Stainless steel wire versus FiberWire suture cerclage fixation to stabilize the humerus in total shoulder arthroplasty

Niklas Renner, MDa,*, Karl Wieser, MDa, Georg Lajtai, MDb, Mark E. Morrey, MDa, Dominik C. Meyer, MDa

aDepartment of Orthopaedics, University of Zürich, Balgrist University Hospital, Zürich, Switzerland
bDepartment of Orthopaedics, Private Hospital Maria Hilf, Klagenfurt, Austria

Hypothesis: No. 5 FiberWire (Arthrex, Naples, FL, USA) cerclage (FWC) and 1.25-mm stainless steel wire cerclage (SSWC) are biomechanically similar in resistance to prosthetic subsidence in shoulder arthroplasty.

Methods: In this laboratory bench study, 3 different surgical knot configurations (4-throw knot, cow hitch, and simple hitch) using a No. 5 FWC were evaluated and compared with a 1.25-mm SSWC. First, distraction tests were performed using bovine femoral cortical half shells mounted on a testing jig. Cerclage tightening, load to a 3-mm gap opening, and load to total failure were measured. Second, uncemented humeral prosthetic stems were inserted into an experimentally split humeral medullary canal, secured by the cerclage. After 100 N of preloading, the prosthesis was advanced into the humerus at a speed of 0.2 mm/s, and resistance during subsidence up to a penetration depth of 10 mm, as well as gap opening, was measured.

Results: Tightening force showed higher values for SSWC (618 N) than FWC (131-137 N) (P < .001). Load to total failure was comparable among the 3 different FWC knots (2,642-2,804 N), which were significantly stronger than SSWC (1,775 N, P < .001). At 3 mm of distraction, SSWC (1,820 N), cow hitch (1,803 N), and single-throw hitch (1,709 N) performed significantly better than a 4-throw knot (1,289 N) (P < .01). Subsidence testing showed no difference in force restraint or gap opening between the best FWC and SSWC.

Conclusions: FWCs appear, in vitro, equally suitable to steel wires to stabilize nondisplaced periprosthetic humeral fractures. To actively reduce a displaced fracture, steel wires may still be the first choice.

Level of evidence: Basic Science, Biomechanics.

Keywords: Cerclage; periprosthetic humeral fracture; total shoulder arthroplasty

Wire cerclages have been well known for bone fixation for over half a century and have usually been performed with steel wires. With the advent of flexible high-strength polyblend-polyethylene suture fibers, the concept of using this material for cerclage purposes appears to be an attractive option. It may offer the advantages of not
interfering with radiologic imaging, potentially easier handling, and no risk of metallosis in the case of metal-metal contact. Periprosthetic humeral fractures can occur during primary (1.2%) or revision shoulder arthroplasty (3.3%) and may require osseous stabilization.2-4,23,24

When fractures arise as a part of humeral insertion, the surgeon must know what fixation techniques will prevent propagation of the fracture6 during the average 17 weeks needed to heal,2 which is much longer than the typical immobilization period after surgery.19 Much of the work on intraoperative fracture fixation has relied on data from the hip and knee literature or from proximal humeral fractures without prostheses; however, no studies address fixation techniques specifically for shoulder arthroplasty and intraoperative fractures.

There are a myriad of techniques that have been discussed, including the use of braided suture, wire, and cable cerclage techniques,2,9,13,18,20,21,25,27,28 to fix fractures or humeral osteotomies in revision surgery. However, the loading pattern occurring from a prosthesis in a fractured shaft is very difficult to predict, and small gapping of the fracture may result in considerable subsidence of the prosthetic shaft. Therefore, it was the purpose of this work to investigate the compression generated by each cerclage construct and to find the best method for creating a stable compressive fixation using high-strength sutures. As a second step, we tested the amount of subsidence of the prosthesis into an experimentally fractured shaft stabilized with a metallic versus a flexible cerclage.

