



# Sacral Screw Loads in Lumbosacral Fixation for Spinal Deformity

Robert S. Pashman, MD,\* Serena S. Hu, MD,\* Michael J. Schendel, PhD, and David S. Bradford, MD\*



Fixation to the sacrum and pelvis is a problem in the operative treatment of spinal deformity. Previous testing of pedicle screws address axial pull-out strength, yet how screws are loaded in vivo remains unknown. The goals of this study were to determine the loads experienced by sacral screws when loaded as part of Cotrel-Dubousset (CD) sacral instrumentation and whether different anterior grafting methods would effect screw loads. Sacral screws were modified to become transducers capable of measuring axial and bending loads. The screw transducers were incorporated into the sacral fixation of CD instrumentation in seven calf spines. Specimens were loaded to simulate flexion. The sacral screws carried axial loads (1.1 N/[Nm of load]) and bending moments (1.1 Nm/[Nm of load]). The results suggest bending of the sacral screws may be important in their failure, and screw loading was not dependent on graft types used. [Key words: biomechanics, fusion, instrumentation, load, spine]

Recognized indications for fusion across the lumbosacral joint are neuromuscular scoliosis with pelvic obliquity, truncal paralysis as a sequelae of progressive muscular weakness, scoliosis with associated degeneration of the lumbosacral spine, painful spondylolisthesis below a previous spinal fusion, and progressive lumbar deformity below a spine previously instrumented for scoliosis.<sup>2,3,5-7,16-19</sup> These patients are particularly susceptible to sacral fixation failure due to osteopenia, poor general health, advanced age, decreased muscle tone, and neurologic or muscular impairment. Moreover, the potential morbidity of postoperative brace or cast application in patients without protective sensation limits the surgeon's ability to protect the fixation until the bony fusion is solid. Indications for first-stage anterior discectomy and fusion include potential augmentation of lumbar fusion rates and improved curve correction with posterior instrumentation.

Instrumentation related failures in long fusions to the sacrum continue to be a significant problem. Osebold et al<sup>22</sup> have reported a 30% loss of sacral hook fixation in a series of patients with anterior and posterior surgery for myelomeningocele. Hook cutout with Harrington instrumentation to the sacrum in patients with spine fractures was noted by McAfee et al<sup>20</sup> as being a significant problem. Kostuik<sup>17</sup> reported a 15% sacral fixation complication rate overall, which increased to 30% when only adult scoliosis patients were considered. Using Luque-Galveston technique, Allen and Ferguson<sup>1</sup> reported a 9%–40% lumbosacral pseudarthrosis rate depending on the technique employed, and Boachie-Adjei et al<sup>6</sup> reported a 23% pseudarthrosis rate with this method. The Cotrel-Dubousset (CD) method with sacral screws was introduced in the hope of improving on some of the poor surgical outcomes seen with other methods. In 1991, however, Devlin et al<sup>9</sup> reported 12 of 27 (44%) patients who underwent reconstruction for adult scoliosis using CD instrumentation to the sacrum had sacral screw failure by pull-out; one patient had sacral screw breakage.<sup>9</sup>

Studies of segmental instrumentation for the treatment of spinal deformity have shown failure occurs outside of the instrumented segment.<sup>21,28</sup> The tendency of the construct to fail in this manner was a function of rigid segmental fixation and enhanced bony fusion, which act to concentrate stresses at the ends of the instrumentation.<sup>25</sup> In long lumbosacral fusions, the sacral fixation is prone to failure, possibly because of the aforementioned stresses, large flexion moments, and the relative porosity of the sacrum.<sup>9</sup> Although newer, more rigid spinal instrumentation systems have increased fusion rates and allow earlier mobilization of patients, the outcome of sacral fixation in long lumbosacral fusions continues to be problematic.

