

# A Comparative Biomechanical Study of Spinal Fixation Using Cotrel-Dubousset Instrumentation

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**A biomechanical study was performed comparing the stiffness and stability of Cotrel-Dubousset (CD) spinal instrumentation with that of segmentally wired Harrington distraction rods and segmentally wired Luque rods under conditions of single-level instability. The axial and torsional stiffness coefficients of each system were determined on a customized geometric spine simulator fashioned from stainless steel. The relative stability of each instrumentation system was then compared by mounting the fixation systems on bovine thoracic spines from 12-week-old calves, destabilized by anterior vertebrectomy to create simulated two column instability. Thirteen spines were tested. Each specimen was tested under axial and torsional loading conditions while monitoring with a personal computer-based data acquisition system was performed. The stability of first- and second-level CD instrumentation was tested on the bovine specimens. First-level CD instrumentation involved double-hook fixation one level above and below the level of instability. Second-level CD instrumentation involved fixation two levels above and below the level of instability without fixation at the intermediate level. In axial loading, double-level wired Harrington distraction rods, double-level wired Luque rods, and first-level CD rods were 26.5%, 18.4%, and 21.5%, respectively, as stable as second-level CD instrumentation. In torsion, double-level Harrington, double-level Luque, and second-level CD rods were 13%, 64%, and 34%, respectively, as stable as first level CD instrumentation. Locking hooks, double-hook configurations, and stabilizing transverse traction devices of the CD contributed to its greater stability. First-level CD instrumentation is recommended for rotational instability while second-level CD instrumentation is preferred for axial instability. [Key words: traumatic spinal instability, instrumentation, Cotrel-Dubousset, segmentally wired rods, biomechanics]**

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**S**UCCESSFUL RECONSTRUCTIVE SURGERY for thoracic and lumbar spine fractures ideally results in restoration of normal anatomy. When local structural elements have been violated, the maintenance of proper geometry often depends on internal fixation until bony union occurs. Such fixation must maintain satisfactory reduction without jeopardizing neural elements.

Harrington instrumentation has been used for fixation of spinal fractures.<sup>9,14</sup> Luque and Harrington techniques have been supplemented with segmental wiring methods in an attempt to improve fixation in the presence of spine instability.<sup>1,4,7,13,16,18,19</sup> Despite overall success with these procedures, complications have arisen as a result of failure of fixation.<sup>2,3,11,20,25</sup>

In 1985, McAfee et al.<sup>21</sup> tested segmentally wired Harrington distraction rods, Harrington distraction rods alone, and segmentally wired Luque rods on appropriately destabilized human cadaver spines. This study demonstrated that segmentally wired Harrington rods were most stable in axial loading, whereas segmentally wired Luque rods were most stable in torsion.

Recently, Cotrel and Dubousset<sup>5</sup> have described a technique for posterior fixation of the spine using knurled rods. While originally designed for scoliosis, this technique has been modified for use with single-level instability. Fixation is achieved via pediculotransverse double-hook purchase at each level and does not require use of wires. Furthermore, the two knurled rods are additionally stabilized via two transverse traction devices which give the overall construction a quadrilateral frame configuration.

In this study, the Cotrel-Dubousset (CD) instrumentation system was compared with segmentally wired Harrington and Luque rods with regard to axial and torsional loading in the presence of single-level spinal instability.

## METHODS

In order to eliminate specimen variability, a geometric spine simulator was developed on which segmentally wired Harrington rods, segmentally wired Luque rods, and CD rods were serially mounted. The fixture was fashioned from stainless steel to geometrically and spatially approximate adult human vertebral bodies and discs in the T10 to L3 region.<sup>17</sup> No attempt was made to simulate the spine in any way other than in gross geometric fashion. The fixture consisted of two proximal metallic "vertebral bodies" spaced 4 cm from two similar structures distally to simulate a single level of spine instability. Axial loading was measured with a 5000 lb-f load cell while displacement was monitored through a linear variable displacement transducer (LVDT). Axial loading was applied at 4.2 mm/sec. Fatigue testing<sup>23</sup> was not performed.

