mographic scans should be obtained. If the computerized scan, or the computerized scan in combination with the standard radiogram, suggests but does not clearly demonstrate a fracture of the pars interarticularis or fractures in the coronal plane, then sagittal and coronal reconstructed images should be obtained. Anteroposterior tomography should be performed if the scanner being used cannot provide sagittal and coronal images. Anteroposterior tomograms demonstrate horizontal fractures most satisfactorily and do not require placing the patient in the lateral decubitus position. Finally, metrizamide myelography should be performed to augment the computerized tomographic scans if the patient's neural deficit is increasing or is not consistent with the level of the vertebral injury or if the patient experiences an early, unexplained plateau during recovery from a neural deficit.

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Spinal Instability as Defined by the Three-column Spine Concept in Acute Spinal Trauma

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This article is a presentation of the concept of the three-column spine. The concept evolved from a retrospective review of 412 thoracolumbar spine injuries and observations on spinal instability. The posterior column consists of what Holdsworth described as the posterior ligamentous complex. The middle column includes the posterior longitudinal ligament, posterior annulus fibrosus, and posterior wall of the vertebral body. The anterior column consists of the anterior vertebral body, anterior annulus fibrosus, and anterior longitudinal ligament. Major spinal injuries are classified into four different categories, all definable in terms of the degree of involvement of each of the three columns. Each type is defined also in terms of its pathomechanics, roentgenograms, and computerized axial tomograms, as well as in terms of its particular stability. The compression fracture is basically stress failure of the anterior column with an intact middle column. The burst fracture indicates failure under compression of both the anterior and middle columns. The seat-belt-type spinal fracture is the result of failure of the posterior and middle columns under tension with an intact anterior hinge. In fracture-dislocations, the structure of all three columns fails from forces acting to various degrees from one or another direction.

Spinal instability was defined by Holdsworth[6] as rupture of the posterior ligamentous complex. This was confirmed by Roaf's[15] study of the mechanics of spinal injuries in which rupture of normal spinal ligaments could not be produced by hyperextension or hyperflexion. The implication was that rupture of the posterior ligamentous complex was not compatible with a stable compression fracture but was pathognomonic of instability initiated by either rotation or translation. Heuritsch and Bohler[2] had an excellent intuitive understanding of the pathomechanics of spinal fractures. They created drawings demonstrating several cases of compression fractures seen in conjunction with disruption of the interspinous ligament.

According to Bohler,[2] in 1932 Heuritsch made an accurate sketch of what was to be called, 16 years later, a Chance fracture.[3] In spite of accumulating clinical evidence,[1,2,5-8,10,17] it has taken some recent biomechanic studies[10,12,14,15] to demonstrate that subluxation, dislocation, and simple instability appear only when the posterior longitudinal ligament and part of the disc are torn in conjunction with the posterior or the anterior ligamentous complex.

The past decade has shown the term "instability" to be a key word in therapeutic indications because it equates, in many cases, with a need for internal stabilization. The purpose of this paper is to introduce a classification based on the new concept of the three-column spine.[5]

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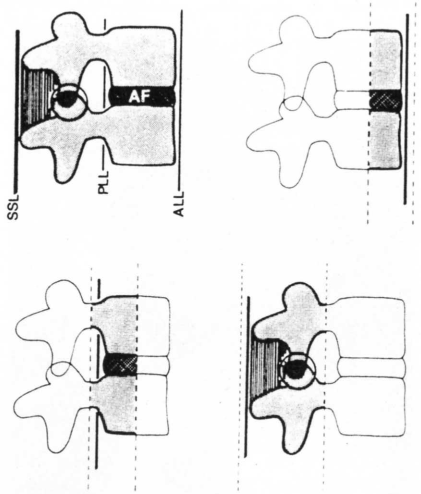


FIG. 1. Illustrations of the anterior, middle, and posterior columns. This and all succeeding figures are published with permission from Francis Denis: The three-column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine 8:817, 1983.

FIG. 2. Anterior compression fracture with disruption of the inferior end-plate (Type C compression fracture). Note the normal height of the posterior part of the vertebral body.

THE THREE-COLUMN SPINE

Recent biomechanic evidence[9,11,13,14] shows that complete rupture of the posterior ligamentous complex alone is not sufficient to establish instability (Fig. 1). Further biomechanic data demonstrate that additional rupture of the posterior longitudinal ligament and posterior annulus fibrosus permits instability in flexion. Complete dislocation requires further disruption of the disc and stripping or disruption of the anterior longitudinal ligament. It appears logical, therefore, to separate the posterior longitudinal ligament, the posterior annulus fibrosus, and the posterior vertebral body into a third column independent of the two others, which plays its own role in the sequence of spinal injury.[4]

The posterior column remains essentially the same as described by Holdsworth.[6] It is formed by the posterior bony complex (posterior arch) alternating with the posterior ligamentous complex: supraspinous ligament, interspinous ligament, capsule, and ligamentum flavum. The middle column is formed by the posterior longitudinal ligament, posterior annulus fibrosus, and the posterior wall of the vertebral body. The anterior column is formed by the anterior longitudinal ligament, the anterior annulus fibrosus, and the anterior part of the vertebral body.