Instrumentation systems that depend on sacral screws for distal stabilization often fail by screw "pull-out."<sup>9</sup> This is indicative of a failure of the bone/screw interface. Carlson et al<sup>8</sup> have observed that bone mineral equivalent densities measured by quantitative computed tomography (QCT), screw orientation, and the screw-rod linkage are important factors in determining pedicle screw failure.<sup>8</sup> Other researchers have measured the loads required to pull sacral screws out of cadaveric bone

From the Department of Orthopaedic Surgery, University of Minnesota, Minneapolis, Minnesota; and the \*Department of Orthopaedic Surgery, University of California, San Francisco, California. Supported by the Department of Orthopaedic Surgery at the University of Minnesota, the Twin Cities Scoliosis Center, and OREF Bristol-Meyers/Zimmer Institutional grant.  
Accepted for publication October 19, 1992.

**Table 1. Mean (n = 7) Screw Loads (Bending Moments or Axial Loads) for Different Specimen States Under Applied Axial-Flexion Loads**

Specimen State	Bending Moment (Nm)		Axial Load (N)		Stiffness (N/mm)
	50 N	100 N	50 N	100 N	
Intact	0.13 ± 0.11	12.5 ± 6.4	10.8 ± 4.3	22.8 ± 9.8	4.2 ± 1.6
Discectomy	0.22 ± 0.23	32.8 ± 15.0†	31.7 ± 6.9	59.1 ± 25.6	3.6 ± 2.3‡
Femoral rings	0.11 ± 0.07*	17.7 ± 8.8*	18.0 ± 3.3*	31.9 ± 10.5	4.2 ± 1.6
Morcelized graft	0.20 ± 0.17*	24.0 ± 9.8*	17.8 ± 9.8*	38.9 ± 19.5	3.9 ± 2.1

Column headings (50 N and 100 N) indicate the amount of load applied on the 22 cm lever arm. \*Not statistically different ( $P > 0.1$ ). †Statistically different from the grafted specimen states ( $P < 0.05$ ). ‡Statistically different from the intact and grafted spine states ( $P < 0.05$ ).

circuits averaged less than 10%. The calibration curves for the axial and bending loads for each screw were fit with linear polynomials, where  $r$  averaged 0.98.

### Observations

There were no instrumentation failures in the seven spines tested. Despite balancing and centering specimens in the MTS, asymmetric loading of the spines was observed during axial-flexion ramp loading. Under loading, collapse of the interspaces was observed with morcelized grafting to a greater extent than with femoral ring grafting. Collapse was limited by compression of the morcelized graft at the high end of the ramp. In general, collapse of the anterior column during loading was associated with small amounts of rod bending at the lower lumbar levels. When the femoral rings were inserted into the disc spaces, however, a large amount of rod bending was noted at the junction of the most distal intact disc and the most proximal femoral ring replacement.

### Stiffness

In two specimens, morcelized and femoral ring graft were interchanged three times and stiffness measurements recorded. For each test, stiffness returned to its original value ( $P < 0.02$ ), validating the sequential testing method employed in the study. The average specimen

configuration stiffnesses (under applied axial-flexion loading) are given in Table 1. Differences between intact and grafted states were not statistically significant ( $P > 0.2$ ).

### Axial-flexion Loading

Bending moments measured in the screws with the specimen under axial-flexion loading were evaluated at two actuator loads (50 N (11 Nm flexion load) and 100 N (22 Nm flexion load)). These loading levels were chosen because they represented early and intermediate loads in the ramp, before the higher loads completely collapsed the graft sites. The average screw loads (moments and axial loads) for the different specimen states are given in Table 1.

### Anterior Flexion Loading

The average bending moment response measured in the screws under the application of the anterior loads was  $0.06 \pm 0.06$  Nm/N for the femoral ring graft configuration and a  $0.09 \pm 0.08$  Nm/N response for the morcelized graft configuration. This difference was not statistically significant. For the same loading, however, femoral ring grafts produced significantly less axial strain ( $2.8 \pm 0.15$  N/N versus  $4.0 \pm 0.39$  N/N) in the screws than morcelized graft during anterior loads ( $P < 0.003$ ) (Figure 4).

