Vincent Arlet
Kevin Draxinger
Lorne Beckman
Thomas Steffen

Square-lashing technique in segmental spinal instrumentation: a biomechanical study

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Abstract Sublaminar wires have been used for many years for segmental spinal instrumentation in scoliosis surgery. More recently, stainless steel wires have been replaced by titanium cables. However, in rigid scoliotic curves, sublaminar wires or simple cables can either brake or pull out. The square-lashing technique was devised to avoid complications such as cable breakage or lamina cutout. The purpose of the study was therefore to test biomechanically the pull out and failure mode of simple sublaminar constructs versus the square-lashing technique. Individual vertebrae were subjected to pullout testing having one of two different constructs (single loop and square lashing) using either monofilament wire or multifilament cables. Four different methods of fixation were therefore tested: single wire construct, square-lashing wiring construct, single cable construct, and square-lashing cable construct. Ultimate failure load and failure mechanism were recorded. For the single wire the construct

failed 12/16 times by wire breakage with an average ultimate failure load of 793 N. For the square-lashing wire the construct failed with pedicle fracture in 14/16, one bilateral lamina fracture, and one wire breakage. Ultimate failure load average was 1,239 N. For the single cable the construct failed 12/16 times due to cable breakage (average force 1,162 N). 10/12 of these breakages were where the cable looped over the rod. For the square-lashing cable all of these constructs (16/16) failed by fracture of the pedicle with an average ultimate failure load of 1,388 N. The square-lashing construct had a higher pullout strength than the single loop and almost no cutting out from the lamina. The square-lashing technique with cables may therefore represent a new advance in segmental spinal instrumentation.

Keywords Segmental spine instrumentation · Biomechanical testing · Failure mode · Pull out strength · Scoliosis

V. Arlet (✉)
Department of Orthopaedics,
University of Virginia,
Charlottesville VA, USA
E-mail: va3e@hscmail.mcc.virginia.edu
Tel.: +1-434-2430266
Fax: +1-434-2430242

V. Arlet · K. Draxinger
L. Beckman · T. Steffen
Division of Orthopedic Surgery,
McGill University, Montreal QC, Canada

Introduction

Segmental spinal instrumentation, introduced by Luque in 1977, first used sublaminar monofilament wires [4]. This represented a breakthrough in spinal instrumentation and has been used worldwide since. With such a segmental instrumentation it was possible to avoid

postoperative immobilization. With the wide spread of such growing techniques concerns about the rate of neurologic complications arise [7]. It was thought that sublaminar wires had a risk for neurological problems due to their stiffness both on insertion and removal. However, with experience and careful insertion one could significantly decrease this risk of such injuries [2].

Girardi et al. [2] used a combination of wire, hooks, and screws to instrument scoliotic spines; they reported only two transient minor neurological problems out of 141 spinal deformity patients. However, sublaminar wires have the potential to either break or cutout through the lamina either during the tightening of the wire or during the follow-up of these patients. To improve the sublaminar wire segmental fixation technique, Songer et al. [6] suggested cables are stronger, more flexible, have superior fatigue failure results, and conform better to the lamina than monofilament wires, potentially decreasing the risk of neurological damage. Multifilament titanium cables have shown to be, between 100 and 600%, stronger than monofilament wires [1]. It has been shown that that multistrand cables have a lesser degree of encroachment in the spine canal than wires [5]. Despite all these improvements of sublaminar instrumentation with cables, sublaminar cables have shown to have a lesser pull out force before failure than pedicle screws or laminar hooks, the reason that why many surgeons do not use them preferring screws or hooks [3].

Having used both sublaminar wires and cables and observed clinically cutout of the lamina as well as cable or wire cutout or cable or wire breakage, we thought that a novel sublaminar fixation technique such as square lashing would avoid such problems. Square lashing is a technique used by pioneers to tie two poles or rods together, by wrapping the rope around several times, tightening the construct by a technique called frapping, and then securing it with a knot. In this experiment, we used the same concept as square lashing; however, we only wrap the wire or cable around the rod and lamina once (see Fig. 1) and fix them by twisting the wire or crimping the cable.

The aim of this experimental study was therefore to compare the ultimate failure load, failure mode, and amount of laminar cutout of a single loop compared to a square-lashing construct using either monofilament wires or multifilament cables.

