Clinical Biomechanics 55 (2018) 18–22

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Posterior cervical spine crisscross fixation: Biomechanical evaluation

Joseph F. Cusick[a], Frank A. Pintar[a,b,*], Joseph S. Cheng[c], Jason I. Lifshutz[d], Narayan Yoganandan[a]

[a] Department of Neurosurgery, Medical College of Wisconsin and Veterans Affairs Medical Center, Milwaukee, WI, United States
[b] Joint Department of Biomedical Engineering, Medical College of Wisconsin and Marquette University, Milwaukee, WI, United States
[c] University of Cincinnati, Cincinnati, OH, United States
[d] Santa Clara Valley Medical Center, San Jose, CA, United States

ARTICLE INFO

Keywords:
Posterior cervical internal fixation
Crisscross facet wiring
Lateral mass plate/screws
Segmental motion

ABSTRACT

Background: Biomechanical/anatomic limitations may limit the successful implantation, maintenance, and risk acceptance of posterior cervical plate/rod fixation for one stage decompression-fusion. A method of posterior fixation (crisscross) that resolves biomechanical deficiencies of previous facet wiring techniques and not reliant upon screw implantation has been devised. The biomechanical performance of the new method of facet fixation was compared to the traditional lateral mass plate/screw fixation method.

Methods: Thirteen human cadaver spine segments (C2-T1) were tested under flexion-compression loading and four were evaluated additionally under pure-moment load. Preparations were evaluated in a sequence of surgical alterations with intact, laminectomy, lateral mass plate/screw fixation, and crisscross facet fixation using forces, displacements and kinematics.

Findings: Combined loading demonstrated significantly lower bending stiffness ($p < 0.05$) between laminectomy compared to crisscross and lateral mass plate/screw preparations. Crisscross fixation showed a comparative tendency for increased stiffness. The increased overall motion induced by laminectomy was resolved by both fixation techniques, with crisscross fixation demonstrating a comparatively more uniform change in segmental motions.

Interpretation: The crisscross technique of facet fixation offers immediate mechanical stability with resolution of increased flexural rotations induced by multi-level laminectomy. Many of the anatomic limitations and potentially deleterious variables that may be associated with multi-level screw fixation are not associated with facet wire passage, and the subsequent fixation using a pattern of wire connection crossing each facet joint exhibits a comparatively more uniform load distribution. Crisscross wire fixation is a valuable addition to the surgical armamentarium for extensive posterior cervical single-stage decompression-fixation.

1. Introduction

A number of early studies reported on the clinical outcomes and potential adverse consequences of multi-level laminectomy (Albert and Vacarro, 1998; Fairbank, 1971; Grubb et al., 1997). In 1995, we reported that multilevel cervical laminectomy induced biomechanical effects which could reduce the efficacy of the procedure (Cusick et al., 1995). These biomechanical findings contrasted the limited concerns expressed by contemporary "in vitro" laboratory studies that cervical laminectomy caused insignificant load-bearing or kinematic alterations (Ding et al., 1991; Goel et al., 1988; Zdeblick et al., 1992). Increasing clinical concerns regarding the potentially adverse effects of laminectomy, and our biomechanical findings, encouraged evaluation of techniques designed to offer a corresponding posterior fixation following multilevel laminectomy. At that time, however, such fixation was reliant on individual facet wires about a structural graft (Callahan et al., 1977; Garfin et al., 1988; Weis et al., 1996), and biomechanical evaluation of this technique was shown not only to fail to resolve the adverse effects of laminectomy but to exasperate many of the changes (Cusick et al., 1997).

These findings and concerns encouraged the development of a facet fixation system that could resolve these deficiencies and permit one-stage multilevel posterior cervical decompression and fixation fusion. The present study describes the biomechanical characteristics of the crisscross (CC) technique that resolves former limitations of facet fixation through a specific interconnection of individual facet wires securing of the facet joint. The biomechanical reliability of this method encouraged clinical implementation although ongoing, the technique application and long-term follow-up all supportive of the validity of the methodology.

---

* Corresponding author at: Joint Department of Biomedical Engineering, Medical College of Wisconsin and Marquette University, Milwaukee, WI, United States.
E-mail address: fpintar@mcw.edu (F.A. Pintar).

https://doi.org/10.1016/j.clinbiomech.2018.04.001
Received 9 October 2017; Accepted 3 April 2018
0268-0033/ Published by Elsevier Ltd.

Since this biomechanical evaluation and clinical applications, posterior fixation with screw systems mainly lateral mass plate/rod (LMPS) and pedicle screw (PS) have achieved increasing widespread acceptance for post laminectomy fixation (Anderson et al., 1991; Barrey et al., 2004; Deen et al., 2003; Fehlings et al., 1994; Kurz and Herkowitz, 1992; Xu et al., 2008). Certain biomechanical or anatomical limitations however, may restrict successful implementation maintenance or risk acceptance (Choueka et al., 1996; Coe et al., 1989; Deen et al., 2006; Inoue et al., 2012; Jones et al., 1997; Kast et al., 2006; Katonis et al., 2011; Kothe et al., 2004; Merola et al., 2002).

The hypothesis for this study is that the novel CC fixation technique that connects a specific sequence of individually positioned facet wires (cables) will resolve the biomechanical effects (strength and motion) induced by multilevel cervical laminectomy with comparable strength to lateral mass screw-plate constructs.

2. Methods

Thirteen unembalmed human cadaver spinal columns (C2 to T2), with care to preserve ligament components, were used in this study. Specimens were selected based on similar radiographic appearance. The mean age, height, and weight were 61 years, 170 cm, and 71 kg, respectively. Cervical columns were fixed superiorly and inferiorly allowing for motion segments from C3 to cervicothoracic junction to be included in this experimental model.

