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A study of the mechanical stability of scoliosis constructs using variable numbers of sublaminar wires

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Abstract Sublaminar wiring with posterior instrumentation is one of the methods used when long fusions involving 10–12 thoracolumbar levels are required. Classically, wires are used at every consecutive level to make the construct as rigid as possible, although complications like dural tears, cerebrospinal fluid leak, and neurological deficit have been reported during their passage. We compared the mechanical stability under torsional strain of five specimens of each of three construct designs, by static and fatigue testing, using an electro-servo-hydraulic testing machine. In construct A, a contoured Hartshill rectangle was used from T2 to L2, with sublaminar wires passed at every level. In construct B, the Hartshill rectangle was wired to the spine at every alternate level. In construct C, every alternate level was wired except at the proximal end, where two consecutive levels were wired. Industrially fabricated spine models were used to prepare these constructs. The intervertebral motion within the construct was measured using the Fastrak magnetic field sensor device. On static testing, no statistically significant difference was found in the rotational displacement of the three construct designs. On fatigue testing, all samples of construct B consistently failed, with breakage of the wire at the most proximal level on the left side. But on adding additional wires to the next level (construct C), all five samples withstood fatigue testing at 300 N load to three million cycles. We conclude that wiring alternate levels instead of every level does not compromise the stability of the construct, provided that the most proximal two levels are consecutively wired. This practice would minimise the risk of dural tears and cord damage during wire passage and reduce surgical time, not to mention the economic benefits.

Keywords Scoliosis · Mechanical testing · Posterior instrumentation

Introduction

Long posterior fusions involving ten or more thoracolumbar segments are undertaken in neuromuscular scoliosis and certain cases of idiopathic scoliosis.

Segmental sublaminar wiring with a Hartshill rectangle is a semi-rigid system. Biomechanical studies have shown that pedicle screw systems are more rigid [6]. Due to the difficulty of usage of pedicle screws in thoracic spine, sublaminar wiring remains one of the valuable methods used to secure posterior instrumentation [17] to spine, particularly in the thoracic spine. It helps in the correction of scoliosis deformity by translation of the segments [6]. Classically sublaminar wires are used at all vertebral levels in order to make the construct as mechanically stable as possible, even though many authors have reported complications such as dural tears, cerebrospinal fluid leak, neurological deficit and late peridural fibrosis to be associated with sublaminar wiring [1, 7, 9, 12, 15, 16]. Yet there is paucity in recent literature of biomechanical studies that examine the role of the number of sublaminar wires used in a long fusion construct.

If it were possible to use sublaminar wires at alternate levels instead of using them at every level, without compromising the mechanical stability of a long construct, the risk of complications, surgical time and cost of surgery would be reduced.

We therefore compared the mechanical rigidity of three different designs of long posterior fusion constructs using different numbers of sublaminar wires with Hartshill rectangles.

Materials and methods

Spine models

Industrially fabricated spine models with intervertebral discs (Adam and Rouilly Ltd., Sittingbourne, Kent, UK) were used.

Implants

Hartshill rectangles made from 6.25-mm-thick stainless steel rods were used. Annealed double-strand sublaminar wires with an average thickness of 1.2 mm (Surgicraft Ltd., Fishing Line Road, Redditch, Worcestershire, UK) were used.

Hartshill rectangle fixation is a modification of the Luque system of segmental spinal instrumentation. The rectangle is prepared by bending a 6.25-mm-thick stainless steel rod to form a rectangle, and welded. It also incorporates a 100° roof that conforms to the shape of the lamina. Moreover, as the wires around the upper and lower horizontal limbs are tightened, they automatically snug down into the corners of the rectangle, giving excellent rotational stability.

A wiring technique was used as described by the developer of the Hartshill rectangle system [4]. A handheld, Robinson Jet twister was used for application of symmetrical primary twist to the sublaminar wires. Fixation was further reinforced with the secondary twist [2].