Material and methods

Eight male thoracic spines [average age 51 (range 35–58)] from T4 to T11 that were harvested and fresh frozen were thawed, dissected free of most soft tissue, and individual vertebrae were separated.

Anterior–posterior bone mineral densities (BMD) of the 64 individual vertebrae were performed (Lunar DPX X-Ray Bone Density with Smart Scan Version 4.6f). Five measurements of each vertebra were taken using an electronic caliper (accurate to 0.1 mm): coronal width, sagittal width and height of each vertebral body, and the cranial–caudal and medial–lateral pedicle diameters.

The vertebrae of each spine were block randomized to one of the four constructs: single loop with wire (WS), square lashing with wire (WL), single loop with cable (CS), and square lashing with cable (CL). Each construct would be tested twice at a vertebral level (T4–T11), thus each construct would be tested a total of 16 times.

Testing

The individual vertebra bodies were clamped with a 600 N load between two plates having 3 mm spikes, which pierced the bony endplates (Fig. 2). This method held the vertebrae well with no movement, and was easier than cementing/potting individual vertebrae. This construct was mounted on the MTS base and was unconstrained in the horizontal plane.

A short 6 mm diameter titanium rod that was anchored horizontally to the piston of the MTS machine [MTS Mini-Bionix 858 hydraulic testing machine (MTS Systems Corporation, Eden Prairie, MN)] was lowered to just touch the lamina of the vertebra on the right side. The randomized construct was assembled by one person (KD).

Fig. 1 Square-lashing technique as initially designed by the pioneers to secure two poles together (a) and as currently done for square-lashing segmental instrumentation (side view (b), top view (c))

Fig. 2 Clamping of the vertebra between two spike plates and pull out testing on the MTS machine

Monofilament wires (Zimmer 18 gauge stainless steel 316L (1.02 mm) were twisted until tight and no overlapping occurred (18 gauge size was chosen as being the most common size of sublaminar wire). Multifilament cables [Synthes (Paoli, PA, USA) stainless steel 1.0 mm with attached crimps] were tensioned to 10.8 N m of torque as per standard technique and the crimper squeezed the crimp.

Biomechanical testing consisted of a straight posterior pullout at 1 mm/s constant displacement until failure of the wire/cable or vertebra (Fig. 2). Distance and load were recorded at 20 Hz using the MTS Teststar SX/Testware software 9. Failure type (wire/cable, vertebra fracture, cutout or wire untwisting) was recorded. Ultimate failure load (N) was determined from the recorded data. Immediately after testing, the amount of cutout of the superior and inferior part of the lamina was estimated, with an accuracy of ± 0.5 mm.

For the statistical analysis, we used a stepwise multiple linear regression, including all dimensional measurements, the BMD values, and the experimental groups coded for material and construct type. A *P* value of less than 0.05 was set for level of significance.

Results

Bone mineral densities and dimensional measurements

These values varied among the spines and the individual vertebra of each spine. Average value was 1.05 g/cm³ (range of 0.59–1.97 g/cm³). There was no significant difference between the groups tested for BMD.

Single wire constructs

This construct failed 14/16 times by wire breakage with an average ultimate failure load of 793 N. There was wire twist unraveling to some degree in all cases with two cases unraveling completely. One wire cut completely through the lamina and one fracture of the pedicle was observed. Average cutout was 1.4 mm of superior lamina and 5.7 mm of the inferior lamina.

Square-lashing wire construct

This construct failed with pedicle fracture in 14/16, one bilateral lamina fracture, and one wire breakage. Ultimate failure load average was 1,239 N. There was minimal cutout (< 1 mm, on average) of both the superior or inferior part of the lamina.

Single cable construct

This construct failed 12/16 times due to cable breakage (average force 1,162 N). 10/12 of these breakages were observed where the cable looped over the rod. Only 4/16 had pedicle breakage. Cutout was mainly in the inferior lamina (average 3.4 mm).

Square-lashing cable construct

All of these constructs (16/16) failed by fracture of the pedicle with an average ultimate failure load of 1,388 N. Cutout of both ends of the lamina was minimal (less than 1 mm) (Table 1).