With the addition of an axis through the geometric center of the metallic vertebral bodies, the fixture could be adapted for testing in torsion. In this configuration, an axial low profile load cell and constant force spring were added to simulate soft tissue attachment and upper body weight while torque was applied through a lever arm (Figure 1). This arrangement was necessary in the absence of a biaxial materials testing machine. Angular rotation was measured with an angular displacement transducer (ADT) while axial compressive force was applied through the axial load cell and constant force spring. Torsional loading was performed at 0.08 radian/sec.

All testing was done on an Instron Universal Testing Machine (Instron Corp., Canton, MA). The analog signals were digitized at a rate of 30 samples/sec using a Fluke 2400B Intelligent Computer Front End data acquisition system in conjunction with an IBM PC XT.<sup>12</sup>

The stiffness of each instrumentation system was calculated in terms of force (N) per displacement. In axial loading force it was expressed as Newtons (N) as measured by the load cells. Similarly, the LVDT was used for measurement of linear displacement and was expressed in terms of centimeters (cm). Force in torsion was expressed in terms of Newton-meters (N.m), while displacement was measured by the ADT and expressed in terms of degrees of rotation (deg). Results were expressed as percentage stiffness coefficients calculated by multiplying the force/displacement ratio by 100 (Table 1).

Standard Harrington distraction rods 12 cm in length were used with superior laminar hooks (#1253) and inferior laminar Moe hooks (#1201-50). Sixteen-gauge Luque wire was used to segmentally wire the levels above and below the level of simulated instability. The distraction hooks were placed two levels above and below the level of instability. Standard 3/16-inch Luque rods were segmentally wired two levels above and below the level of instability with 16-gauge Luque wire.

After the double-level Harrington and Luque systems had been tested on the simulator, the CD system was tested. Since strict CD protocol required only single-level instrumentation,<sup>8</sup> the CD was applied to a single level above and below the level of instability. Twelve-centimeter CD rods were used with proximal and distal double-hook configurations using CD hooks (#102 and #103).

After testing on the spine simulator was completed, similar instrumentation studies were carried out on fresh frozen bovine thoracic spines harvested from 12-week-old Guernsey calves. This animal model was selected for testing purposes in view of the relatively uniform biomechanical quality of the bone involved.<sup>27</sup> Of note, occult destructive spinal pathology was expected to hamper the

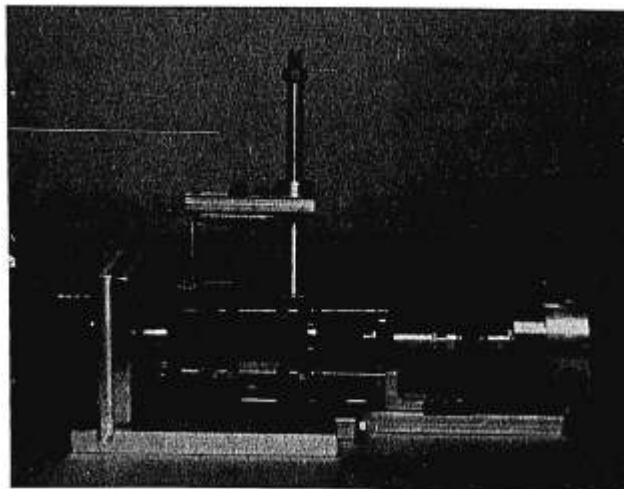


Fig 1. Geometric spine simulator (modified for torsion) with first-level Cotrel-Dubouset instrumentation mounted.

