior anulus fibrosus, and anterior longitudinal ligament. The sagittal view of the three-column separation is shown in Figure 1 (for axial view refer to figure on page 687). Since its introduction and varied acceptance, many researchers have utilized Denis' classification to explain the pathomechanics of the human spine. Based on data derived from this classification, surgical procedures and instrumentation systems have been developed so as to appropriately address specific pathologies and restore proper spinal stability and mechanics.

SPINAL FRACTURES AND SPINAL INSTABILITY

Clinical Data

The contribution of the anterior column to the mechanics of spinal fractures and the role it plays in treatment decisions has been studied by several authors. McCormack et al.,[19] in a retrospective

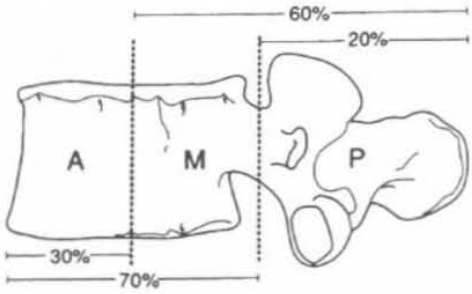

FIGURE 1. Sagittal view of a lumbar vertebra, illustrating the boundaries of the anterior, middle, and posterior columns, as well as the load-carrying capacity (LLC) of each column.

examination of 28 patients with three-column spinal fractures surgically stabilized by short-segment posterior instrumentation, recognized the need for anterior column support in certain fractures. After applying a load-sharing classification scoring system based on the amount of damaged vertebral body, spread of fracture site fragments, and the amount of corrected traumatic kyphosis, the authors found a positive correlation between screw failure and a high load-sharing classification score. They concluded that the use of a strut graft is indicated in three-column injuries with high scores (> 7) so as to protect the cantilever posterior instrumentation from bearing all the stress prior to bony fusion.

In a study that correlated a retrospective, nonoperative thoracolumbar burst fracture experience in neurologically intact patients with cadaveric biomechanical data, James et al.[12] illustrated the importance of analyzing both the anterior and posterior columns when determining the degree of stability of burst fractures. In both phases of this study, middle column involvement was found to poorly correlate with instability, while combined anterior and posterior column involvement was biomechanically least stable. Patients who sustained both anterior and middle column injuries, and were treated conservatively (nonoperatively), were stable and healed satisfactorily. This data is not in agreement with those of Panjabi,[20] who aimed to validate the three-column theory using a biomechanical trauma model and a novel flexibility scoring system. He concluded that the middle column is the primary determinate of mechanical stability in the thoracolumbar spinal region, based on its significant correlation with nearly all flexibility parameters.

Cadaveric Biomechanical Data

Many researchers have utilized cadaveric spinal models to investigate the mechanical contributions and characteristics of the anterior column. Haher published a series of human cadaveric studies addressing the axial load-bearing capacity of the spine as well as the contributions of each column to mechanical and structural properties.[6–9] His studies illustrate the stabilizing effect of the anterior column and the mechanical disadvantage of the middle column in axial rotation, as well as the load-carrying capacity (LLC)[6] of the anterior and middle columns relative to the posterior column. Utilizing the method of Reuleaux, the instantaneous axes of rotation (IARs) in axial rotation[7] and sagittal plane motion[8] were analyzed in relation to the three columns of the spine, with and without instrumentation. In all instances, the IAR was found to migrate toward the stiffest portion of the specimen. Removal of the anterior column resulted in posterior migration of the IAR (Fig. 2), while removal of the posterior column resulted in anterior migration of the IAR (Fig. 3). In axial rotation, the IAR of the intact spine was found to consistently reside posterior to the posterior longitudinal ligament (PLL) within the spinal canal. Instrumentation of a

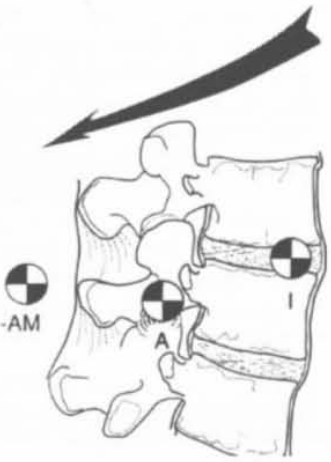

FIGURE 2. The location of the IAR of the spine is shown with flexion. The IAR migrates posteriorly from its intact position (I) as the anterior column (–A) is destroyed, and more so when both the anterior and middle columns are destroyed (–AM).

anterior column-deficient specimen with an anterior plate resulted in anterior migration of the IAR toward the implant (Fig. 4). The largest decrease in torsional stiffness occurred after removal of the anterior column.[9] This is because the anterior column is in a mechanically advantageous location, relative to the IAR of the intact spine. A larger-moment arm corresponds to a greater mechanical ability to resist rotation. The facets, which had previously been regarded as the primary restraints to axial rotation, are in relatively close anatomic proximity to the intact IAR, and therefore lack the mechanical advantage of the anterior annulus. In Haher's study, removal of one or both facets did not reduce torsional stability as much as removal of the anterior anulus fibrosus.