CLASSIFICATION OF SPINAL FRACTURES

The minor injuries represented by fractures of transverse processes, articular processes, pars interarticularis, and spinous processes involve only a part of the posterior column and do not lead to acute instability. The more significant spinal injuries are classified into four different categories.

COMPRESSION FRACTURES

Definition. The compression fracture is a failure under compression of the anterior column (Fig. 2). The middle column is intact and acts as a hinge. The more severe the

compression fracture, the more likely it will be to present, in addition to the anterior wedging, a partial failure of the posterior column, indicating the tension forces at that level. The fact that the middle column is intact is of major importance because it prevents the fracture from subluxation or compression of the neural elements by fragmentation and retropulsion of the fragment of the posterior wall into the canal. Both of these instances are neurologic threats encountered in fracture-dislocations for the former and in burst fractures for the latter.

Roentgenographic characteristics. The lateral film shows a normal posterior body cortex and a normal height of the posterior vertebral body (intact middle column). There is no subluxation of the body above or the body below. The interspinous distance of the compressed segment is increased in proportions that are geometrically expected from the angulation at that level. The anteroposterior film shows the lateral wedging in lateral compression fractures (Fig. 3).

CAT scan characteristics. Computerized axial tomography is rarely indicated in compression fractures, but when done it will demonstrate an intact vertebral ring (intact middle column). There is no retropulsion of bone into the canal (Fig. 4).

BURST FRACTURES

Definition. The burst fracture results from failure under axial load of both the anterior and the middle columns originating at the level of one or both end-plates of the same vertebra.

Roentgenographic characteristics. The lateral roentgenogram demonstrates a fracture of the posterior wall cortex, loss of height of the posterior vertebral body, and tilting and retropulsion of the fragment of bone into the canal of either or both end-plates (compression failure of the middle column) (Fig. 5). The anteroposterior roentgenogram demonstrates the pathognomonic increase of the interpediculate distance, the vertical laminar fracture, and the splaying of the posterior joints (Fig.

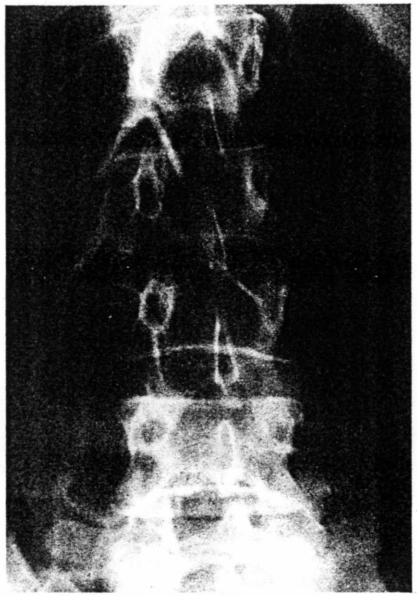


FIG. 3. Lateral compression fracture.

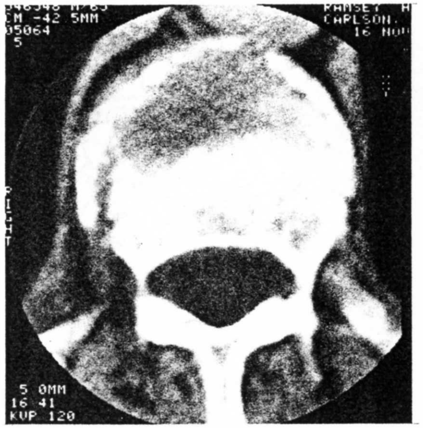


FIG. 4. Computerized axial tomogram of a compression fracture. Note anterior end-plate fracture and totally intact posterior wall of the vertebral body.

