
The Contribution of the Three Columns of the Spine to Spinal Stability: A Biomechanical Model

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Summary

The load carrying capacity (LCC) of the human spine was evaluated in 10 human cadaver spines. The specimens consisted of segments from T11 to S1 with markers placed on the specimens at each vertebral level in both Ap and lateral planes. The specimens were loaded to 1250 N and spinal deflections were recorded and photographed at 125 N intervals during the loading cycle. In 5 specimens, axial and flexion loads were applied to the intact spine. The anterior and middle columns were destroyed in sequence at L2 and the loading process repeated. In the remaining 5 specimens, axial and extension loads were applied with the spine intact and after the posterior and middle columns were destroyed in sequence at L2. Load deflection curves were generated for each test and comparisons were made between intact spines and spines with single and double column destruction. Results: When the axis of loading was anterior to the posterior longitudinal ligament (PLL), destruction of the anterior and middle columns reduced the LCC by 46% and 68% respectively and destruction of the posterior and middle columns reduced the LCC by 30% and 63% respectively. There was minimal change in the LCC when the axis of loading was posterior to the PLL and the anterior and middle columns were destroyed.

Two column destruction of the spine reduced its load carrying capacity for flexion loads by 70%. In thoracolumbar spinal fractures where flexion loads are predominant and anticipated, the authors conclude that surgical stabilisation is indicated with double column failure.

Keywords: *Spinal stability; Spinal columns; Load carrying capacity.*

Definitions of spinal stability and indications for surgical stabilisation or brace containment of spinal injuries have varied over time (Burke and Murry, 1976;

Denis, 1982; Frankel *et al.*, 1969; Holdsworth, 1963; Jacobs *et al.*, 1980). Although Hippocrates stated that all fractures should be anatomically reduced, with many spinal fractures anatomical reduction and surgical stabilisation are not necessary and the results of such treatment may be worse than the subsequent untreated spinal deformity. Numerous classification schemes and indications for surgical treatment of spinal fractures have been published to date. These classifications however usually have been based on supine roentgenograms of the injured spine (Bedbrook and Edibaum, 1973; Holdsworth, 1963; Leidholdt *et al.*, 1969; Nicoll, 1949; Riggins and Kraus, 1977) or on anatomical dissections of intact cadaveric spines (Rissanen, 1960; White and Panjabi, 1978; White *et al.*, 1981). Indications for operative intervention have varied with each classification system and often have been based on the long term follow-up of patients with non-operatively treated fractures (Bohlmann, 1976; Burke and Murry, 1976; Lewis and McKibbin, 1974; Malcolm, 1979; Nicoll, 1949; Roberts and Curtiss, 1970; Young, 1973) or on arbitrary predetermined measurements from supine films (Bedbrook and Edibaum, 1973; Denis, 1982; Morris *et al.*, 1961; Rissanen, 1960). With the advent of the three column classification of spinal anatomy a more precise analysis of spinal stability was made possible (Denis, 1982, 1984; McAfee *et al.*, 1982). Knowing which columns are intact can better enable the clinician to interpret the integrity of the spine as a load-bearing column. An understanding of the contribution of each column to overall stability would greatly enhance our understanding of the unstable spine.

Materials and methods

Ten spines were harvested by the authors from autopsy specimens. The specimens consisted of intact spines from C1 to S1. The specimens had no intrinsic deformities and were frozen at -20°C until testing. The age, sex, cause of death, and general health of the donors were known. The paravertebral musculature was dissected from the specimens at the time of testing. The spines were transected through the vertebral bodies at the level of T11 and S1 and thawed to room temperature. The planes of transection were parallel at the end plates and were perpendicular to the long axis of the spine. The specimens were placed between the stationary and mobile plates of a Tinius-Olsen Super 'L' UTM (Tinius Olsen Testing Machine Company, Pa, USA). A deflection gauge (0.01 mm increments) was placed on the mobile plate. Compressive loads and corresponding deflections were recorded. Flexion and extension were added to the normal sagittal curves of the spine by angulation of the superior load plate and measured using a goniometer. Lateral photographs were taken of the specimens at 125 N increments in the loading and unloading phase. Each specimen was loaded to 1250 N over time periods of 3 minutes. The loading cycle was repeated 3 times. A 10-minute recovery time was used between each loading cycle. The specimens were unloaded and similar data was recorded. Each specimen was loaded according to the scheme in Tables I and II.