In similar but independent biomechanical studies of unstable calf spines, Lim[14] and An[2] created a 1.5-cm anterior and middle column defect by removing the L3–L4 disc and adjacent end plates in order to biomechanically analyze the stabilizing contributions of several instrumentation systems with and without an interbody anterior graft. Lim, investigating both anterior and posterior instrumentation, found that anterior plate and rod systems increased stability more than posterior devices, with or without the use of a polymethylmethacrylate (PMMA) block to simulate an interbody anterior graft. Use of anterior instrumentation with grafting provided a significant stabilizing effect in all loading directions compared with the intact specimen.

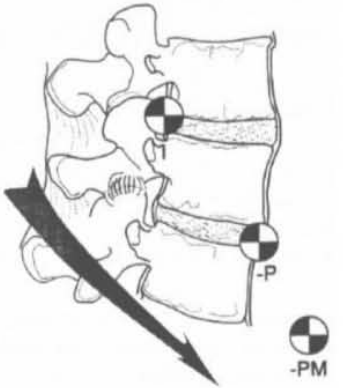

FIGURE 3. The location of the IAR of the spine is shown with extension. The IAR migrates anteriorly from its intact position (I) as the posterior column is destroyed (–P), and more so when both the posterior and middle columns are destroyed (–PM).

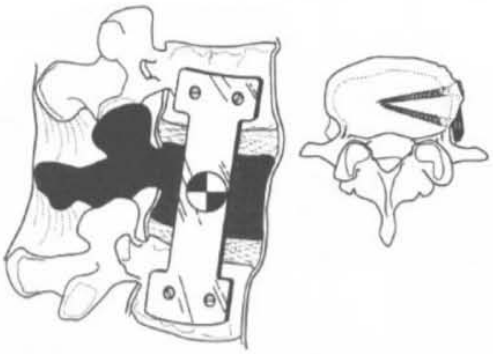

FIGURE 4. Rigid instrumentation of a structurally compromised spine, such as the Syracuse plate shown here, results in the migration of the IAR to the instrumentation, which is now the stiffest part of the composite section.

An, in a study of four anterior instrumentation systems, found that stability in all motions is restored when an interbody graft is inserted. Both studies illustrate the need for surgeons to intelligently select instrumentation which addresses the pathology, especially in the anteriorly destabilized spine.

While Lim, An, and others have removed the adjacent end plates in the destabilization of the anterior column, many surgeons feel that the end plate offers vital resistance to graft subsidence in the heavily loaded anterior column and thus choose not to remove it prior to interbody graft insertion. Hollowell and colleagues[11] tested seven different graft types in 63 isolated human cadaveric thoracic vertebral bodies, applying monotonic axial compressive loads to each configuration. They concluded that preservation of the vertebral end plate did not significantly increase the resistance to graft subsidence. The use of a titanium mesh cage provided the greatest resistance to axial load.

Shono, McAfee, and Cunningham[22] performed a biomechanical analysis of thoracolumbar burst fractures on 24 fresh human cadaveric spines. After creating clinically identical L1 burst fractures, the abilities of two different posterior instrumentation systems to restore stability were biomechanically investigated with and without anterior reconstruction via a Kaneda device. In all loading conditions, the authors reported increased stability with anterior reconstruction. They concluded that the anterior reconstruction method permits effective decompression of the spinal canal and offers superior mechanical stability compared with the indirect decompression and stabilization of posterior instrumentation.

Mechanical Data

Performance validation of spinal instrumentation systems, according to the Food and Drug Administration, includes mechanical testing using the Standard for Spinal Devices by the American Society for Testing and Materials (ASTM).[1] This standard recognizes the structural and biomechanical importance of the anterior column, as it uses ultrahigh molecular weight polyethylene (UHMWP) blocks to simulate lumbar vertebrae in a corpectomy model. It is widely accepted that this is a worst-case scenario in spinal instability. The importance of anterior column reconstruction and its effect on load sharing have been demonstrated by several authors utilizing this model.

Caruso and colleagues[3] applied cyclic, nondestructive loads to a spectrum of 48 different spinal instrumentation systems (anterior, posterior, or both) using an MTS 858 Bionix material-testing apparatus. Axial stiffness measurements were made with and without the use of a titanium Harms cage (DePuy-Motech Spine, Warsaw, IN) as anterior column support for each construct. Graphical and statistical analysis of the data revealed an inverse relationship between axial stiffness of the construct alone and the percent increase in stiffness realized with the addition of a Harms cage. These mechanical data correlate with the clinical data obtained by McCormack et al.,[19] indicating the reduction of motion and therefore decrease in screw strain achieved by reconstructing the anterior column. In a study using a similar testing protocol, Margulies and colleagues[16] found that properly addressing the anterior column via a strut graft increases the surgeon's posterior instrumentation options, such as substitution of transpedicular screws by hook claws in patients with osteoporosis.