Table 1. Instrumentation Stiffness as Determined Using Geometric Simulator

System	Axial (N/cm)	Torsion	
		<9N.m N.m/deg	>9N.m N.m/deg
Hw	5473 ( 93%)	0.55 ( 18%)	0.40 ( 5%)
Lu	* *	3.00 (100%)	0.44 ( 5%)
CD (1)	5886 (100%)	2.20 ( 73%)	8.50 (100%)

\*Not tested since no spinous process was present on geometric simulator.

Hw: Harrington distraction rods (double-level, segmentally wired, Moe hooks)

Lu: Luque rods (double-level, segmentally wired)

CD (1): first-level CD instrumentation

biomechanical quality of available human cadaver specimens from a population ranging from 19 to 87 years of age.

Two-column instability<sup>6</sup> was created by single-level complete vertebrectomy, resecting through the disc and pedicles at a single level (Figure 2). Twelve-segment specimens were fixed at either end with multiple screws, leaving ten segments free. After destabilization and instrumentation, a total of five free segments remained in the composite, which was subsequently tested. Each spine was kept hydrated and frozen in sealed double plastic bags at  $-40^{\circ}\text{C}$  until 24 hours prior to use. It was then thawed overnight at  $3^{\circ}\text{C}$  and tested within 3 hours of defrosting. Every effort was made to maintain uniform hydration by using sealed bags until the last possible moment and then hydrating with a continuous fine saline spray mist.

Bovine specimen testing included two configurations of CD instrumentation. First-level CD arrangement was similar to that used on the geometric simulator, where double-hook fixation was applied one level above and below the instability (Figures 3 and 4). Second-level configuration involved similar hook placement on the next level proximally and distally (Figure 5). Thus, two levels were spanned above and below the instability but no fixation was introduced at the intermediate level.

In order to more closely simulate *in vivo* conditions, several uninstrumented levels were maintained at either end of the instrumented portion of the spine. Specifically, two levels above and three levels below were preserved. Therefore, testing of the bovine spines included both instrumented as well as free segments. In all cases except first-level CD, a total of ten levels were involved: the level of the vertebrectomy, two levels above and below incorporated within the limits of fixation, as well as two free levels above and three free levels below the instrumented segments. In the case of first-level CD, a total of eight levels were tested since only three levels (as opposed to five) were incorporated in the instrumentation. However, the same number of free segments were used.

Once destabilized, each spine was instrumented with either double-level segmentally wired Harrington rods, double-level segmentally wired Luque rods, or one of the two CD configurations prior to testing. Three control specimens were destabilized but not instrumented prior to testing. The uniaxial Instron machine was modified for torsional testing by mounting the spines in a slider-crank mechanism to generate controlled torque on the proximal end of the spine while maintaining a 134 N preload axially.

A total of 52 studies were carried out on 13 spines. In each case, a series of four studies were completed in the linear range prior to taking the system to failure.

## RESULTS

Table 1 summarizes the results obtained using the geometric spine simulator. This device was used to estimate relative behavior of the various instrumentation systems prior to testing them on bovine specimens. Absolute values are given in appropriate units.