Constructs

Three types of construct design were prepared. In construct A, a contoured Hartshill rectangle was secured to a thoracolumbar spine model with sublaminar wires used at every level from T2 to L2. In

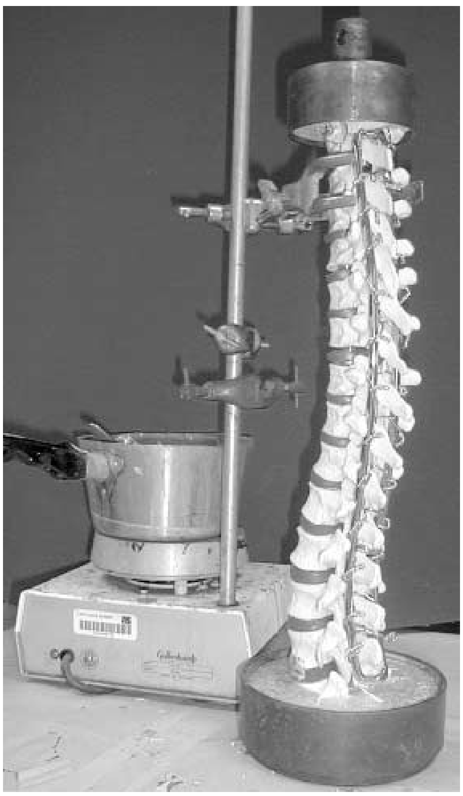

Fig. 1 A construct from T2 to L2 fixed with a contoured Hartshill rectangle and stabilised with sublaminar wires at all levels, in the process of being secured to the metallic pots at both ends

Fig. 2 The construct has been mounted for testing on the electro-servo-hydraulic machine. The Fastrak sensors are secured to the T6 and T12 vertebrae. The transmitter that emits magnetic field signals is placed in front of the assembly

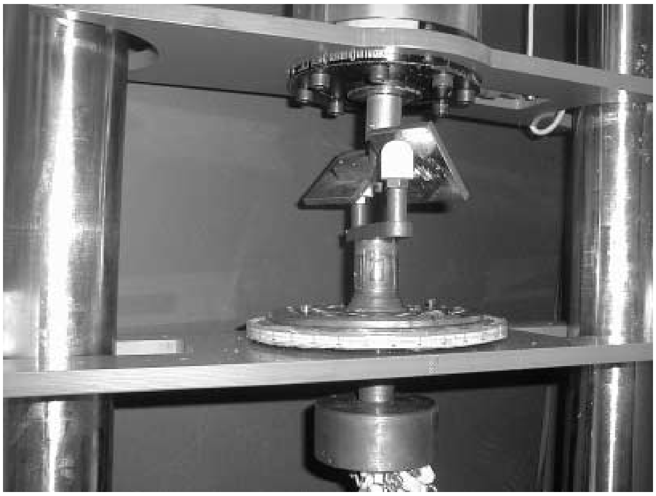

Fig. 3 A close-up view of the slant plate mechanism, which converts axial forces into torsional forces

construct B, sublaminar wires were used at alternate levels to secure the contoured Hartshill rectangle to a thoracolumbar spine model from T2 to L2. In construct C, sublaminar wires were used consecutively at the two most proximal levels and from then on at alternate levels.

Biomechanical testing set-up

Biomechanical analysis was performed in an open-air environment, at an ambient room temperature of 25°C. At either end, the constructs were secured to metallic pots, using a lead-bismuth compound (Fig. 1). This compound has peculiar properties. It melts at 70°, and therefore does not damage the spine model when it is poured into the pot. It cools at room temperature, and solidifies without contracting, thus firmly fixing the spine model to the pot. The whole assembly was then mounted on the electro-servo-hydraulic (ESH) testing machine (Fig. 2). The ESH machine allows compressive loading. Torsional loading of the construct was achieved through a slanting plate loading mechanism (Fig. 3) at the proximal end of the construct, which converts vertical loads into torsional loads. It consists of two metal plates which are attached at a 45° inclination and have a mirror finish to minimise friction.

Static and fatigue testing was carried out on five samples of each type of construct.

Data collection

Static testing

Progressively increasing torsional load up to 300 N was applied to the construct. The torsional displacement produced in the vertebrae within the construct at 300 N was measured using the Fastrak (Fastrak Polhemus, Colchester, Vt., USA) equipment (Fig. 4).

The Fastrak equipment consists of a transmitter placed in front of the construct, which emits low-frequency magnetic field signals. The sensors, which are attached securely with tape to the T6 and T12 vertebrae on the construct, pick up these signals and transmit them as digital signals to a Pentium II, 400 MHz computer. Using the Fastrak software, the position and orientation of the sensors can be traced in six degrees of freedom, and the information is displayed in graphical format. Using this set-up, the torsional displacement produced within the construct was measured in degrees.