Postoperative Animal Models

Only a few studies have utilized postoperative animal models to investigate the biomechanical response of the anterior column to instrumented and noninstrumented fusions. McAfee et al., in studies published in 1989 and 1991, utilized a canine model of anterior and posterior column instability to allow in vivo observation of bone remodeling and arthrodesis following spinal surgery.[17,18] Various posterior instrumentation systems were implanted with and without posterolateral bone grafting. In addition, posterolateral bone grafting was independently examined. Observation 6 months after surgery revealed that a significantly improved probability of achieving a stable spinal fusion occurs if spinal instrumentation is used, independent of instrumentation type. Multiplanar, nondestructive mechanical testing of the harvested spines (after removing all instrumentation) revealed that fusions performed with instrumentation were significantly more rigid than those performed without instrumentation. Histomorphometric analysis of fusion masses showed that an inversely linear correlation exists between implant stiffness and volumetric bone density, a phenomenon the authors called "device-related osteoporosis." The rigid instrumentation, while providing immediate postoperative stability which increased the probability of a fusion, shielded the anterior column from bearing the stress necessary to achieve a denser fusion mass. This illustrates the need for dynamic instrumentation systems, which increase load sharing and decrease stress shielding as the bony fusion mass progresses.

Craven and colleagues[4] built upon the work of McAfee by addressing the issues of rod diameter and hardware removal on fusion stiffness and bone mineral density. They found that stiffer fusions developed as the degree of load sharing increased (smaller rod diameters). Removal of all instrumentation (12 weeks after the initial instrumented fusions) resulted in an increase in bone mineral density as a function of postoperative recovery time. The authors predict that a 6.35-mm diameter rod will initially allow 70% of the axial load borne by the human spine to be imparted upon the anterior and middle columns, thereby possibly providing optimum fusion/bone stiffening while limiting bone stress-shielding effects. The danger in such an extrapolation of data is the fact that this study was done in quadrupeds, whose intradiscal pressures are not yet completely understood.

More recent work by Kotani, McAfee, and Kaneda[13] utilized a sheep model to demonstrate the ability of transpedicular instrumentation to provide some stabilization to the anterior and middle columns. Biomechancial, radiological, and macroscopical

analysis of 18 sheep were conducted at 4 months postoperatively, confirming the presence of a solid posterolateral intratransverse process fusion in all animals. Each specimen was tested with and without transpedicular instrumentation. A significant difference in stiffness was noted between instrumented and noninstrumented spines in sagittal plane motion. In addition, histomorphometric analysis of the vertebral body spanned by the instrumentation revealed a 38% decrease in volumetric bone density as compared to the sham group, illustrating the stress-shielding ability of this instrumentation. This study qualified and quantified the three-column nature of transpedicular instrumentation, even when used in conjunction with a solid posterolateral fusion mass. It is worth reiterating that transpedicular fixation alone cannot provide ample anterior column support in the presence of anterior and/or middle column instability.

DEFORMITY CORRECTION

Haher's studies on the contribution of the anterior column to rotational stability are the foundation for the use of anterolateral instrumentation for the correction of scoliotic deformities.[8] By removing the anterior annulus, the surgeon removes the primary restraint to rotation. Insertion of anterolateral instrumentation after coronal and sagittal plane correction allows the surgeon the maximum stabilization to the anteriorly destabilized spine. This is because of the instrumentation's mechanical advantage, which is a function of its distance from the axis of rotation.

Just as in the correction of scoliotic deformities, the surgical correction of kyphotic deformities requires the reestablishment of physiologic biomechanical properties of the spine. Lowe[15] and Ponte[21] have independently examined the biomechanical role of the anterior column in the correction of kyphotic deformities. Lowe,[15] in the treatment of Scheuermann's kyphosis, uses a Cobb measurement of 50° on a supine hyperextension radiograph to determine the need to surgically address the anterior column. Curves which do not correct to under 50° are indicated for an anterior column release with subsequent anterior instrumentation. Those which do correct to under 50° can be structurally and mechanically managed using posterior instrumentation alone. By releasing the anterior column, the axis of rotation is shifted posteriorly, thereby shortening the moment arm and placing less stress on the posterior instrumentation. At the same time, a greater mechanical advantage (via an increased moment arm) is given to the anterior instrumentation.