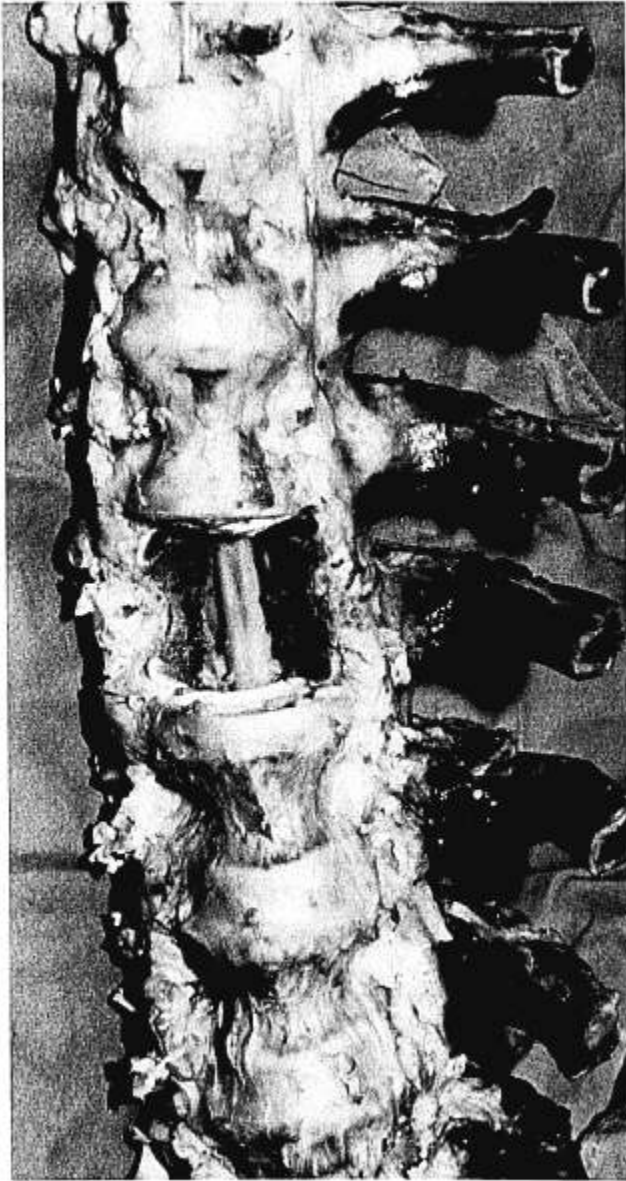


Fig 2. Bovine spine destabilized by vertebrectomy.

Percentage expressions refer to normalized stiffness coefficient multiplied by 100.

The results of testing bovine specimens under axial and torsional loading are summarized in Table 2. Graphic representation of these data are provided in Figure 6.

When the instrumented spines were taken to higher loads, failure occurred with hook or wire dislodgement or breakage, or by soft tissue failure. Wired Harrington instrumentation failed in axial loading as a result of soft tissue failure (facet joint capsule) at the junction between instrumented and mobile levels. In torsion, the initial mode of failure was hook dislodgement. Wired Luque and CD instrumentation (single- and double-level) failed in both axial loading and in torsion by soft tissue failure at the superior junction between instrumented and free levels.

#### DISCUSSION

Neither segmentally wired double-level Harrington distraction rods nor segmentally wired double-level Luque rods provide maxi-

mum stability in both axial and torsional loading.<sup>21</sup> Since the CD system intuitively appeared to offer added stability in both of these modes, a study was undertaken to compare the stiffness and stability of the CD with that of the other two systems under conditions of single level instability.

Due to the great differences in material properties between metal and bone, testing of instrumentation stiffness alone cannot be performed on human or animal spines.<sup>10,15,22,26</sup> Therefore, instrumentation stiffnesses in this study were evaluated on a customized geometric spine simulator which eliminated specimen variability.<sup>24</sup> The slope of the curve obtained in testing was directly related to the stiffness of the instrumentation. At torsional loads greater than 9 N.m, the relative stiffness coefficients of the wired Harrington, Luque, and first-level CD were .05, .05, and 1.00, respectively. Although Moe hooks were used in an attempt to provide more torsional stability to the Harrington system, the lack of direct purchase on the rod proximally precluded secure torsional stabilization.