Materials and methods

Stainless steel wire cerclage (SSWC) of 1.25 mm in diameter (Synthes, Solothurn, Switzerland) and No. 5 FiberWire (Arthrex, Naples, FL, USA) cerclage (FWC) were used in this study. FiberWire (FW) is made of ultrahigh–molecular weight polyethylene (UHMWPE) and polyester braided over a UHMWPE core.

Distraction test

Cerclage testing followed a previously established protocol.16,29 Fresh-frozen bovine femur (–20°C) was used for the assessment. The bone was thawed and kept humid for the investigation. Before testing, all soft tissue surrounding the bone was removed and pieces of 65 mm in length were cut from the mid diaphysis. To fit the bone shells on the testing jig, the intramedullary canal was reamed up to 25 mm and the fragment was cut into 2 parts. The outer diameter of the 2 pieces was 40 mm. All cerclage systems were tested using the same specimen. After preparation of the bone shells, they were fit on the testing jig, which consisted of 2 metallic half cylinders with a radius of 25 mm, forming a full circle. The upper half cylinder was connected to a 20-kN load cell. Between the bone shells, a gap of 1 mm was maintained during the test to avoid load transfer via the testing machine. For all assessments, we used the same universal material testing machine (Zwick 1456; Zwick/Roell, Ulm, Germany), which recorded the data using dedicated software (testExpert 10; Zwick/Roell). We evaluated the data regarding load (in newtons) and displacement (in millimeters), which were digitally recorded, and the deformation curve and the mode of failure were documented.

We twisted 1.25-mm double-looped cerclage wires with dedicated pliers (Müller, St. Gallen, Switzerland) under permanent traction on the cerclage wires. Values of 940 ± 26 N were determined in a series of 5 samples as the range of ultimate compressive force achieved by twisting. The cerclages were therefore twisted on the testing jig until approximately 90% of the maximally expected force was reached. After 6 turns, the free wire ends were cut outside the crimp, which was then bent forward (in the direction of the twisting) to minimize loss of pre-tension.29

Double-looped No. 5 FW slings were performed and secured with 3 different knots as described later. Each setup was tested 10 times. After preliminary testing, a standard surgical knot with 4 throws was deemed suitable as a control group. Furthermore, 2 sling hitches with 4 simple knots on top (cow hitch and single-throw hitch) as depicted in Figures 1 and 2 were tested.

At the cerclage setup, pre-tension was measured at the following time points: (1) after wire twisting, (2) after removal of pliers, (3) after cutting the wire ends, (4) after bending the crimp, and (5) 1 minute later. The FW pre-tension was measured after secure knot tying. After 1 minute, a constant tensile force with a speed of 0.2 mm/s was applied, and load leading to a 1-, 2-, and 3-mm gap opening, as well as load to total failure, was recorded. The end of the test was defined as 90% force shutdown or gap opening of 20 mm between the bone shells.

Subsidence test

Ten fresh-frozen (–20°C) proximal humeri of human specimens were prepared for this investigation. Standard anteroposterior radiographs of each bone were obtained, and all bones were matched into 2 approximately equal groups regarding their cortical indexes.11 After thawing of all proximal cadaveric humeri, the heads were resected exactly at the level of the anatomic neck and a medial longitudinal split ("humerotomy") of 10 cm in length was performed with the aid of an oscillating saw. The medullary canal was rasped manually using rasps from the Zimmer Anatomical Shoulder System (Zimmer, Winterthur, Switzerland) until solid resistance was felt from cortical contact in the canal. Each specimen was fixed in a vertical fixation device on the machine table, and an uncemented proximal humeral prosthesis (Zimmer) was inserted into the medullary canal until solid resistance was felt at the calcar using either a double-wire cerclage (n = 5) or an FW double-loop cerclage (cow hitch) (n = 5), which has previously been determined as best for the purpose (Fig. 3).