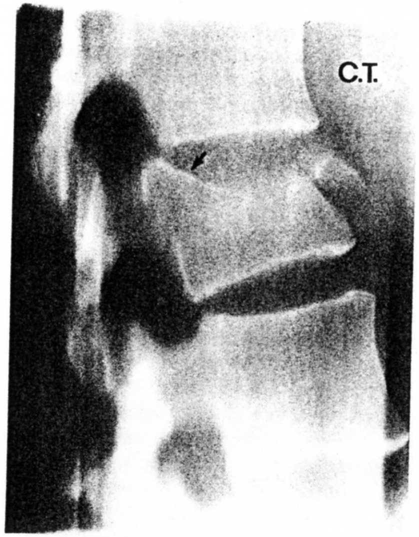


FIG. 5. Lateral tomogram of a burst fracture (Type B) showing severe disruption of superior end-plate, loss of height of posterior vertebral body, and fracture of posterior wall of body. The arrow shows the large fragment retropulsed into the canal.

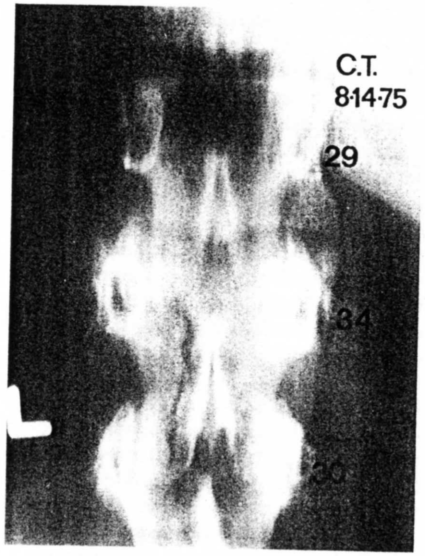


FIG. 6. Anteroposterior tomogram of a burst fracture. Note the increased interpediculate distance (34 mm) and the vertical laminar fracture.

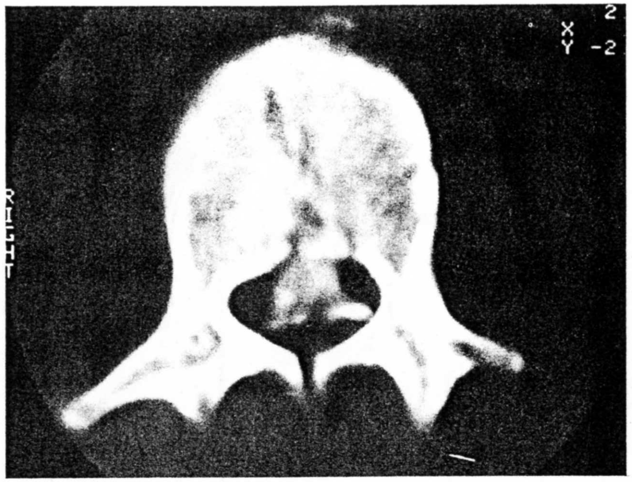


FIG. 7. Computerized axial tomogram of a burst fracture. Note the large fragment of bone retropulsed from the posterior wall.

6). The latter two signs are another expression of the increase of the interpediculate distance leading to the splay of the entire posterior arch. The vertical fracture of the lamina may not be seen at the time of surgery because in most cases it is a greenstick fracture of the anterior cortex of the lamina with an intact posterior cortex. The operator should decorticate the posterior arch very carefully.

CAT scan characteristics. The vertebral ring is fractured both anteriorly and posteriorly. This fragment of bone retropulsed from the vertebral body is sequestrated in the spinal canal and locked in position by the posterior arch (Fig. 7).

Classification of burst fractures. The burst fracture described by Holdsworth with comminution of the entire vertebra and without kyphosis involves both end-plates and is mainly localized in the low lumbar region (L3, L4, and L5). The majority of burst fractures involve only one plate (the superior one in most cases). For this reason, five different types of burst fractures are described (Fig. 8). Type A: Fracture of both end-plates due to pure axial load. The bone is retropulsed into the canal at the level of both discs adjacent to the comminuted vertebra. Type B: Fracture of the superior end-plate. This is the most common burst fracture. It is encountered mainly at the thoracolumbar junction and its mechanism is a combination of axial load with flexion. Decompression should be performed at the upper level only when indicated. Type C: Fracture of the inferior end-plate. This fracture pattern is rare. The mechanism of injury also appears to be axial load and flexion. Type D: Burst rotation. This fracture could be misdiagnosed as a fracture-dislocation because of the rotational component of injury. It presents, however, all the pathognomonic signs of burst fractures, with increase of the interpediculate distance, comminution of the vertebral body, vertical fracture of the lamina, retropulsion of bone into the canal, and loss of posterior height. Computerized axial tomography as well as myelography may identify the large fragment of bone occluding the canal. The mechanism of this injury is a combination of axial load and rotation. Type E: Burst lateral flexion. This type of fracture differs from the lateral compression fracture in that it presents an increase of the interpediculate distance on

