Knot strength of cerclage bands and wires

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I compared the knot strength of loop- and twist-knotted cerclage wires, and Parham and CPC bands, using a knot-slip resistance test. Two twist-knot devices and one loop-knot device were used to apply cerclage wires, and a band clamp was used to apply bands to a 5-cm-diameter split circular jaw mounted on a tensile testing machine. For all the wire sizes tested, the twisted knot provided greater resistance to knot failure than did the loop knot. Knot resistance increased with increase in wire size for all the devices tested. Neither band produced knot-slip resistance as great as 1.2-mm twist-knotted wire.

Due to the complexities of surgical use and the variability of forces on cerclage, clinical application is difficult to duplicate in vitro. It is necessary to model the clinical situation as a sequence of events that can be isolated and examined individually. I have compared strengths under direct tensile load of the type of knot used to secure cerclage wire and bands using a modification of the knot-slip resistance test.

Materials and methods

Three instruments were used to apply cerclage wires: the Rhinelander Wire Tightener-Twister (Richards Manufacturing Co., Inc., Memphis, TN, U.S.A.), ASIF Wire Tightener (Synthes Lts., Wayne, PA, U.S.A.), and Ochsner Wire Twister (Figure 1, Codman & Shurtleff, Inc., Randolph, MA, U.S.A.). Wire specimens of 316L stainless steel of three different diameters were obtained from Synthes Lts.; 0.8, 1.0, and 1.2 mm for the Rhinelander and the Ochsner models, and 0.8, 1.0, and 1.25 mm for the ASIF. Bands were applied with a Parham band clamp (Richards Manufacturing Co., Inc.). Standard 5.0-mm-wide and 19-cm-long Parham bands (Richards Manufacturing Co.), and 7.9-mm-wide and 19-cm-long Circumferential Partial Contact (CPC) bands (Richards Manufacturing Co.) were used (Figure 2). All the cerclage were applied to a 5-cm-diameter split circular jaw mounted on a tensile testing machine (MTS tensile testing machine type T5002, Minneapolis, MN, U.S.A.). Output was recorded on an X-Y plotter (Hewlett-Packard Model # 7015 B, Palo Alto, CA, U.S.A.) with knot resistance measured in newtons and knot deformation measured in millimeters.

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Ten specimens of each of the three gauge wires for all three instruments, and of each band, were tested. All the instruments were used according to proper clinical technique (Rhinelander 1958, Rooks et al. 1982, Withrow 1978). Wires and bands were aligned such that the knot was located centrally between the two segments of the jaw (Figure 3). The ASIF loop was cut leaving a 4-mm wire end. Twists were cut leaving three full twists, or approximately 5 mm of twist. Twists were not bent. Bands were secured through a preformed slot. All 110 specimens were run at a cross-head speed of 10 mm/min, and testing stopped once complete separation of the knot was achieved and a resistance value of 0 newtons was recorded.

Knot-slip resistance for each of the 110 tests was measured at the yield point and at peak load at slip from the resultant force-deformation curves. Maximum, minimum, and average knot strengths and corresponding SD and SE were calculated for each combination of wire size and applying instrument, or band. The 10 force-deformation curves for each combination of wire size and applying instrument or band were digitized and an average curve was drawn. Force data for each combination of wire size and applying instrument or band were analyzed by one-way analysis of variance. Treatment sums of squares were broken down into appropriate orthogonal comparisons with 1 df each. The F-values were calculated to detect significant differences in the means. Differences at $P < 0.01$ were considered significant.