The apparently greater stiffness of the Luque at lower loads on the simulator stemmed from the presence of multiple wired fixation points (see Table 1). However, once early hook settling oc-

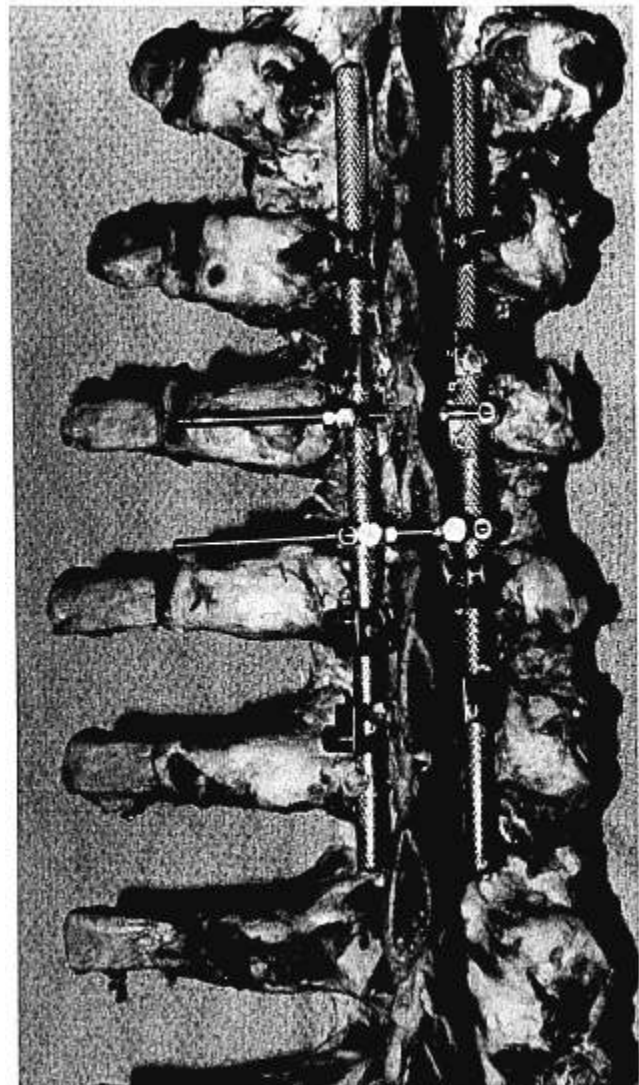
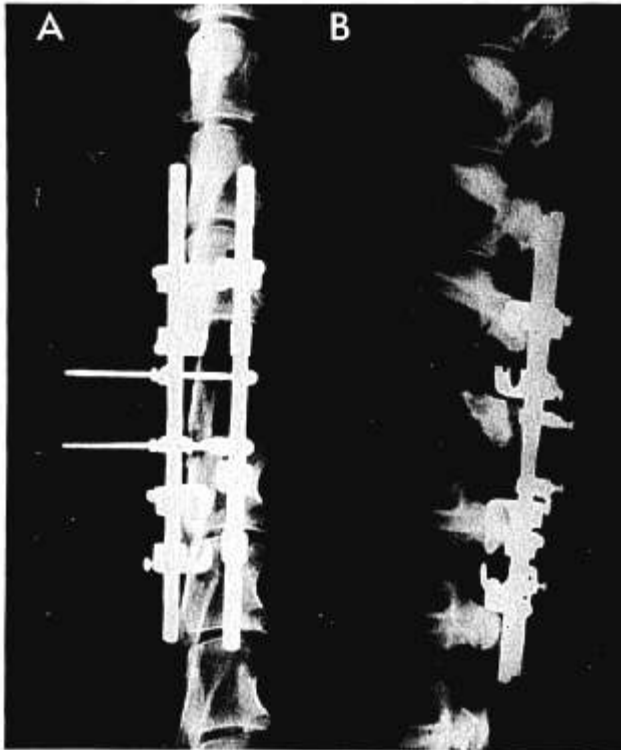
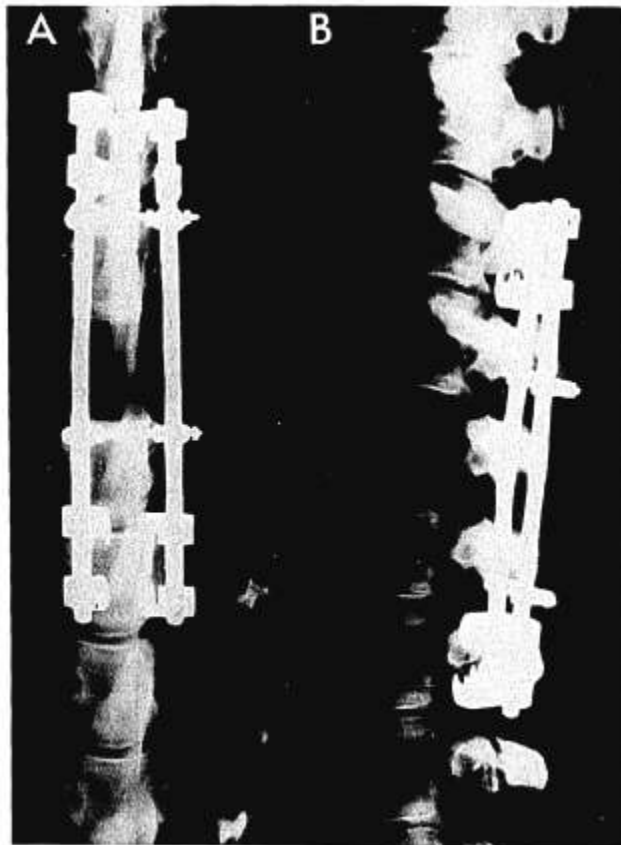


