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The mechanical role of laminar hook protection of pedicle screws at the caudal end vertebra

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Abstract Biomechanical studies have shown hooks to be superior to pedicle screws in pull-out, especially in osteoporosis. This study evaluates the possible increase in stiffness of pedicle screws provided by laminar hooks while applying non-destructive forces to a vertebrectomy model assembled with Compact Cotrel Dubousset (CCD) instrumentation. Synthetic vertebrae were employed in a three-level vertebrectomy model. CCD screw-based three-level constructs with and without sublaminar hooks in the caudal element were tested in flexion, extension, compression, lateral bending, and torsion. There was no statistically significant

advantage in adding inferior laminar hooks to a caudal end vertebra that had bilateral pedicle screws in any of the testing modes. Torsional stability, however, was augmented, but not significantly. Torsional instability and osteoporotic bone may be the clinical justifications for adding laminar hooks below screws in the caudal end vertebra.

Key words Spinal instrumentation · Pedicle screws · Laminar hooks · Torsional instability

Introduction

Pedicle screws, particularly at the end of a construct, are subjected to great pull-out forces and moments. Failures due to loosening and screw breakage have been well documented in the literature [3, 6–9, 13, 14, 18]. The purpose of this study was to determine whether laminar hooks applied to the caudal vertebra lamina would increase the stiffness of the pedicle screw constructs. The theoretical reason for advocating using hooks to supplement pedicle screws is based on biomechanical studies that have shown hooks to be superior to pedicle screws in pull-out, especially in osteoporosis [5], where the degenerative condition affects the lamina less than the pedicles.

This study was designed to determine whether laminar hooks applied in conjunction with pedicle screws at the lower end vertebral level increased the stiffness of the constructs.

Methods

Compact Cotrel Dubousset (CCD) instrumentation (Sofamor, France) was fixed to ultra-high molecular weight polyethylene (UHMWPE) cylinders, simulating vertebrae, that were milled to specifications previously reported [6], and in accordance with the ASTM standard [1]. UHMWPE cylinders were fixated with bilateral pairs of open CCD pedicular screws (Tulip screws, model C960L45) above and below a single vertebrectomy defect. The defect consisted of the height of a vertebral simulant and the height of two disc spaces. The superior cylinder was fixed with an additional set of screws. The inferior cylinder was fixed with bilateral pedicle screws. Inferior laminar hooks (model C1113) were placed bilaterally into 3-mm deep, tight-fitting milled holes on the inferior surface (Fig. 1). Bilateral 7-mm diameter longitudinal rods 120 mm long (model 9147CV) were placed, and two DLT struts were added (Fig. 2).

Four different construct configurations of the lower vertebra were tested (Fig. 2).

Configuration 1 consisted of both bilateral pedicle screws and laminar hooks. Configuration 2 had the right caudal hook removed. Configuration 3 lacked laminar hooks, while configuration 4 was only missing the left caudal pedicle screw.

Fig. 1 Inferior body fixated with bilateral pedicle screws and instrumented with bilateral laminar hooks as in construct 1 (Fig. 2)

Fig. 2 Configuration of the four constructs. The distal vertebra: 1 two pedicle screws and two laminar hooks; 2 two pedicle screws and one laminar hook; 3 two pedicle screws only; 4 one pedicle screw and two laminar hooks. The proximal vertebra was fixed with four screws to maximize the effect on the distal vertebra

An Instron model 1321 biaxial materials tester was used to perform non-destructive stiffness tests on the constructs in axial compression, flexion, extension, left and right bending, and rotation. The experiment was repeated on an MTS 1821 biaxial testing machine for compression and torsion.

Three testing maneuvers were employed in the study. The first one consisted of axial compressive loading forces ranging from a pre-load force of 10 N to 110 N at the peak load. The second maneuver was left and right bending, flexion, and extension, using a 10-cm lever arm in order to apply eccentric loads ranging from 10

N to 110 N at a rate of 1 Nm/s. A 70 N static load plate was rigidly attached to the superior element throughout testing.

Torsional loading between 1 Nm to 7 Nm at a rate of 0.4 Nm/s with a constant 100 N axial static compressive load was performed by rigidly gripping both and inferior simulants. The torsional moment was applied directly to the superior aspect of the UHMWPE block, and the axis of rotation was at the geometric center of the block.

For each construct, 6 runs of cyclic loading were applied on the Instron, and 11 on the MTS. The first runs were treated as a conditioning run for all tests on both machines, and were discarded from the analysis. This was repeated after disassembling and reconstructing the construct. All data were collected using a data acquisition board and software.

Statistical analysis

A two-way analysis of variance was performed to assess the differences between specimens within testing groups for both the original and reconstructed models. Logarithmic transformations on the data were performed to stabilize the variances. Duncan multiple comparison procedures were performed to assess pairwise differences among fixed effects within a position group, while preserving the overall type I error at less than or equal to 0.05.

Results

The results of the tests were identical on both testing machines (Table 1). Construct 4 was found to be consistently weaker than the other setups when the various forces were applied. In flexion, extension, and left and right bending, the stiffest model was construct 3. It was statistically stiffer than construct 2 ($P < 0.05$), but not construct 1 ($P > 0.05$), when the different bending forces were applied. During compression construct 1 was stiffer than constructs 2 and 3, but not significantly so ($P > 0.05$). During torsion construct 1 was the stiffest, but the difference between it and constructs 2 and 3 was not significant ($P > 0.05$).