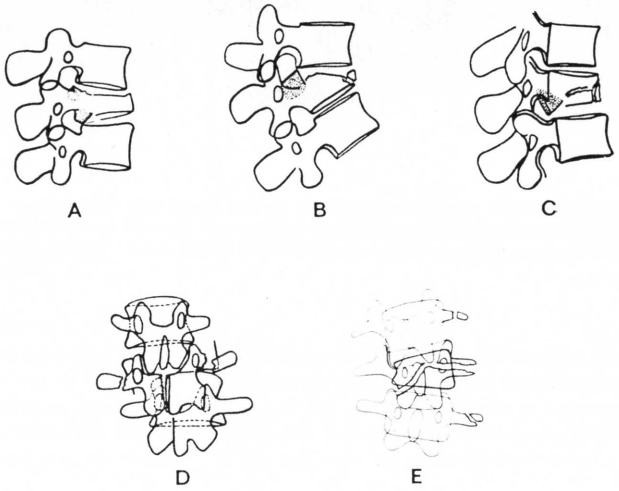


FIG. 8. Classification of burst fractures: Types A, B, and C are mainly diagnosed on lateral roentgenograms; their anteroposterior roentgenograms reveal the basic pathognomonic features seen in Figs. 5–6. Types D and E are diagnosed on anteroposterior roentgenograms. The lateral film of a Type D looks like a Type A, whereas the lateral film of a Type E may look like Type A, B, or C.

anteroposterior roentgenogram. The lateral film will disclose the retropulsion of bone from the posterior wall into the canal. Computerized axial tomography again identifies the extruded fragment and shows it to be somewhat more lateralized as compared with the other types of burst fractures.

SEAT-BELT-TYPE INJURIES

Definition. These injuries represent a failure of both the posterior and middle columns under tension forces generated by flexion with its axis placed in the anterior column. The anterior part of the anterior column may partially fail under compression but will not lose its role as a hinge. This type of injury will be unstable in flexion and will not present with association of subluxation, which indicates that the anterior hinge is also disrupted and that fracture dislocation is present.

Roentgenographic characteristics. A pathognomonic sign of this type of injury is the horizontal split of the transverse processes as well as of the pedicles. There may be a horizontal fracture of the spinous process or of the pars intra-articularis, or also, in some cases, an increase of the interspinous distance with a minimal spinous process avulsion. The height of the posterior vertebral body is increased or there may be an increase of the disc space posteriorly at the level of the injury.

CAT scan characteristics. CAT scan does not provide additional information for this type of injury because the horizontal cuts are often parallel to the plane of injury. Coned-down views or lateral tomograms are more useful in terms of identifying the precise level of the fracture.

Subtypes of seat-belt-type injuries. These injuries are divided into one- and two-level lesions (Fig. 9). One-level lesions may present as a simple Chance fracture going through bone or as a ligamentous disruption starting at the level of the supraspinous ligament and proceeding to the anterior part of the disc. Two-level lesions are comparable to the condition presented in hangman's fracture in which the middle column may rupture either through the bone or through the disc.

FRACTURE-DISLOCATIONS

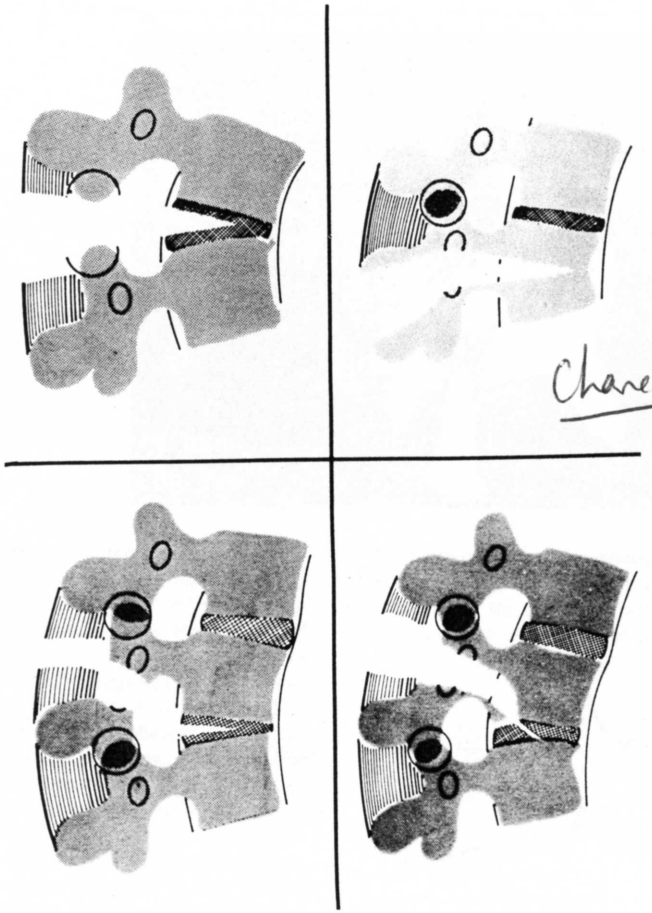
Definition. This is the most unstable of injuries and presents with failure of all three columns under compression, tension, rotation, or shear.