Fig 3. Bovine spine instrumented with first-level Cotrel-Dubousset instrumentation.



**Fig 4.** **A**, Anteroposterior and **B**, lateral roentgenograms of destabilized bovine spine instrumented with first-level Cotrel-Dubousset instrumentation.



**Fig 5.** **A**, Anteroposterior and **B**, lateral roentgenograms of destabilized bovine spine instrumented with second-level Cotrel-Dubousset instrumentation.

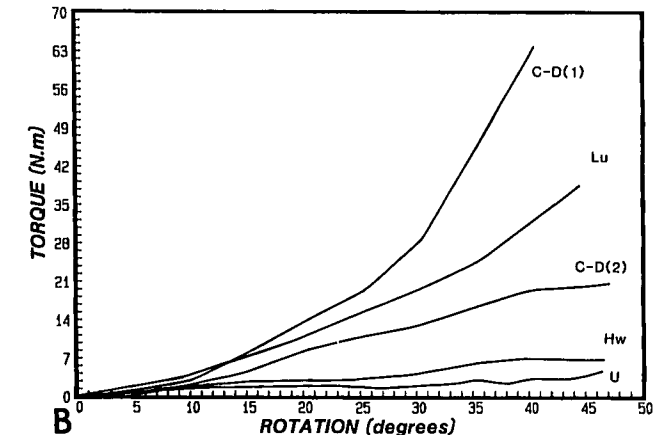
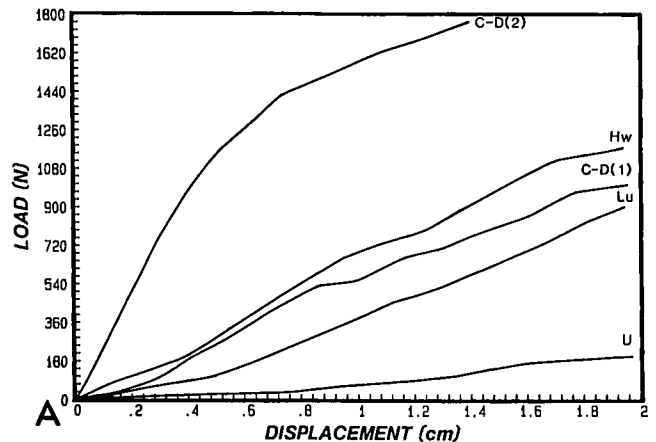
**Table 2.** Axial and Torsional Stability of Instrumentation Systems Mounted on Bovine Spines