Results

All the twist knots failed by untwisting, and all the loop knots failed by unbending followed by slipping of the wire end through the preformed loop. The bands failed when the smooth end passed through the preformed

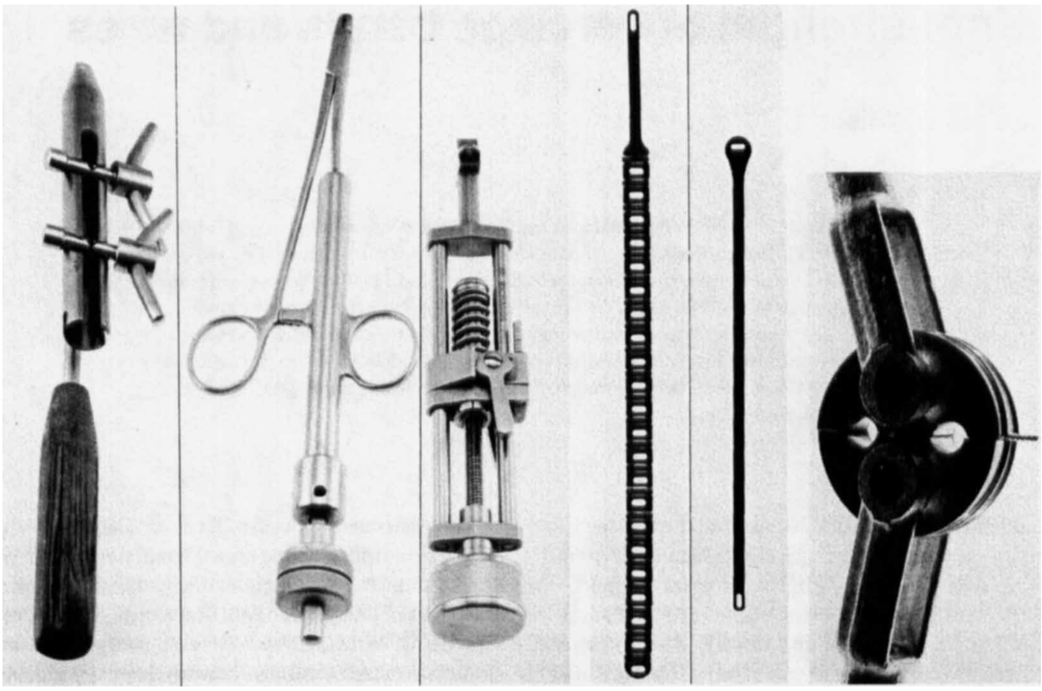

Figure 1 Figure 2 Figure 3

Figure 1. Instruments used to apply cerclage. Left to right — ASIF Wire Tightener, Ochsner Wire Twister, Rhinelander Wire Tightener-Twister.
Figure 2. Circumferential Partial Contact (left) and Parham (right) bands.
Figure 3. Tensile testing equipment with wire in place prior to application of load.

slot in the band. None of the wires or bands failed by breakage.

For 0.8-mm wire, there was a significant difference between all the three mean peak loads with the highest resistance recorded with the Rhinelander applicator (362 N) and the lowest with the ASIF (216 N). Both types of twist-knotted cerclage had greater knot-slip resistance than the loop-knotted cerclage (Table 1). The mean yield points of the two twist-knotted cerclage were similar (216 N and 224 N), and both were greater than the mean yield point of the loop-knotted wires (158 N).

Knot-slip resistance increased with increase in wire size. For 1.0-mm wire, all three yield and peak-load means differed. Once again, the Rhinelander applied twist knots recorded the greatest resistance with the loop-knotted cerclage producing far less knot resistance than either twist knots (Table 1, Figure 4).

The 1.2-mm wire was used with both twist-knotted devices. The Rhinelander cerclage had a mean yield point of 644 N and a mean peak load of 887 N. The Ochsner cerclage had a mean yield point of 550 N and a mean peak load of 711 N. Wire of 1.25 gauge was used with the ASIF loop, and, although larger in size, the loop-knotted wire produced far less knot resistance; the mean yield point was 384 N and the mean peak load was 530 N. There was a difference between all the recorded means.

Wire instrument or band type	Wire size (mm)		
	8	1	1.2 (1.25)[a]
Rhinelander	362 (7) 216 (23)	560 (11) 388 (14)	887 (23) 644 (16)
Ochsner	311 (14) 224 (23)	478 (19) 323 (24)	711 (16) 550 (17)
ASIF	216 (23) 158 (9)	378 (51) 270 (19)	530 (92) 384 (42)
		Bands	
Parham		540 (61) 495 (48)	
CPC		766 (132) 325 (74)	

[a] 1.2 mm wire was used with the Rhinelander and Ochsner applicator, whereas 1.25 mm wire was used with the ASIF.