Roentgenographic characteristics. Its pathognomonic sign is the subluxation or dislocation seen on anteroposterior or lateral roentgenograms. Some indirect signs may suggest this type of injury in the presence of multiple rib fractures, multiple transverse process fractures, fracture of a unilateral articular process, slight increased height of a disc, or minimal vertebral body offset.

Subtypes of fracture-dislocations. There are three major mechanisms in fracture-dislocations: flexion rotation, shear, and flexion distraction.

Flexion-rotation fracture-dislocation (Fig. 10). This injury has been described by Holdsworth[6] and also by Roaf.[15] There is usually a complete rupture of the posterior and middle columns under tension and rotation. The anterior column may fail in rotation or sometimes in varying combinations of compression and rotation. The failure at the level of the middle and anterior columns may occur through the vertebral body or purely through the disc. Roentgenographic characteristics, the pathognomonic sign of the fracture-dislocation, will be the subluxation or dislocation of a vertebral segment on another one. There is frequently an increase of the interspinous distance and a displaced fracture of a superior articular process on one side, indicating rotational failure of the posterior column. Multiple transverse process fractures and multiple rib fractures are frequent. A slight amount of rotation between the segment above and the segment below may be observed.

Computerized axial tomography in flexion rotation. This may demonstrate the occlusion of the canal resulting from the offset of one vertebra on another (Fig. 11). It will occasionally show jumped facets not identifiable on plain roentgenograms. It may also show a fragment of bone retropulsed into the canal, indicating a burst fracture. However, a significant difference between the burst fracture fragment and the fragment seen in fracture-dislocations is that the burst fracture is covered in the former by an intact posterior longitu-



Chance.

FIG. 9. (Upper Left) One-level seat-belt-type injury through the ligaments. (Upper Right) One-level seat-belt-type injury through bone (Chance fracture). (Lower Left) Two-level seat-belt-type injury through ligaments at the level of the middle column. (Lower Right) Two-level seat-belt-type injury through ligaments at the level of the middle column.

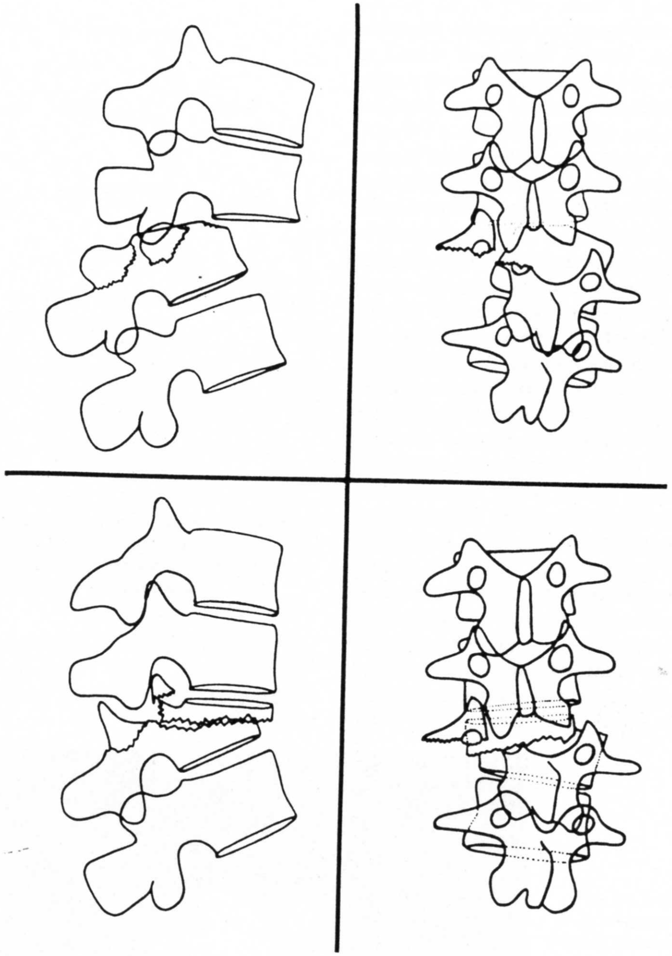


FIG. 10. (Upper Left) Lateral diagram of a fracture-dislocation of the flexion-rotation type through the disc. Note the superior articular process fracture on one side only. (Upper Right) Anteroposterior diagram of a fracture-dislocation of the flexion-rotation type through the disc. Note the fracture of the left superior articular surface. (Lower Left) Lateral diagram of a fracture-dislocation of the flexion-rotation type through bone (slice fracture). (Lower Right) Anteroposterior diagram of a fracture-dislocation of the flexion-rotation type through bone (slice fracture). Note the difference in rotation between both spinal segments.

dinal ligament, whereas this same structure is torn in the latter. The implication of this is twofold: first, in terms of stability of the injury, and second, in terms of reduction of the retropulsed fragment by ligamentotaxis.