Fig. 4 Sensors of the Fastrak equipment are attached to the T6 and T12 vertebrae. The transmitter placed in front of the construct emits low-frequency magnetic field signals. The sensors pick up the field signals and transmit them in digital format to the computer, allowing it to calculate the movement produced within the construct in six degrees of freedom

At a sampling frequency of 10 Hz for load-displacement data acquisition, three channels of data: time (in seconds), load (in Newtons) and displacement (in degrees) were recorded. These data were downloaded to a spreadsheet (Excel, Microsoft) for analysis.

Five models of each construct design (A, B and C) were tested. The mean of the rotational displacement produced at a torsional load of 300 N in the five experiments for each type of construct were compared using one way analysis of variance (ANOVA).

Fatigue testing

A torsional load of 300 N was applied at a frequency of 5 Hz, either to implant failure or up to a maximum of three million cycles,

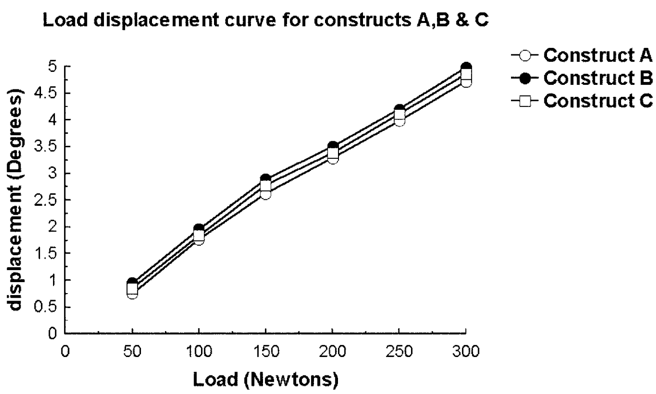

Fig. 5 The load-displacement curve is plotted for construct A (*clear round*), construct B (*dark round*) and construct C (*square*)

Table 1 Torsional displacement (degrees) in five samples each of constructs A, B and C on application of 300 N static load

Construct A	Construct B	Construct C
4.88	4.63	4.86
4.91	4.98	4.68
4.55	4.91	4.59
4.66	4.71	4.93
4.72	4.98	4.90

Table 2 Calculation table for the rotational displacement on static testing of five samples each of constructs A, B and C showing the mean, standard error of mean (SEM), standard deviation (SD), variance, sum, number of samples (*N*), and sum of squares (SS)

	Construct A	Construct B	Construct C
Mean	4.744	4.842	4.792
SEM	0.0675722	0.0724845	0.06658829
SD	0.151096	0.1620802	0.14889594
Variance	0.02283	0.02627	0.02217
Sum	23.72	24.21	23.96
N	5	5	5
SS	0.09132	0.10508	0.08868

for each of the five samples of the three construct designs, and their performance was observed.

Results

The load displacement curves for constructs A, B and C are shown in Fig. 5. The response to static testing in all three samples was linear, thus confirming the feasibility of our testing system design.

Static testing

Comparing the rotational displacement (in degrees) produced in the five samples of each of the three types of construct (Table 1) using ANOVA (Table 2, Table 3), there was no statistically significant difference ($P>0.05$) between constructs A, B and C.

Fatigue testing

All samples in the construct A design withstood three million cycles.

All samples in the construct B design failed before three million cycles. The mean number of cycles at failure for the five samples was 1.80 (±0.12) million. The most proximal wire at the left-hand corner failed in all samples of construct B (Fig. 6).

In construct C, where the most proximal two consecutive levels were wired, all five samples withstood three million cycles.

Discussion

There is no established testing standard for biomechanical evaluation of posterior long fusion constructs. Cadaveric and animal specimens can be used to test the mechanical properties of a single implant design. However, they have been shown to vary widely in bone mineral density and strength [18, 19], and are thus unsuitable for comparing stability of different construct designs. Therefore, we used industrially fabricated spine models.

However rigid a construct, the implant will still fail in time if fusion fails to occur. As such, the amount of metalwork introduced should be the minimum that is required to securely hold the spine in the desired position until the fusion process is complete.

Takemura and co-workers [13] conducted a biomechanical study of the development of scoliosis using a thoracolumbar spine model. They applied compressive, lateral flexion and rotational forces in various orders to spine models, and found that the rotational forces were the most important forces in the production of scoliotic deformity.

