Introduction
Metallic rod-based systems are currently the standard for correcting spinal deformities and facilitating spinal fusion. Although stainless steel and titanium are by far the most widely used rod materials used for spinal implant surgery, different alloys and conditions can render a range of properties. Cold-worked stainless steel is the strongest and most rigid material. In the annealed condition, stainless is much easier to bend, but also offers lower strength. Titanium alloy (Ti-6Al-4V) is nearly as strong as cold-worked stainless steel, but is much more flexible. Unalloyed (commercially pure) titanium is also much easier to bend, but offers the lowest strength.

Selection of the appropriate material depends on the difficulty of the operation, weight and activity of the patient, sensitivity of the patient to certain metals (nickel particularly) among others. Bending the rod in situ requires a high modulus, low strength rod such as annealed stainless steel. However, titanium alloys offer better corrosion resistance and fewer concerns regarding patient sensitivity. The fatigue strength of all alloys can be affected by bending operations. The purpose of this study was to evaluate the ease of bending and the effect of bending and rebending on the fatigue strength of four commercially available spinal rod materials.

Methods
Four different rod types, all ¼" diameter, were studied: 1) titanium alloy (Ti-6-4); 2) commercially pure titanium (CPTi); 3) 316L cold-drawn stainless steel (SS-CD); and 4) 316L annealed stainless steel (SS-A). Unilateral lumbar spinal constructs were assembled according to the ASTM F1717 test standard. To test springback during rod contouring, constructs were placed in the test machine and rod curvature was measured during application of load and following removal of the load. Fatigue testing was carried out in compression loading and constructs were tested until the rod failed or 5 million cycles were reached. S/N curves were generated from the data. To test the effect of bending and rebending, the rods were bent to a lordotic radius of curvature [1], bent back to straight, then fatigue testing was repeated.

Essential Results
SS-A rods had the lowest springback during contouring, 15% when bent to a final radius of curvature typical of lordosis [1] in the lumbar spine. CPTi rods had the next closest springback of 20%, followed by SS-CD rods (28%), then Ti-6-4 (35%). When straight, virgin rods assembled in unilateral corpectomy constructs were tested in compressive fatigue, the endurance limits of the four rods types were as follows: 490N for SS-CD, 410N for SS-A, 400N for Ti-6-4, and 230N for CPTi (Figure 1). When the Ti-6-4 rods were bent to a lordotic radius of curvature, then bent back to straight before fatigue testing, the endurance limit of the rods dropped to 180N, which is 45% of the virgin strength. For CPTi rods, the endurance limit dropped to 180N, which is 78% of the virgin strength (Figure 2).

Discussion
Ease of contouring and high fatigue strength are essential requirements for spinal rods used in scoliosis procedures. Improving ease of contouring is typically achieved by sacrificing strength. However, with a carefully chosen material, the durability of a lower strength, easily contourable rod may be comparable to a higher strength rod after demanding bending and rebending operations.

References

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