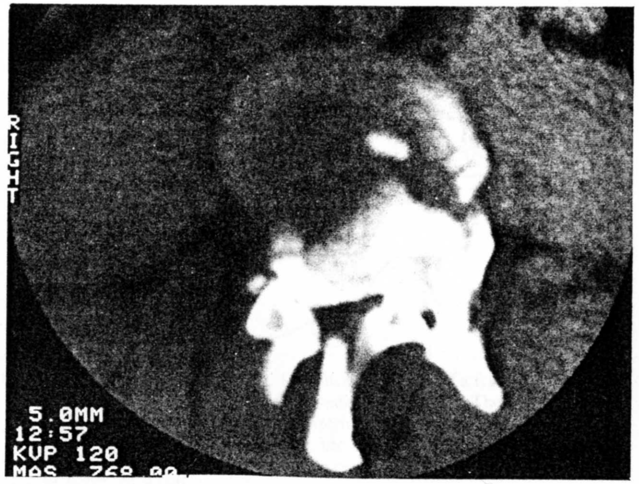


FIG. 11. Computerized axial tomogram of an L2–L3 lumbar fracture-dislocation of the flexion-rotation type. Note the fracture of the right superior articular process of L3 and the 80% neural canal obstruction resulting from the malalignment.

Shear type of fracture-dislocation. This injury results from an extension type of mechanism in which the anterior longitudinal ligament is disrupted. The disc is first torn anteriorly to posteriorly until the continued shearing force translates the upper segment on top of the inferior segment, or vice versa. (1) In the posteroanterior shear subtype (Fig. 12), the segment above is sheared off forward on top of the segment below. The posterior arch of the last one or two vertebrae of the upper segment is usually fractured in the translation, leaving a floating posterior arch behind. The frequency of dural tear and complete paraplegia is very high in this type of fracture. (2) In the anteroposterior shear, the segment above shears off on the segment below in a posterior direction. Its posterior arch has nothing to clear during its posterior displacement; therefore, no free-floating laminae exist (Figs. 13 and 14).

Fracture-dislocation of the flexion-distraction type. This injury resembles the seat-belt type of injury with disruption of both the posterior and middle columns under tension. However, in addition, it presents tear of the anterior annulus fibrosus, allowing stripping of the anterior longitudinal ligament during subluxation or dislocation (Fig. 15).

Roentgenographic characteristics. This is a symmetrical type of injury with frequent horizontal split of the transverse process pedicle and spinous process. This injury may be sub-

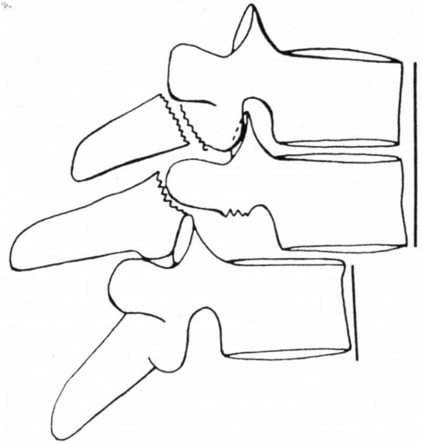


FIG. 12. Lateral diagram of a posteroanterior shear injury. Note the intact anterior vertebral bodies. The spinous process or entire posterior arch may be fractured by the same mechanism, leaving a "floating lamina" behind.

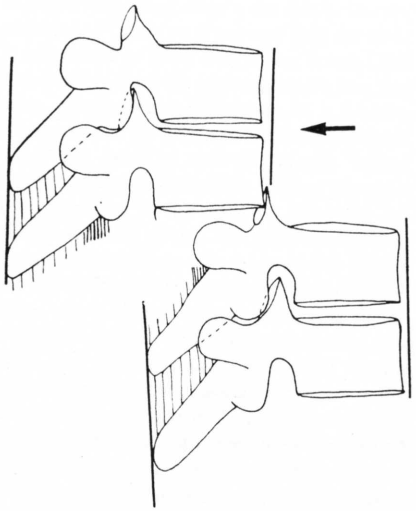


FIG. 13. Lateral diagram of an anteroposterior shear injury. The posterior arches and anterior vertebral bodies may be entirely intact, but the three ligamentous columns are disrupted.

divided into the seat-belt-type injuries in one- and two-level types.