The specimens were divided into 2 groups of 5 each. The first 5 specimens were tested intact with the loads applied axially and in 20 degrees of flexion (Fig. 1A and B). The anterior column was then destroyed at L2 including the anterior longitudinal ligament, the anterior aspect of the vertebral body and the

Table I Loading scheme of spines in flexion

Spine	Load
Intact	Axial Flexion
(-)Anterior column	Axial Flexion
(-) Anterior and middle column	Axial Flexion

Table II Loading scheme of five spines in extension

Spine	Load
Intact	Axial Extension
(-)Posterior column	Axial Extension
(-) Poterior and middle column	Axial Extension

anterior aspect of the disc (Fig. 1C). The specimens were again loaded axially and in flexion. The middle column was then destroyed at the same level including the posterior aspect of the disc, posterior vertebral body and the posterior longitudinal ligament and loaded in similar fashion (Fig. 1D). The next 5 specimens were loaded axially and in extension. The specimens were loaded with all three columns intact, after destruction of the posterior column (Fig. 1D) and finally with the destruction of the posterior and middle columns (Fig. 1E).

The data was plotted with the axes load vs. deflection (Fig. 2). The load needed to achieve a specific deflection was found. The stiffness (N) of the specimen was calculated from the tangent slope of the load deflection curve at a given deflection. The effects of column destruction are apparent when the load deflection curves are superimposed (Fig. 3).

The loading carrying capacity (LCC) of the spine was calculated for each test by using the following formula:

$$LCC = \frac{L_{Sp^{(\#)} Def.-Col}}{L_{Sp^{(\#)} Def. Intact}} \times 100$$

where L is defined as the load needed to achieve a specific deformation: Sp(#) represents the specific spine being tested: (- Col) represents the column that has been destroyed: LCC is defined as the ability of the spine to support a given load as compared to the intact specimen. An intact spine is defined as having an LCC of 100%.

The amount of load needed for a given deformation between intact and compromised specimens was compared and their ratio calculated. The LCC was calculated for each spine with respect to its method of loading and the number

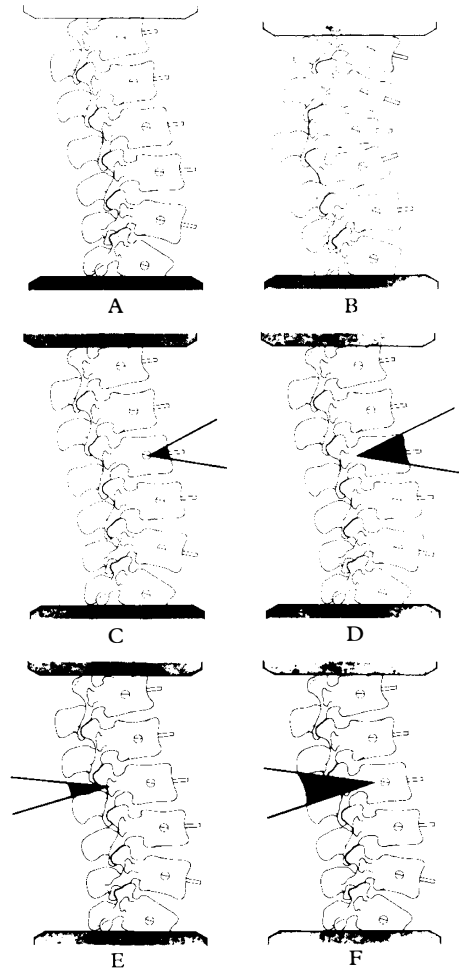


Figure 1 Diagrammatic representation of the sequential column destruction of the spines. 1A: Intact spine T12–L5 with normal sagittal plane maintained. 1B: Intact spine in 20° of flexion. 1C: Destruction of the anterior column. 1D: Destruction of the anterior and middle column. 1E: Destruction of the posterior column. 1F: Destruction of the posterior and middle column.

of columns destroyed (Table III). The average values of the LCC for all groups and methods of loading are shown in Table IV.

Results

The LCC of the spine is a function of the number of intact columns. Table III represents the effect of the comprised columns on the LCC of the spine. The average values for a given column defect is shown in Table IV. With isolated destruction of the anterior or posterior columns, one could expect a loss in the LCC of 22%. The loss of the LCC increases with flexion in an anteriorly compromised spine, and with extension with a posteriorly compromised spine. The LCC decreased an additional 24% with flexion in the specimen with anterior column destruction and by an additional 8% with extension in the