### Discussion

Previous authors have discussed the utility and limitations of the calf-spine model for in vitro biomechanical testing.<sup>4,13,14,27</sup> Because in vitro biologic tissues are subject to mechanical change with time and dehydration, this model is impractical for use in long-term cyclic loading experiments. Within the constraints of time (average 3.5-hour testing period), the model is useful for testing mechanical properties of spine-instrumentation constructs, although a direct in vivo correlation is debated.<sup>4</sup> This is due mostly to the loading methods.

Load to failure testing of bone screws in vitro has been commonly performed by axial "pull-out" testing. Screw "pull-out" in bone has been variably reported as 400–800 newtons by axial distraction.<sup>11,26</sup> The assumption for screw failure in these studies is through

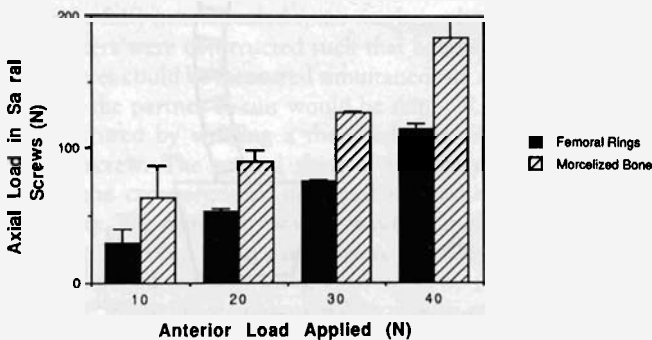


Figure 4. Sacral screws carried much higher axial loads when loaded in the anterior flexion method. For this load technique, the sacral screws in the morcelized bone graft configuration carried a significantly ( $P < 0.05$ ) higher amount of axial load than when in the femoral ring graft configuration.

axial distractive forces; the influence of moments (bending or torque) is not considered. Zindrick et al<sup>29</sup> and Dohring and Krag<sup>10</sup> have examined the effects of bending on screw fixation. Screw design and bone mineral density have been stated as important factors based on such studies.<sup>11</sup> In fact, little is known about the mechanism of screw failure in vivo.

In this study, a maximum of 47.2 N distraction force was generated in the screws during the 0–150 N ramp load range. At 500 N of axial-flexion loading, which is considered to be within the physiologic range,<sup>4</sup> a maximum of 78 N axial distraction force was generated in the screws. These values are well below the documented range of pull-out values associated screws as reported in the literature.<sup>11,26</sup> Conversely, significant moments were generated in the sacral screws during 0–150 N ramp loading. These data suggest that cyclic moments generated in the screws during loading may weaken the bone–screw interface, thereby enabling the screws to fail at lower axial “pull-out” forces. Zindrick et al<sup>29</sup> found as few as 134 toggling cycles (of unreported load) caused significant loosening of the screws. Our study has shown screw bending to occur as the construct is loaded thus bending may be a large component of the failure mode.

If the screw loading remained linear the data from this study indicate that to obtain a 400 N screw axial load (the minimum “pull-out” force reported<sup>11</sup>) would require a 369-Nm axial-flexion load. This large axial-flexion load would also induce a 414-Nm bending load in the screws, which is large enough to cause the screws themselves to fail (bending stress of 4.1 GPa).