Definition of instability. As Whitesides[18] pointed out, a stable spine is one that can withstand stress without progressive deformity or further neurologic damage. An unstable spine is thus one that may lead to an increased deformity or an increased neurologic deficit. In order to incorporate that notion into the present classification, the author has subdivided instability into the three potential combinations of these complications. (1) Instability of the first degree is a mechanical instability with risk of chronic kyphosis. It applies to the severe compression fracture with posterior column disruption as well as to some of the seat-belt-type injuries. (2) Instability of the second degree is a neurologic instability. The so-called stable burst fracture falls into this category as further vertical collapse of the fractured vertebra may lead to more retropulsion of bone into the canal in the early post-traumatic phase and to higher risks of post-traumatic spinal stenosis after healing of the fracture. Both of these situations may precipitate neurologic complications in a previously intact patient. (3) Instability of the third degree is both a mechanical and a neurologic instability. Fracture-dislocations and unstable burst fractures with or without existing neurologic damage are in this category.

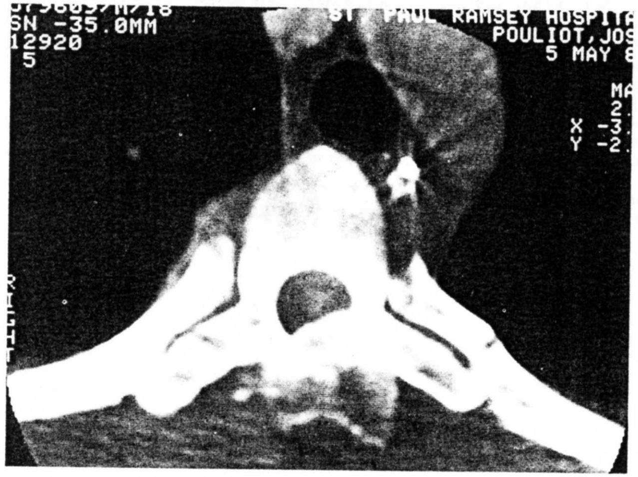


FIG. 14. Computerized axial tomogram of a fracture-dislocation of the anteroposterior shear type. Note the anterior aspect of the superior vertebral body locked on the superior facets of the inferior vertebral body.

DISCUSSION

Nicoll[10] reported a classification of dorsal and lumbar spinal injuries based on four main types: anterior wedge fracture, lateral wedge fracture, fracture-dislocation, and isolated fracture of the neural arch. This classification may be confusing because under the heading "Neural Arch Fractures" the author includes Chance fractures with chronic spondylolisthesis as well as traumatic spondylolisthesis. Nicoll believed that rotation was responsible for these neural arch fractures and that the lateral wedge fracture was due to flexion rotation; both of these mechanisms were formerly attributed to fracture-dislocations by most authors.

Olof Perey[12] subjected one-level spinal motion segments consisting of two vertebrae and the intervening disc to a strong force of axial load with a fast rate of loading. The amount of stress used was established at a right angle to the cross-sectional dimension. Disc spaces were visualized by diskography. Four experimental series were made in which the maximum forces were calculated to be 1050, 1250, and 1350 kiloponds during approximately 0.06 seconds. A total of 76 experiments were performed, which demonstrated how vertebral end-plate fractures occurred experimentally. Only two cases of double end-plate disruption were observed (two out of 24 experiments done with two-level spinal motion segments as opposed to frequent rupture of both endplates encountered in the clinical series). It should be noted also that the changes at the level of the posterior arch were not mentioned.

Roaf[15] demonstrated that discs, joints, and ligaments were rather resistant to distraction, flexion, and extension but were very vulnerable to rotation and horizontal shearing forces. His experimental work suggested that rupture of the anterior longitudinal ligament in hyperextension was impossible and that neural arches fractured first. When the spine was rotated in extension, the anterior longitudinal ligament easily ruptured; therefore, the so-called hyperextension injury was actually a rotation-extension injury. Similarly, Roaf was unable to experimentally reproduce rupture of the posterior ligamentous complex as observed clinically in severe compression fractures. It appears that his results were greatly influenced by the limited degree of freedom of his biomechanic testing apparatus, which lacked, in particular, the essential versatility of being able to combine predetermined vectors of forces. Smith and Kaufer[16] reported 24 lumbar spine injuries sustained by persons wearing a lap seat belt who were involved in motorcycle accidents. Twenty of these patients presented a specific pattern of lumbar spine injury: a transverse type of lumbar fracture believed to be extremely rare in unbelted individuals. The authors emphasized the risk of abdominal contusions associated with the spinal injury and characterized the disruption as osseous, ligamentous, or both. There was little or no decrease in anterior vertical height of the involved vertebral body. Most disruption occurred between the first and third lumbar vertebrae. It was assumed that the axis of flexion of the spine during injury was at the level of the lap belt pressing over a thick layer