Also, when axial load is applied to the construct, the flexion of the spine in the sagittal and coronal planes would be resisted by the Hartshill rectangle. By altering the number of sublaminar wires in the construct, one would expect the rotational stability of the construct to be affected most. Wever et al. [14] observed that the imbalance between forces in the anterior and posterior spinal columns leads to vertebral rotational deformities. We therefore chose to test the mechanical rigidity of the constructs against static and fatigue torsional loading.

Table 3 ANOVA table depicting sum of squares (SS), degrees of freedom (df) and mean square (Ms). The calculated *f* value *F*(cal) is less than the *F* limit at 1% level of significance, which indicates that there is no significant difference in the rotational displacement between constructs A, B and C

Source of variation	SS	df	Ms	*F*(cal)		*P*[*F*≤*F*(cal)]	*F*(0.01)
Between constructs	0.0240133	2	0.01200667	0.505402	NS ($P>0.05$)	0.61554906	6.9266081
Within constructs	0.28508	12	0.02375667				
Total	0.3090933	14					

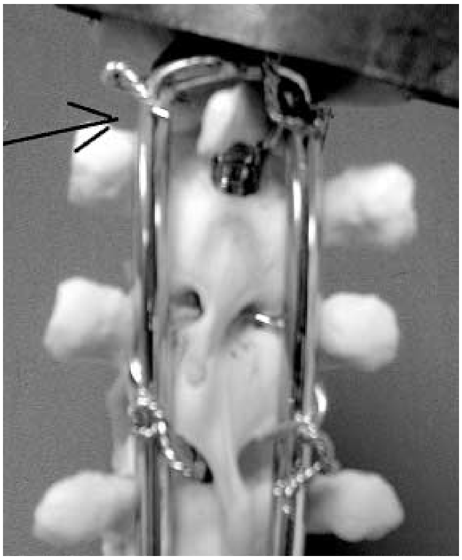

Fig. 6 The *arrow* shows the most proximal left-side corner wire broken in construct B after 1.80 million cycles at 300 N and 5 Hz frequency

Fusion is optimally promoted when intervertebral motion of the affected levels is minimised [10]. Our static testing showed that using sublaminar wires at alternate levels rather than at all levels did not significantly increase intervertebral motion.

Wire breakage is the single commonest cause of failure of posterior segmental instrumentation, occurring in 2.9% of all cases and representing 57% of all failures [5].

In long fusion constructs, the wires at the proximal end are subjected to the highest loads, and are therefore the most likely sites for failure on repetitive loading [2]. This was demonstrated in our study by the fact that in all samples of construct B, the most proximal wire failed consistently on fatigue loading to 1.80 (±0.12) million cycles. Other studies have also shown that the stability of the constructs is lower in the upper thoracic spine. Heller et al. [8] found that the tensile force required to cause failure of constructs using sublaminar wires was significantly lower in upper thoracic spine, progressively increasing in the lower segments. This problem can be overcome by wiring the two most proximal consecutive levels (construct C).

Fatigue testing of a construct design is an indicator of long-term implant survivorship [10]. Fatiguing constructs A and C, at 300 N, resulted in no slippage or failure up to three million cycles, indicating that this load magnitude was within the endurance limit of the two constructs.

One of the limitations of our experiment was that the torsional load was not applied uniformly at every segment of the spine. As the loading mechanism is attached to the construct at its proximal end, the most proximal levels are subjected to maximum load, and the torsional load decreases as it is transmitted to the lower levels of the construct. However, in vivo, the stability of the construct at the distal end is usually not an issue of concern, as it is now customary to use pedicle screws at the lower levels, which impart much greater stability [3, 6, 11]. Secondly we could not devise, or find in literature, a satisfactory method to apply torsional load evenly at all levels in a long fusion construct.

As mentioned above, in real patients we use pedicle screws in the lumbar vertebrae. However, as this study was designed to compare the rigidity of the constructs using different numbers of sublaminar wires, we did not use pedicle screws in the design of our constructs, in order to minimise the number of variables.

It would be desirable to extend the observations of this study by finite element model analysis.

Conclusion

Using sublaminar wires at alternate levels in long fusion constructs does not significantly compromise the rigidity of the construct, provided that, at the most proximal two levels, wires are used at consecutive levels.

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