Strict statistical criteria were used during the comparison of screw bending moments and axial loads measured for the two grafting conditions. Despite the observation that a majority of screws carried decreased bending moments during axial flexion loading with femoral ring grafts, the interspecimen variance was high and a statistically significant difference between the two grafting conditions was not found. In contrast, during anterior flexion loading, the axial distraction screw loads were significantly less for the femoral ring graft configuration than for the morcelized graft state. Anterior loading in this manner produced significantly more anterior disc space collapse, which may account for these findings. Although other authors have used anterior vector loading for mechanical tests on lumbosacral fixation, the clinical relevance of this load state is uncertain.<sup>4</sup>

This study has shown use of the screw transducer to be a valuable technique for determining the prominent types of stresses seen by the screw when it is tested as a component of a fixation construct. Additionally, this study has shown that the bending moments generated in the screws during flexion loading were more prominent than the axial stresses and probably are much more important when considering the longevity of sacral

fixation. Anterior discectomies without grafting resulted in higher screw loads and probably would be more prone to instrumentation failure.

## References

1. Allen BL Jr, Ferguson RL. The Galveston technique of pelvic fixation with L-rod instrumentation of the spine. *Spine* 1984;9(4):388–94.
2. Allen BL Jr, Ferguson RL. A 1988 perspective on the Galveston technique of pelvic fixation. *Orthop Clin North Am* 1988;19:409–418.
3. Allen BL Jr, Ferguson RL. The Galveston experience with L-Rod instrumentation for adolescent idiopathic scoliosis. *Clin Orthop* 1988;229:59–69.
4. Ashman RB, Birch JG, Bone LB, et al. Mechanical testing of spinal instrumentation. *Clin Orthop* 1988;227:113–25.
5. Balderston RA, Winter RB, Moe JH, Bradford DS, Lonstein JE. Fusion of the sacrum for nonparalytic scoliosis in the adult. *Spine* 1986;11:824–9.
6. Boachie-Adjei O, Dendrinos GK, Ogilvie JW, Bradford DS. Management of adult spinal deformity with combined anterior-posterior arthrodesis and Luque-Galveston instrumentation. *J Spinal Disorders* 1991;4:131–41.
7. Bradford DS. Adult scoliosis current concepts of treatment. *Clin Orthop* 1988;229:70–87.
8. Carlson GD, Anderson DR, Abitol JJ, et al. The effects of screw orientation, linkage and bone density on sacral screw fixation. Transactions of the 37th Annual Meeting, Orthopaedic Research Society 1991;16:22.
9. Devlin VJ, Boachie-Adjei O, Bradford DS, Ogilvie JW, Transfeldt EE. Treatment of adult spinal deformity with fusion to the sacrum using CD instrumentation. *J Spinal Disorders* 1991;4(1):1–14.
10. Dohring EJ, Krag MH. Sacral screw fixation: an anatomic morphologic and mechanical study. Transactions of the American Academy of Orthopaedic Surgeons 58th Annual Meeting, 1991:114.
11. Ekstrom L, Hansson T, Afonja A. The pull-out strength of intrapedicular screws in relation to the vertebral bone mineral content. First World Congress of Biomechanics, La Jolla, CA, August 30 to September 4, 1990.
12. George DC, Krag MH, Johnson CC, VanHal ME, Haugh LP, Grobler LJ. Hole preparation techniques for transpedicle screws effect of pullout strength from human cadaver vertebrae. *Spine* 1991;16:181–4.
13. Gurr KR, McAfee PC, Chi-Ming Shih. Biomechanical analysis of posterior instrumentation systems after decompressive laminectomy. *J Bone Joint Surg* 1988;70(A):680–91.
14. Gurr KR, McAfee PC, Chi-Ming Shih. Biomechanical analysis of anterior and posterior instrumentation systems after corpectomy. *J Bone Joint Surg* 1988;70(A):1182–91.
15. Halvorson TL, Kelly LA, Whitecloud TS, Cook SD. Transpedicular screw pullout strengths in normal and osteoporotic human spines. Transactions of the 37th Annual Meeting of The Orthopaedic Research Society 1991;16:24.
16. Kostuik JP. Decision making in adult scoliosis. *Spine* 1979;4:521–5.
17. Kostuik JP. Treatment of scoliosis in the adult thoracolumbar spine with special reference to fusion to the sacrum. *Orthop Clin North Am* 1988;19:371–81.