The mean peak load for the Parham band was 540 N, with a mean yield point of 495 N. The CPC band produced greater peak load values than the Parham band, with a mean of 766 N; however, the mean yield point for this raised-band design was less than the Parham bands (Figure 5).

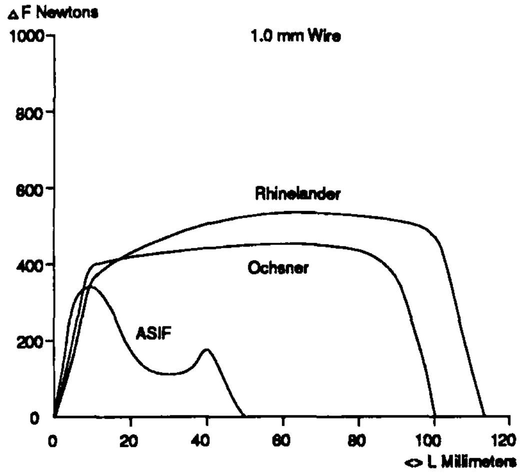

Figure 4. Comparative knot-slip resistance for 1.0-mm wire applied with the ASIF Wire Tightener, Ochsner Wire Twister, and Rhinelander Wire Tightener-Twister. (From Wilson et al. 1985)

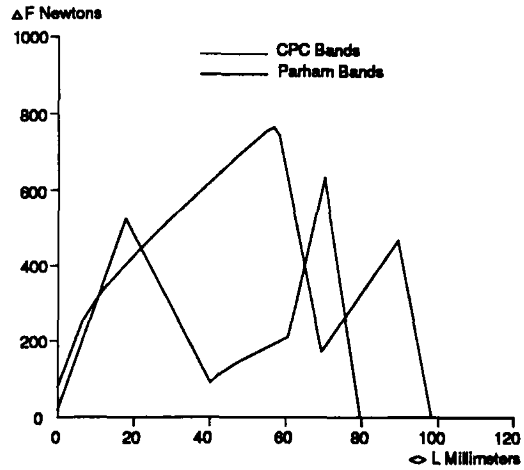

Figure 5. Comparative knot-slip resistance for CPC and Parham Bands.

Discussion

A common misconception is that because bands are wide they are stronger than wires. However, the area moment of inertia for a band, a thin rectangle, is influenced by its width and the cube of its thickness. Similarly, the area moment of inertia for a wire, of circular geometry, is based on the fourth power of the diameter. Making a band wide will not make its area moment of inertia appreciably larger, whereas a similar increase in the diameter of a wire does. Neither band performed better than the twist-knotted 1.2-mm cerclage wire.

Advantages and disadvantages have been stated for both plain and raised bands. Whereas plain bands have been shown to block centrifugal blood flow (Rhinelander 1974, Rhinelander and Wilson 1982), raised bands make accurate fixation of fragments more difficult (Rhinelander and Stewart 1983). Cerclage bands are, by their nature, very wide. Concern over possible compromise to cortical vascularity would necessitate placement with some gap between adjacent bands. Thus, fewer bands than wires could be placed over a given diaphyseal distance. My study suggests that fixation with multiple cerclage wires may be stronger than a similar fixation with bands.

Although loop-knot devices have been shown to produce greater final wire tension than twist-knot devices (Rooks et al. 1982), all of my loop knots had less ultimate strength than comparative twist knots. The yield points for loop-knotted cerclage were also less than twist-knotted cerclage. Cerclage are often used circumferentially around a diaphysis to stabilize oblique fracture planes. If subjected to weight bearing, these fracture interfaces tend to slide, resulting in forces that are similar to those under which the cerclage in this study were tested. The greater ultimate strength and higher yield point of twist-knotted cerclage, plus their ability to maintain peak-load resistance over a large deformation, would suggest that cerclage with twist knots would be superior to cerclage with loop knots.

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