For subsidence measurements, on the same test machine mentioned earlier, a compressive load was applied onto the prosthesis by lowering the cross-head at a constant speed of 0.2 mm/s and resistance during subsidence of the prosthesis was measured. Tests were completed when a penetration depth of 10 mm was reached. Load to subsidence was recorded with a force-strain curve. Videos were recorded using a Nikon D800 digital camera (Nikon, Tokyo, Japan) that was equipped with a specific macro-objective (Telecentric Visionmes Lenses 16/16/0.1;...
Carl Zeiss, Oberkochen, Germany) from every subsidence test, and gap opening was measured with Adobe Photoshop CS5 (Adobe Systems, Munich, Germany).

Statistical analysis

To detect significant differences among the groups regarding loss of pre-tension, gap opening, total failure, and subsidence resistance force, 1-way analysis of variance was performed. The significance level was defined as $\alpha = .05$.

Results

Distraction test

Wire tightening of the 1.25-mm wire cerclage resulted in a primary pre-tension of $817 \pm 16$ N and decreased to $806 \pm 20$ N after removal of the pliers, to $780 \pm 27$ N after cutting of the wire, and to $618 \pm 75$ N after bending of the crimp; thereafter, it remained stable after 1 minute.
With 131 N for the 4-throw control knot, 137 N for the cow hitch, and 133 N for the single-throw hitch, the maximum pre-tension values of the FWC were not significantly different among the 3 knots \((P > .05)\); however, maximum pre-tension was significantly lower than pretension of the wire cerclages.

Distraction force and load at total failure of the different cerclage configurations are shown in Figure 4. All cerclages failed by either unraveling of the twist or wire breakage at the innermost turn of the twist. All FWCs ripped apart by rupture at the innermost thread of the knot. At 1 and 2 mm of displacement, all FWCs exhibited comparable results but showed significantly lower results than the SSWC. However, load at 3 mm of fragment separation showed similar results for the SSWC (1,820 N; range, 1539 – 2058 N; SD, 256 N), FW cow hitch (1,803 N; range, 1339 – 2040 N; SD, 246 N), and FW single-throw hitch (1,709 N; range, 1498 – 1867 N; SD, 113 N); these loads were significantly higher compared with that of the FW 4-throw knots (1,289 N; range, 741 – 1734 N; SD, 353 N). Load to total failure was, however, comparable among the 3 different FW cerclage knots, which were significantly stronger than SSWC.

Subsidence test

Force required to press the prosthesis from 1 to 10 mm into the humerus (subsidence) after application of a cerclage is shown in Figure 5. There was no significant difference between the cerclage wires and FWCs. We recorded a slightly greater gap opening using SSWC compared with the FW group, without reaching a statistical difference (Fig. 6).

Discussion

Iatrogenic fractures or humeral osteotomies may occur in primary or revision shoulder arthroplasty. Factors such as osteopenia, female sex, and rheumatoid arthritis are associated with intraoperative fractures, have a prevalence of 0.6% to 3%, and account for nearly 20% of all complications.\(^2,7,14,23,25,30,31\) Various treatment options such as cerclage wiring, plating, and interfragmentary screw insertion\(^12\) have been proposed. Regarding the specific cerclage technique, various constructs addressing the violation of the bone have been reported,\(^10,15,22\) but to our knowledge, no systematic testing of the ideal biomechanical technique has been conducted in combination with a humeral prosthesis. We conducted our test setup because biomechanical testing of common suture materials showed that a single-loop No. 5 FW is the suture material that has the closest material properties regarding load to failure and stiffness compared with a 1.25-mm stainless steel wire.\(^20\)

Cerclage fixation of bone may follow 2 purposes: first, to reduce a displaced fracture, and second, to secure bone against further fracture crack propagation. Regarding the first task, we could show that cerclage wires are far more suitable to actively compress bone, with an approximately 5-fold higher compressive load created as compared with the suture construct, which might be an advantage to reduce a fracture. Beyond that, SSWC provided more resistance to fragment separation at small distances (1-2 mm) in combination with strong cortical bovine femur shells in our laboratory bench test because of the higher elasticity of the FWC.