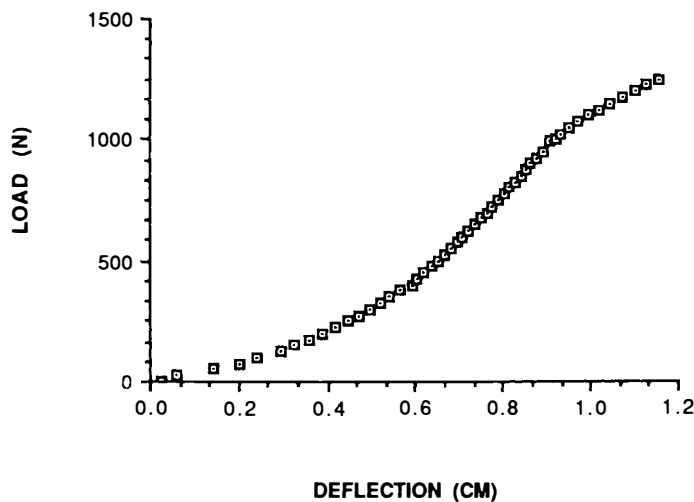


Figure 2 Load deflection curve: Applied load plotted against the deflection of the spine. SP6.3 load time 4:09:00.

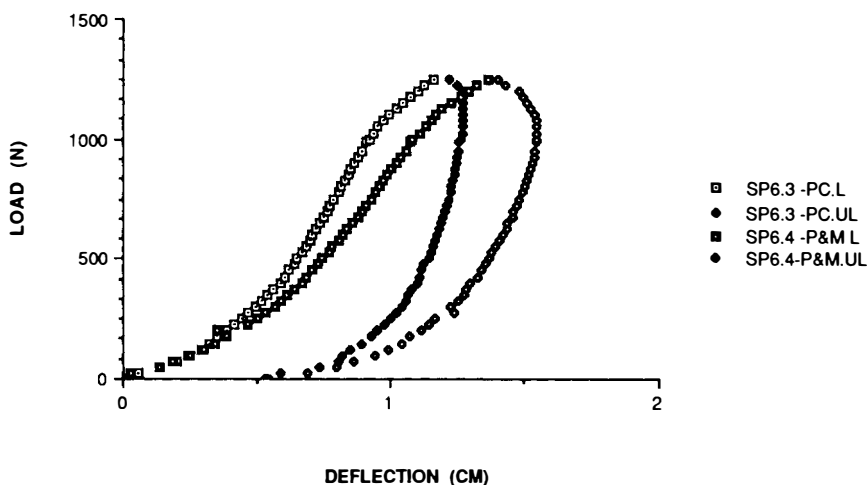


Figure 3 Overlay plot from intact and compromised curves showing effect of column destruction on the ability of the spine to support a load at a given deflection. Curves represent the loading and unloading cycles of a specimen with posterior column destruction compared with the same specimen with posterior and middle destruction. SP6.3-PC.L (Spine 6 with destruction of the posterior column in loading). SP6.4-P&M.L (Spine 6 with destruction of the posterior and middle columns in loading.)

specimen with loss of the posterior column. The LCC decreased with multiple column failure. The LCC decreased 70% with anterior and middle destruction in flexion. This represented a 6.5% increase as compared to axial loading. With posterior and middle column destruction the LCC decreases to 40%. When tested in extension the loss of the LCC was 65%. All LCC values are dependent upon the true loading axis. The loading of the specimen and the assumed loading axis were analysed in conjunction with the photographs taken at 125 N intervals during loading. This would assure proper loading technique. Adding flexion or extension to the specimen further decreased the LCC. This was

Table III Load carrying capacity of spines measured at a specific deflection. Column; designates the columns destroyed and the mode of loading (Axial, flexion and extension). Load in newtons. LCC; Load carrying capacity. N; stiffness of the specimen. Time; the time for the loading cycle.