Data analysis

Using stepwise multiple linear regression with, initially, all dimensional measurements, the BMD values, and the experimental groups coded for material and construct type included, only the four following variables were identified as significant explanatory variables (vertebral coronal body diameter, BMD, material type (cable or

Table 1 Summary of failure modes

Construct	Lamina cutout (complete)	Construct failure	Pedicle breakage
Wire single loop	1	14	1
Wire square lashing	0	1	15 ^a
Cable single loop	0	12	4
Cable square lashing	0	0	16

^aOne was a double pedicle fracture

Table 2 Multivariate analysis and the significant explanatory variables

	Co-efficient (N)	P value
Vertebral coronal diameter (mm)	21	0.01
BMD (g/cm ³)	338	0.02
Material (wire/cable)	210	0.003
Construct (single/square lashing)	414	<0.0001

wire) or the construct type (simple or square lashing) (Table 2). The other variables such as vertebral body level, sagittal width, height of the vertebral body, and pedicle sizes were not found as significant explanatory variables.

Looking at the Box plot of ultimate failure force the square-lashing construct increases the amount of force needed to fail the construct by 414 N compared to a single loop using either the wire or cable, whereas the cable increased only the ultimate failure load by 210 N compared to wire (Fig. 3).

Discussion

Sublaminar wires were the initial segmental spinal instrumentation of choice. The initial enthusiasm of such technique was tempered by the fear of increased neurologic complications [7]. Neurologic complications were thought to be related to the stiffness of the wires and their intrusion in the spine canal. However, with the advent of new segmental fixation with cables, the advantages of the square-lashing configuration could mean a comeback of such segmental fixation.

The biomechanical downside of any segmental instrumentation with wire or cable is threefold. The wires or cables may break, they may cut out through the

laminae, and they do not provide with rotational, longitudinal or transverse stability. The purpose of this experiment was to test the pullout strength and the cutout of the square-lashing construct.

We found a significant difference between the single loop and the square-lashing technique. The square lashing proved to be 414 N stronger than the single loop using either the wire or cable (Fig. 2). This was naturally to be expected as two strands of the same cable pass under the lamina and therefore make the construct stronger.

On examination, the single loop multifilament cables broke every time in the area as it passed over the rod indicating an area of high tension/forces across the wire at this point. With the square lashing nothing like this happened as one side of the rod there is the loop and on the other side there is the small titanium crimp that rests over the rods where the cables are crimped.

The shape of the lamina, thicker at the superior edge and tapering toward the inferior part of the lamina, probably leads to increased cutout of the inferior lamina. With the single loop construct, the upward pull of the rod pulls the wire inward as well as upward possibly causing the cutout. The square-lashing construct has little or no force pulling inward and upward; therefore, the cutout is minimal if any.

The construction of the square lashing is simple. In most cases, the surgeon is passing a double loop of wire or cable initially. For square lashing, the wire just needs to be separated and the rod passed between the two sides, and then pulled backward to snug it up to the rod using jet twister for instance. For square lashing the sublaminar cable, the surgeon passes first a leader below the lamina and then the double sublaminar cable. The rest is done in the same way as with the wire except that two tensioners have to be applied on each cable to bring

Fig. 3 Box plot of the different construct and the ultimate failure loads: in *dark* the two different square-lashing constructs, in *light* the single loops constructs

Fig. 4 Cerebral palsy girl with 63 scoliosis (a). In the thoracic spine square lashing is carried out to ensure a segmental thoracic fixation and avoid any prominent hardware. The cables are passed under the lamina with a suture pull-through mechanism (b). The rods have been threaded in the loop of each square-lashing cables. Tension is brought to 392 N on each side of the cable with a cable tensioner (c). Clinical aspect after crimping of the two cables in the titanium crimping box (d). Postoperative final result demonstrating the square lashing in the thoracic spine (e)

the cable snug to the rod. Tricks, like using a pull-through suture to pass the cable loop, temporary suction tubing passed in the loops of the cables, make the use of the technique easy in the spine. To make sure that the cable gets tensioned on either side of the loop and does not catch on one lamina, the tensioning of the square-lashing construct must be done on either side of the system and one must use a double tensioning devise. The “trauma” cable that is used also for femoral shaft fractures fits perfectly with these needs and this is the one we are using for such technique (Fig. 4).

Conclusions

The square-lashing construct has a greater ultimate failure strength than a single loop construct, whether using monofilament wires or multifilament cables. Square-lashing technique fails by pull out of the pedicles and not by wire or cable breakage. One can expect that the square-lashing technique will also offer increased torsional and translational rigidity over simple sublaminal wire techniques. Clinical experience has so far shown promising results.

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