However, resistance against gap formation of more than 3 mm and ultimate load to failure were significantly higher using an FW suture cerclage. The cow hitch presented in this study with simple throws performed best regarding ultimate failure load and stiffness. As described by Lenz et al,\(^16\) failure of all cerclages occurred by either unraveling of the twist or wire breakage at the innermost turn of the twist. However, all FWCs ripped apart by rupture at the innermost thread of the knot, and knot slippage was never observed, despite the small number of only 4 throws.\(^17\)

These very different resistance and strain behaviors among the tested suture and wire cerclage models, however, did not significantly influence resistance and opening of the gap during prosthetic stem subsidence. Although
there was a slightly greater gap opening during the test for the SSWC compared with the FW group, no statistical difference was found and gap opening was only 1 to 1.5 mm in the case of 1 cm of prosthetic stem subsidence.

It is questionable whether the potential pre-tensioning of the SSWC up to 966 N is of practical importance, especially on osteopenic or osteoporotic bone, because the wires may cut through the bone. Vice versa, the use of a nonmetallic cerclage construct has potential advantages such as better adaptation to the bone surface, decrease of soft tissue irritation by the crimp, and no risk of metal-on-metal debris.

The equivalent results in subsidence testing of the FW and the stainless steel wire despite the higher stiffness of the metallic SSWC may be explained by 2 aspects. First, the suture construct may compensate for its elasticity with

**Figure 4** Distraction to 1, 2, and 3 mm (± standard deviation), as well as load leading to total failure (± standard deviation), for tested cerclage types (n = 10; ** P < .01; *** P < .001).

**Figure 5** Force needed (± standard deviation) to press the shaft of the proximal humeral prosthesis 1 to 10 mm into the medullary canal. Testing showed no difference between the cerclage systems.

**Figure 6** Gap opening (± standard deviation) (in millimeters) at proximal humerus split at 1 to 10 mm of subsidence of prosthesis stem.
the greater surface area to distribute the load on the bone and may thus cut less into the soft periosteum and bone. Second, the weakest area appears to be the soft cancellous canal even though radiologically measured well-tapered prostheses were implanted. Therefore, the elasticity of the wire construct is not the weakest link and thus not the limiting factor for subsidence.

There are some limitations of this investigation. First, we used very strong cortical bovine femur shells for our laboratory bench test, which did not allow any plastic deformation as occurs in vivo but which was necessary to isolate the behavior of the wire and suture. Second, subsidence testing was performed with different stem sizes and cadaveric humeri having, despite matching, variable biomechanical characteristics. Furthermore, to limit the variables of the test setup, we decided against performing cyclic testing.\(^{5,18}\)

However, despite the aforementioned limitations, our results appear to be in line with comparable data on the use of nonmetallic cerclage material in orthopaedic surgery\(^{6,10,22,26}\) and even with a report assessing a specifically designed commercial braided UHMWPE fiber cable to fix a peri-prosthetic fracture in revision shoulder arthroplasty.\(^{10}\) In summary, because we could not find relevant downsides to the suture cerclage fixation on the humerus in combination with prostheses assessed in this study, the associated advantages, such as ease of handling, low cost, good tissue compatibility, and no interference with radiologic imaging, may make this method an attractive option in patients in whom no relevant bone gap needs to be closed.

**Conclusion**

Suture (FW) cerclages in shoulder arthroplasty provide a safe, affordable, simple, and readily available technique to stabilize periprosthetic fractures or humeral osteotomies as long as no gap needs to be actively closed by the cerclage. Particularly in patients with osteopenic or osteoporotic bone, the use of an FWC provides sufficient stability comparable with established wire cerclages, with the benefit of no radiologic interference. The shortcoming of this study is the lack of cyclic testing, which may be further assessed to confirm our results in a repeated load assessment.

**Disclaimer**

Zimmer provided the proximal humeral prosthesis stem from the Anatomical Shoulder System for our test setup. The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

**References**