Discussion

The model

Our goal in this study was to evaluate the net contribution of laminar hooks on a spinal implant's stiffness. Synthetic models allow for such an evaluation without the contribution of soft tissues, giving the surgeon an idea of the maximal contribution possible from a given spinal implant. In addition, using UHMWPE cylinders allows other investigators to reproduce the results easily. Using cadaveric spines may present problems with regard to inter-speci-

Table 1 Stiffness of Compact Cottrel-Dubousset constructs with and without caudal hooks

Construct	Compression ^a (N/mm)	Torsion ^a (Nm/°)	Flexion ^b (Nm/mm)	Extension ^b (Nm/mm)	Right bending ^b (Nm/mm)	Left bending ^b (Nm/mm)
1	211.35	7.18	1.57	3.47	4.68	6.28
2	207.53	6.88	1.55	3.76	4.31	5.39
3	207.05	6.56	1.67	4.01	4.76	7.08
4	140.18	3.25	1.02	3.15	3.69	unstable

^a Tested on Instron and MTS

^b Tested on Instron

men variability, bone density, pedicle angle insertion, interpedicular distance, symmetry, uniformity, degree of post-mortem degradation, and replicability, thus making it difficult to determine the influence of these factors on the spinal implants, and possibly not allowing other investigators to replicate results.

The laminar hooks

The objective of this study was to test to what extent the laminar hooks add to the stiffness of the whole construct, and the net contribution of the spinal implant on stiffness. The end vertebra's implant in a construct is prone to excessive forces and stress. The price for the loss of motion, and the fusion long lever arm, is ultimately paid by the disc next to the fusion mass [17]. However, until the fusion occurs, and the bony mass is consolidated, the implant's engagement of the end vertebra is in jeopardy.

The rationale for laminar hook-pedicle screw combinations is that the hooks protect the screws from known modes of failure seen in unstable thoracolumbar fractures. McLain et al reviewed their series of unstable fractures treated with three-level CCD instrumentation using 6-mm diameter, 45-mm long pedicle screws without hook supplementation [13]. In their study, five of ten implants failed within 2–4 months postoperatively. Bending, breakage, loosening or pull-out of screws was noted. The most common failure mode was bending, which occurred at the entrance point of the screw or at the thread-shank junction. Only one screw pull-out/loosening occurred. Some cases of bending were attributed to prestressing of screws during implantation.

Coe et al. found that Harrington laminar hooks at 646 N proved much stronger in pull-out tests than CCD pedicle screws (345 N) and Steffee screws (430 N) [5]. They concluded that the degree of osteoporosis is not relevant in hook pull-out failure and that laminar hooks are the strongest means of fixation against pull-out. This is due to the larger proportion of cortical bone in lamina as compared to pedicles.

Chopin and Morin demonstrated that pedicle screw-laminar hook combinations, as tested in this study, are useful in the treatment of thoracolumbar fractures [3]. Farcy et al. also used this combination, and even combined it with other constructs [10, 16].

It is not clear whether the hooks that protect from pull-out have any role in the stiffness of the construct when the anterior column is disrupted. Posterior fixation alone in vertically unstable fractures with disrupted anterior column integrity has been shown to lead to progressive kyphosis [2, 11, 13]. In our study, laminar hook supplementation did not alter stiffness in flexion mode. However, we did not record hysteresis changes after several cycles in the anterior bending modes, which suggests changes in either pedicle shank bending, or settling in the plastic-metal interface, longitudinal rod bending, settling in the screw-rod or laminar-rod connectors. Thus, while cyclic testing was not conducted, it is doubtful that hook

supplementation can resist the progressive kyphosis noted in pedicle-screw constructs employed in combined anterior and middle column injury.

In our study, the hook added only to the torsional stiffness of a three-level construct – a finding that is supported by the results of Stephens et al. [15]. We found no statistically significant increase in stiffness when bilateral inferior laminar hooks were added to a model vertebra in anterior, right, and posterior bending and compression. In torsion, however, the stiffness was about 9% higher.

Construct 3 was the stiffest in all modes of testing except torsion; it has the shortest longitudinal members. Adding laminar hooks elongates the longitudinal members. The hooks' direction of purchase permits them to translate anteriorly, but lateral and posterior motion is prevented. We propose that the connection between the caudal pedicle screw and the longitudinal rod in the CCD system approximates a fully constrained union. Therefore, in flexion the effective lever arm consists only of the length of the rod between the pedicle screws adjacent to the defect. Thus, the laminar hooks distal to the constrained connection effectively are removed from participation. For this reason, there was no statistically significant improvement in stiffness when pedicle screws were augmented with laminar hooks. The force direction in torsion involves both the hooks and the screws.

The question of whether laminar hook-pedicle screw combinations provide greater stiffness than pedicle screws alone is relevant if increasing stiffness per se is a desired engineering dimension. CCD is a fully constrained system and hence endurance to bending is probably the most important consideration in the design. With this in mind, the addition of hooks, which presumably are being used in a claw mode to prevent implant or implant-bone interface failure, is beneficial only for torsional instability. Anterior column repair is not stable to torsional forces, and the use of posterior hook augmentation may be justified.

Conclusion

In the present study there was no significant increase in stiffness during flexion, extension, right bending, and compression when bilateral inferior laminar hooks were added to a vertebra that has bilateral pedicle screws in a three-level construct. When tested in torsion, the constructs were stiffer. We propose that the connection between the caudal pedicle screw and the longitudinal rod in the CCD system approximates a fully constrained union. Therefore, in flexion the effective lever arm consists only of the length of rod between the pedicle screws adjacent to the defect. Thus, the laminar hooks distal to the constrained connection effectively are removed from participation. For this reason, there was no statistically significant improvement in stiffness when pedicle screws were augmented with laminar hooks.

Torsional instability and osteoporotic bone may be the clinical justifications for adding laminar hooks below screws in the caudal end vertebra.

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