Load carrying capacity				
Column	Load (N)	LCC (%)	N	Time
Spine 1 Loads measured at deflection of 1.27 cm				
Intact axial	1110	100	0.57	3:30
Intact (flex)	1110	100	0.25	3:40
(-) Ant col (ax)	557	50	0.31	2:50
(-) Ant flex	532	48	0.24	3:10
(-) A & M (ax)	333	30	0.21	3:35
(-) A & M (flex)	400	35	0.33	3:00
Spine 2 Loads measured at deflection of 0.4 cm				
Intact (axial)	622	100	2.0	2:55
Intact (flex)	620	100	1.9	2:50
(-) Ant col (ax)	555	90	1.7	3:10
(-) Ant col (flex)	440	70	1.5	4:40
(-) A & M col (ax)	178	30	0.26	4:46
(-) A & M col (fl)	111	17	0.34	2:57
Spine 3 Loads measured at deflection of 0.6 cm				
Intact (axial)	888	100	0.8	3:00
Intact (flex)	820	93	0.7	3:30
(-) Ant col (ax)	700	80	0.5	2:50
(-) Ant col (flex)	640	72	0.51	3:00
(-) A & M col (ax)	577	65	0.61	4:00
(-) A & M col (fl)	532	60	0.65	3:30
Spine 4 Loads measured at deflection of 0.9 cm				
Intact (axial)	1110	100	0.81	3:30
Intact (flex)	1065	95	0.80	3:00
(-) Ant col (ax)	999	90	0.72	4:30
(-) A & M col (ax)	300	30	0.32	2:30
Spine 5 Loads measured at deflection of 0.76 cm				
Intact (axial)	1000	100	2.0	5:04
Intact (flex)	888	88	2.0	5:70
(-) Ant col (ax)	540	54	1.2	4:00
(-) Ant col (flex)	440	44	0.5	4:30
(-) A & M col (fl)	177	17	0.8	3:30
Spine 6 Loads measured at a deflection of 1.0 cm				
Intact (axial)	1110	100	0.77	3:24
(-) Posterior col	900	81	0.65	4:09
(-) Post & mid	420	40	0.53	3:45
Spine 7 Loads measured at a deflection of 0.653 cm				
Intact (axial)	1200	100	0.92	5:19
(-) Posterior col	1021	85	0.90	2:20
(-) Post & mid col	666	55	0.84	2:41
(-) Post & mid (ext)	440	37	0.71	2:10
Spine 8 Loads measured at a deflection of 0.76 cm				
Intact (axial)	800	100	0.82	4:50
Intact (ext)	710	89	0.55	5:17
(-) Posterior	754	94	0.83	4:40
(-) Post (ext)	666	83	0.56	3:49
(-) Post & mid (ax)	577	72	0.83	3:23
(-) Post & mid (ext)	300	31	0.53	2:51
Spine 9 Loads measured at a deflection of 0.5 cm				
Intact (axial)	667	100	0.95	2:45
(-) Posterior (ax)	444	66	0.84	2:04
(-) Post & mid (ax)	448	73	0.80	3:00
(-) Post & mid (ext)	266	40	0.52	1:45
Spine 10 Loads measured at a deflection of 0.65 cm				
Intact (axial)	843	100	0.6	3:50
(-) Post (ext)	532	63	0.56	4:20
(-) Post & mid (ext)	310	36	0.30	3:40

Table IV Average load carrying capacities (LCC) and the loss of the LCC for that specimen

Average LCC values Column	Load	LCC (%)	Loss of LCC (%)
(-) Anterior	Axial	77.5	22.5
(-) Anterior	Flexion	54.0	46.0
(-) Anterior and Middle	Axial	38.8	61.2
(-) Anterior and Middle	Flexion	32.3	67.7
(-) Posterior	Axial	77.6	22.4
(-) Posterior	Extension	70.0	30.0
(-) Posterior and Middle	Axial	61.6	38.4
(-) Posterior and Middle	Extension	36.8	63.2

evident in both the intact and compromised spine (Table IV). The stiffness (N) of the specimens decreased with column destruction. The decrease in stiffness was proportional to the number of columns destroyed.

Discussion

The indications for surgery of the injured or compromised spine are often based upon the supine (unloaded) roentgenograms. It is difficult or even impossible to predict the load carrying capability of that spine based on X-rays that neither reflect the character of the spine at the moment of injury, nor represent the spine in the loaded or physiological situation. Each portion or column of the spine contributes a strength to the overall intact spine. In assigning a relative strength to each part of the spine, a predicted or resultant strength could be calculated by a summation of those parts that are compromised.

Table III contains the results of the Load deflection curves for each specimen. The capability of the specimen to support a given load decreased as the number of columns were destroyed. This effect was most significant with the destruction of the anterior and middle columns and was augmented when the axis of loading was placed over the compromised column or columns. The data compares favourably with the work of Tenser and Mayer (1983) concerning the major load-bearing elements of the spine. The stiffness of the specimens decreased with single and multiple column destruction.

The average stiffness was larger in flexion than in extension when compared to the intact specimen. This finding is presumably due to the increased load carrying capacity of the anterior column (Edward *et al.*, 1987).

Conclusion

An attempt has been made to quantitatively analyse the contribution of each column of the spine to overall stability. The anterior and posterior columns individually are responsible for 22% of the load carrying capacity of the spine under axial loading. With flexion and extension, the Loss of the LCC increases to 46% and 30% respectively. The anterior and middle columns combined are responsible for 68% of the load carrying capability (LCC) of the spine with flexion. The posterior and middle columns combined contribute 63% of the

LCC with extension. The true axis of loading and the rate of loading must be known before any load deflection data can be interpreted.

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