Ponte[21] advocates a series of interlaminar closing wedge osteotomies designed to provide harmonious correction through the shortening of the posterior column. Biomechanically, this results in migration of the axis of rotation to the anterior column, which gives a mechanical advantage to the posterior instrumentation. No anterior exposure is needed and only minimal lengthening of the anterior column results.

CONCLUSION

Understanding the contribution of the anterior column to spinal mechanics affords the clinician the opportunity to choose the treatment option which is most viable for a given pathology. Instrumentation should be chosen in response to the pathomechanics which have been altered by the injury. The goal of instrumentation is to provide three-dimensional stability in a restored physiologic manner until a bony fusion can occur. The anterior column, given its load-bearing responsibilities, its mechanical advantage as per its distance from the normal axis of rotation, and its incidence of traumatic or iatrogenic involvement, requires added surgical attention when instrumentation decisions are being made.

REFERENCES

1. American Society for Testing and Materials: 1997 Standard for Spinal Devices. Standard F1717. West Conshohocken, PA, American Society for Testing and Materials, 1997.
2. An H, Lim TH, You JW, et al: Biomechanical evaluation of anterior and posterior thoracolumbar spinal instrumentation. Spine 20:1122–1127, 1995.
3. Caruso SA, Yeung AW, Margulies JY, et al: Inverse effects of load sharing and stress shielding. Presented at the 64th Annual Meeting of the American Academy of Orthopedic Surgeons, San Francisco, 1997.
4. Craven TG, Carson WL, Asher MA, Robinson RG: The effects of implant stiffness on the bypassed bone mineral density and facet fusion stiffness of the canine spine. Spine 19:1664–1973, 1994.
5. Denis F: Spinal instability as defined by the three-column spine concept in acute spinal trauma. Clin Orthop 189:65–76, 1984.
6. Haher TR, Tozzi JM, Lospinuso MF, et al: The contribution of the three columns of the spine to spinal stability: A biomechanical model. Paraplegia 27:432–439, 1989.
7. Haher TR, O'Brien M, Felmly WT, et al: Instantaneous axis of rotation as a function of the three columns of the spine. Spine 17(Suppl 6):S149–S154, 1992.
8. Haher TR, Bergman M, O'Brien M, et al: The effect of the three columns of the spine on the instantaneous axis of rotation on flexion and extension. Spine 16(Suppl 8):S312–S318, 1991.
9. Haher TR, Felmly WT, Baruch H, et al: The contribution of the three columns of the spine to rotational stability: A biomechanical model. Spine 14:663–669, 1989.
10. Holdsworth FW: Diagnosis and treatment of fractures of the spine. Manit Med Rev 48:13-15, 1968.
11. Hollowell JP, Vollmer DG, Wilson CR, et al: Biomechanical analysis of thoracolumbar interbody constructs: How important is the end plate? Spine 21:1032–1036, 1996.
12. James KS, Wenger KH, Schlegel JD, Dunn HK: Biomechanical evaluation of the stability of thoracolumbar burst fractures. Spine 19:1731–1740, 1994.
13. Kotani Y, Cunningham BW, Cappuccino A, et al: The role of spinal instrumentation in augmenting lumbar posterolateral fusion. Spine 21:278–287, 1996.
14. Lim TH, An HS, Hong JH, et al: Biomechanical evaluation of anterior and posterior fixations in an unstable calf spine model. Spine 22:261–266, 1997.
15. Lowe TG: Biomechanical aspects of the surgical treatments of kyphotic deformities. Spine State Art Rev 10:433–454, 1996.
16. Margulies JY, Caruso SA, Chattar-Cora D, et al: Substitution of transpedicular screws by hook claws in a vertebrectomy model. J Spinal Disord 11:36–40, 1998.
17. McAfee PC, Farey ID, Sutterlin CE, et al: 1989 Volvo Award in basic science: Device-related osteoporosis with spinal instrumentation. Spine 14:919–926, 1989.
18. McAfee PC, Farey ID, Sutterlin CE, et al: The effect of spinal implant rigidity on vertebral bone density: A canine model. Spine 16(Suppl 6):S190–S197, 1991.
19. McCormack T, Karaikovic E, Gaines RW: The load-sharing classification of spinal fractures. Spine 19:1741–1744, 1994.
20. Panjabi MM, Oxland TR, Kifune M, et al: Validity of the three-column theory of thoracolumbar fractures: A biomechanical investigation. Spine 20:1122–1127, 1995.
21. Ponte A: Scheuermann's kyphosis: Posterior shortening procedure by segmental closing wedge resections. Orthop Trans 19:603, 1995.
22. Shono Y, McAfee PC, Cunningham BW: Experimental study of thoracolumbar burst fractures: A radiographic and biomechanical analysis of anterior and posterior instrumentation systems. Spine 19:1711–1722, 1994.

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