FAILED POSTERIOR SPINAL FUSION: THE ROLE OF VERTEBRAL BONE MINERAL DENSITY AND LAMINAR HARDNESS ON CABLE TENSION LOSS

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Introduction: Failure rates for posterior cervical arthrodeses using sublaminar wiring techniques remain high even with the advent of metal cables. This investigation involved measuring the interaction between laminar bone and cable in both static and dynamic loading environments in order to identify a possible causative factor for failed fusion. It is known that bone, as a viscoelastic material, will deform over time under applied stresses. A major mechanism by which cable based arthrodeses may fail relates to the loss of cable tension resulting from deformation of cortical bone in direct contact with the cable. The purpose of these experiments was to determine the influence of cable type and bone quality on tension loss. The clinical situation was simulated using human cadaveric spines and static and dynamic loading conditions.

Methods: Four fresh-frozen cervical spine specimens were cleaned of soft-tissue and DEXA scanned to quantify the relative bone mineral densities of each vertebral level. The vertebral bodies were then potted leaving the laminae exposed for application of the rod and cable. A custom, strain-gauged cable tensioner was used to record tension over time. In total, there were 65 static tests and 27 dynamic tests of 1) Codman Sof’ wire, 2) Sofamor-Danek Atlas and 3) Spinal Concepts titanium cables and 4) SecureStrand polyethylene cables. The in-vitro model consisted of a single loop of cable around a metal rod juxtaposed to a portion of cervical spine lamina, similar to the type of construct applied in occipital-cervical and subaxial fusions. Each cable system was randomly placed on each lamina allowing for paired statistical comparisons of the results. As per the manufacturer’s specifications, the Surgical Dynamics cable was tested using a two-loop configuration. In order to match the compressive force on the bone the cable tension was cut in half for the two-loop configuration. For direct comparison with the other systems, the Surgical Dynamics cable was also tested using the single-loop, full tension configuration.

Preliminary experiments over extended periods of time (up to 24 hours) demonstrated that approximately 99% of the static tension loss occurred within the first 15 minutes after applying tension. Consequently, static tension loss experiments involved a rapid increase of cable tension to a nominal maximum of 100 N followed by 15 minutes of monitored tension loss. The dynamic tension loss experiments involved application of 1000 cycles of 100 N with 100 N peak destructive load applied to the rod. This loading configuration was intended to simulate a worst case scenario of several weeks of flexion/extension loading events without external bracing. Percentage of tension loss was compared between the different systems using a paired Student’s t-test. After these tests the lamina were sectioned and repotted in polyurethane in preparation for a standard Brinnell’s type hardness test. Static, dynamic and hardness tests were also conducted on steel rod controls to identify the source of tension loss, whether from deformation of the bone or stretch of the cable. Pearson’s correlation analysis was used to assess the correlation between the tension loss results and bone mineral density and laminar hardness.

Results: The static tension loss was comparable between the three titanium cable systems, but was significantly greater with the polyethylene cable. Likewise the dynamic tension loss was comparable between the metal cables and greater with the polyethylene cable (Fig. 1). Static tension loss with titanium cables was well correlated (r_w=0.537, p_w=0.076) with laminar hardness but not correlated with bone mineral density (r_w=-0.060, p_w=0.525). Static tension loss was not well correlated with either parameter in the case of the polyethylene cables. Dynamic tension loss in all cable systems was better correlated with vertebral bone mineral density (r_w=-0.438, p_w=0.201) than with laminar hardness (r_w=0.229, p_w=0.579). When a comparison is made between the static tension loss of the titanium cables wrapped around a steel rod versus a cervical lamina, it is evident that roughly 90% of the tension loss is due to stretch of the bone. In contrast, the same comparison with the polyethylene system revealed that nearly all of the tension loss was due to stretch of the cable.

Discussion: The viscoelastic response of bone to cerclage cable in the static and dynamically loaded situation involves bone and cable deformation. These deformations produce tension loss in the cable that may lead to increased micromotion and failed fusion. This phenomenon may explain the high failure rate for posterior cervical arthrodeses using sublaminar wiring techniques. This study found an average of 23% static tension loss in metal cables and 56% tension loss with a polyethylene cable system. An additional 29% and 63% of the remaining tension was lost with the metal and polyethylene cables respectively when the cable experienced 1000 cycles of 100 N peak load. Interestingly, the variance of dynamic tension loss was five times the variance of the static tension loss. Specifically, repetitive loading produced effects ranging from no effect to a complete loss of tension with the same metal cable system. The wide variability and large average magnitude of dynamic tension loss demonstrates the importance of postoperative bracing to supplement internal fixation with sublaminar cables.

In both static and dynamic experiments, 90% of the metal cable tension loss was due to bony deformation. In contrast, 100% of the polyethylene tension loss was due to the creep of the cables. No significant difference was found in static or dynamic tension loss between the metal cable systems. The poor performance of the SecureStrand cable in our experiments suggests that clinical use of these polyethylene cables will result in greater amounts of motion across the fusion site. Although a small amount of micromotion could be beneficial, an increase in motion is generally associated with increased pseudarthrosis.

Static tension loss in metal cables was correlated with laminar hardness, a site-specific materials test. Static tension loss was not correlated with vertebral bone mineral density, a measurement that is highly dependent on vertebral body bone quality. Vertebral body density may not be closely associated with laminar bone quality. However, dynamic tension loss was better correlated with the vertebral bone mineral density than with laminar hardness. This result makes intuitive sense because the whole cervical vertebra sustained the cyclic loads.

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