System	Axial		Torsional	
	(N/cm)	%	(N.m/deg)	%
CD(2)	2500	100	0.4700	34
CD(1)	536	21.5	1.3600	100
Hw	662	26.5	0.1780	13
Lu	459	18.4	0.8750	64
U	100	4.0	0.0778	5

CD(1): first-level CD instrumentation  
 CD(2): second-level CD instrumentation  
 Hw: Harrington distraction rods (double-level, segmentally wired, Moe hooks)  
 Lu: Luque rods (double-level, segmentally wired)  
 U: Uninstrumented, destabilized spine

ceeded (>9 N.m) the greater torsional stability of the CD became evident. Therefore, the early portion of this curve is an artifact of hook settling. Furthermore, the wires that provided good early fixation began to untwist at higher loads, leading to failure of fixation.

After stiffness coefficients had been determined, comparative stability of each instrumentation system was evaluated by mounting on appropriately destabilized bovine spines and testing under axial and torsional loading conditions (see Figure 6). In these tests,



**Fig 6.** **A**, Axial load testing on bovine specimens (N vs cm). **B**, Torsional load testing on bovine specimens (Nm vs deg). CD1 = first-level Cotrel-Dubousset instrumentation; CD2 = second-level Cotrel-Dubousset instrumentation; Hw = Harrington distraction rods (double-level, segmentally wired, Moe hooks); Lu = Luque rods (double-level, segmentally wired); U = Uninstrumented, destabilized spine.

the slope represented a combination of both instrumented as well as uninstrumented segments. While testing on the simulator gave information regarding instrumentation stiffness alone, the instrumented bovine specimen system provided data regarding overall stability.

Since the bovine spines were much larger and stronger than human spines, assessment of the mode of failure for the various types of instrumentation cannot be directly correlated to the human spine. Nevertheless, it was observed that the Luque and CD systems did not fail within the instrumented levels but rather at their junction with the free-motion segments. Therefore, adequate internal fixation had been provided. Since hook dislodgement occurred in torsion with Harrington instrumentation, internal fixation was less secure.

As tested on both the geometric model as well as on the bovine spines, the first-level CD system provided the greatest resistance to torsional forces. On the bovine spines, CD instrumentation provided 50% more torsional stability than the double-level segmentally wired Luque (0.64). This was probably a result of three factors: 1) locking of the knurled rod by the hook set screws; 2) presence of stabilizing transverse traction devices; and 3) use of double-hook configurations. Loss of torsional stability in going from first- to second-level instrumentation (1.00 to 0.35) was due to the absence of segmental fixation in the intermediate vertebral level.

In axial loading on the simulator, the double-level Harrington and first-level CD were very similar in stiffness (0.93 and 1.00, respectively). On the bovine specimens, the greater stiffness demonstrated by the second-level CD (relative stiffness coefficient = 1.0) was most likely due to the presence of three-point fixation in combination with secure double-hook fixation. Since the first-level CD configuration (stiffness coefficient = .21) only spanned across the destabilized level, no fulcrum was available to provide three-point fixation. Axial load stability with second-level CD instrumentation was nearly 400% that of double-level wired Harrington rods (stiffness coefficient = 0.26).

Clearly, both first- and second-level CD configurations constitute single-level fixation. These arrangements differ only in the longitudinal length of the internal fixation frame.

There is no doubt that four-level, double-hook, segmental CD instrumentation would provide the greatest axial and torsional stability. While such instrumentation may be tested in the laboratory it is not clinically relevant since such hook implantation is precluded by the limits of space in the human spine.

These results indicate that second-level CD instrumentation should be used when an injury is present that is largely vertical in its nature (i.e., burst fracture). Injuries which are primarily translational are best stabilized by first-level CD instrumentation. Studies are in progress to determine optimum hook placement for maximizing torsional and axial stability with a single configuration.

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