Retro-reflective targets were introduced into bony landmarks of each vertebra for obtaining overall and localized temporal kinematics. All 13 specimens were evaluated under complex loading (flexion-compression), and four of these specimens had additional evaluation using a pure-moment loading technique. This latter group of four also had inclusion of LMPS fixation as a component of the surgical alterations with the sequence consisting of intact, C4-C6 laminectomy, LMPS, and CC fixation. For the pure-moment loading, these specimens were mounted on a loading frame that included an inferiorly mounted six-axis load cell. The pure-moment load was applied using equal and opposite dead weights through cables and pulleys at the ends of a lever arm attached to the superior end of the preparation. The six-axis load cell fixed to the base of the preparation was used to monitor the loads such that adjustments to the pulley locations could be made to confirmed pure moments (Yoganandan et al., 2007). The specimens were tested under flexion and extension. Under each mode, pure moments were applied at 0.33, 0.5, 1.0, and 1.5 Nm levels. These load cycles were performed with data collection obtained on the third cycle.

To more closely replicate the clinical condition, complex loading studies were performed in all 13 specimens. A custom-designed fixture, described in a previous study, was attached to the proximal end of the specimens to apply flexion-compression loading while minimizing off-axis shear forces (Yoganandan et al., 1995). The force-deflection data from the piston load cell, the linear variable differential transformer, and the output generalized force histories from the distal six-axis load cell were recorded throughout the time of loading using a modular digital data acquisition system. The kinematic data were continuously recorded using a video motion analyzer. The strength data from the load cell and the force gauge were synchronized with the kinematic data using a single trigger. Force-time and deflection-time traces from the piston sensors were transformed into a force-deflection curve for analysis of stiffness. Stiffness of the structure was defined as the slope of the force-deflection curve in its most linear phase.

Localized kinematics of the structure were derived from: three targets inserted into each vertebra for kinematic analysis. The position of each vertebra (considered as a rigid body) was recorded at each load step using a 3-D motion tracking system (Motion Analysis Corp., Santa Rosa, CA USA). Spinal kinematic responses were obtained as angular rotations in the sagittal plane. Rotational measures under load were derived for each spinal level and expressed as angular motion with respect to the unloaded state.

Biomechanical responses were recorded using pure moment in 4 of 13 specimens and complex loading studies in all 13 specimens. A three-level laminectomy with attention to maintaining facet integrity was performed. Specimens were loaded using the previously described methods. In the four specimens where both pure moment and complex loading was done, the pure moment test was done before the complex loading for each surgically-altered configuration. The same four specimens also underwent LMPS fixation with a small notched plate-screw set (DePuy Synthes Inc., Raynham MA, USA). Lateral mass screws were inserted after defining the facet line and lateral aspect of the lateral mass. All screw holes were drilled with a 2.0 bit and after measuring the appropriate plate 3.5 mm titanium cortical bone screws to achieve bicortical fixation. These specimens were again loaded using the same parameters.

All 13 specimens, including the four LMPS preparations, underwent facet fixation using the CC technique. This technique, which will be described in greater detail in discussion of clinical applications, consists of interconnections of individual components of the commercial Sofwire cable system (DePuy Spine Inc., Raynham MA, USA) passed through drill holes in the superior aspect of the inferior facet. The 20-

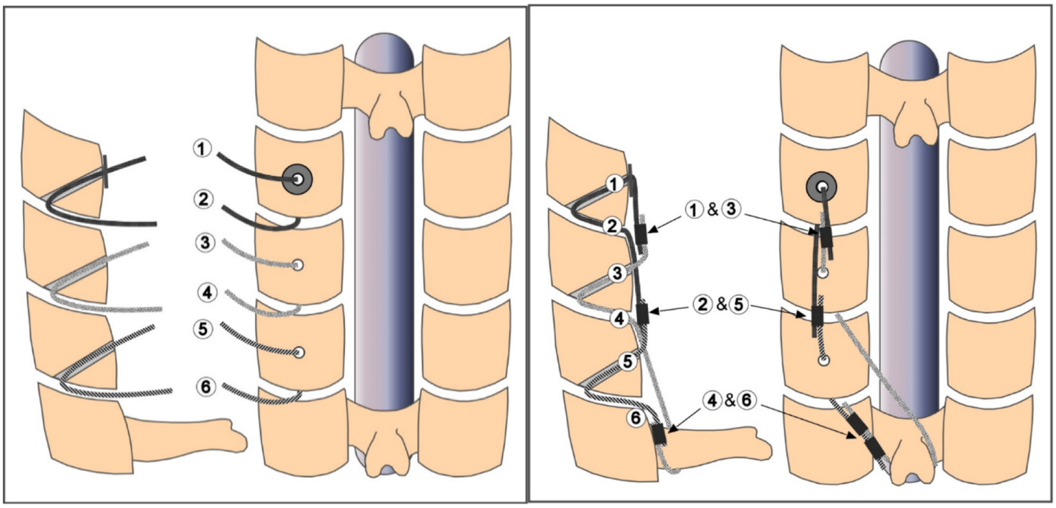

Fig. 1. Illustrations in the three-level laminectomy preparation demonstrating the sequence of cable interconnections necessary to achieve facet fixation by crossing each facet joint. The last cable encircles the inferior spinous process (cable 1 to 3; 2 to 5; and 4 to 6). The stress points at the proximal and distal connections are mitigated by inclusion of a small button and double crimps, respectively, performed in a bilateral manner.