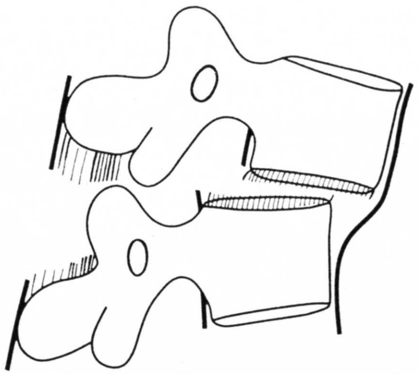


FIG. 15. Lateral diagram of a fracture-dislocation of the flexion-distraction type. The posterior, middle, and anterior ligamentous columns are disrupted, but the anterior longitudinal ligament is intact and strips off the vertebral body below.

of tissue separating it from the spine. The implications of such an access are that the spine is submitted to pure distraction forces. This assumption may be challenged for two reasons. Firstly, the lap belt acts as a fulcrum that becomes the access of flexion only if and when the bending strength of the "spinal beam" under consideration is nil at the point of application of the fulcrum. Secondly, indirect evidence of this was demonstrated by Gordon Armstrong, who pointed out that in the 15 Chance fractures in the present series there was a slight vertical shortening of the anterior vertebral body, demonstrating *post facto* that the instantaneous axis of flexion was somewhere in the anterior column at the time of injury (unpublished data). It should be added also that an instantaneous axis of flexion is dynamic, not static, and moves during the sequence of rupture from somewhere in the middle column to somewhere in the anterior column as the ligaments or bony parts rupture posteriorly to anteriorly. Panjabi *et al.*,[11] in an individual study conducted to establish the thresholds of thoracic spine stability, demonstrated that under flexion loads the thoracic functional spinal unit is on the verge of instability when all ligaments posterior to and including the posterior half of the discs are cut. Nagel *et al.*[9] tested five fresh human cadavers to determine range-of-motion measurements between the first and second lumbar vertebrae after progressive disruption of the motion segment. Their study showed that an anterior flexion of 20° or a lateral flexion of 10° seen on a routine roentgenogram indicated that all posterior ligaments and at least part of the annulus fibrosus must be disrupted.

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A Mechanistic Classification of Thoracolumbar Spine Fractures

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Thoracolumbar spinal injuries are classified on the basis of the mechanical mode of failure of the vertebral bodies. The fractures are presented in seven categories. Emphasis is placed on the injury component causing the fracture patterns. The choice of instrumentation for surgery is based on the surgeon's understanding of these injury patterns.

At the present time there is no universally accepted classification of thoracolumbar spine fractures. The schema suggested by Holdsworth[14] has perhaps been the most widely used in clinical reviews and has been the cornerstone for many subsequent classifications. However, this system ignores a number of variables that could be weighed in treatment decisions. What effect, if any, these variables might have on treatment outcome is a focus of current interest. However, until all recognizable variables are critically analyzed, the surgeon will be able to make only "educated" assumptions about them when deciding what therapeutic mode is most efficacious for a particular patient.

Approximately five years ago, in treating spinal fracture patients by the application of L-rod instrumentation, it became apparent that in a majority of operative cases there is bone in the neural canal. Thirty-four of 54 patients seen at the authors' hospital from October 1976 to August 1981 had bone from the posterior vertebral body encroaching on the neural canal. Twelve patients in this group had similar fracture patterns, but radiographic documentation was insufficient to decide if they had bone in the neural canal. On closer review, the authors noted that among their cases this retropulsed bone followed a consistent group of patterns. The most common among the patterns was the compressive flexion lesion in which the superior margin of the vertebral body rotated into the neural canal. This comprised 46% of the 54 fractures. Nine percent of this group had bone in the canal secondary to vertical compression injuries. The lesions had either a symmetrical bulging pattern of the posterior vertebral body wall into the neural canal or an enfolding pattern of failure. In both types of vertical compression lesions the posterior vertebral body height was shortened.

Review of the relevant literature suggested that either the phenomenon of bone in the neural canal had for the most part been ignored[8,12] or the frequency distribution of the types of thoracolumbar fractures had dramatically changed. Although there is no way to accurately discern these alternatives, the authors believe that in the absence of tomo-

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