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SHOULDER

A biomechanical assessment of a novel double endobutton technique versus a coracoid cerclage sling for acromioclavicular and coracoclavicular injuries

**Cori Grantham · Nathanael Heckmann ·
Lawrence Wang · James E. Tibone · Steven Struhl ·
Thay Q. Lee**

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Abstract
Purpose Recently, many acromioclavicular–coracoclavicular (AC–CC) ligament reconstruction techniques address only the CC ligament. However, many of these techniques are costly, time-consuming, and require the use of allogenic grafts, making them prone to creep and failure or novel devices making them challenging for orthopaedic surgeons. The purpose of this study was to compare the biomechanical characteristics of a double endobutton technique using a standard endobutton CL with those of a coracoid cerclage sling (CS) for reconstruction of the CC ligaments.
Methods Anterior–posterior (AP) translation and superior–inferior (SI) translation were quantified for eight matched pairs of intact AC joints. One shoulder from each pair underwent a double endobutton repair, using an endobutton CL modified with an additional endobutton (Smith & Nephew, Memphis, Tenn) and placed through holes in the coracoid and clavicle. The contra-lateral shoulder received a coracoid sling reconstruction using an anterior tibialis tendon. Translation testing was repeated after reconstruction, followed by load-to-failure testing. Paired *t* tests were used for statistical analysis.
Results The CS technique demonstrated a greater SI and AP translation than the double endobutton technique ($p < 0.05$). Additionally, the double endobutton technique had a greater stiffness (40.2 ± 11.0 vs. 20.3 ± 6.4 N/mm, $p = 0.005$), yield load (168.5 ± 11.0 vs. 86.8 ± 22.9 N, $p = 0.002$), and ultimate load (504.4 ± 199.7 vs. 213.2 ± 103.4 N, $p = 0.026$) when compared to the CS technique.
Conclusion The double endobutton technique yielded less translation about the AC joint and displayed stronger load-to-failure characteristics than the CS reconstruction. As such, this technique may be better suited to restore native AC–CC biomechanics, reduce post-operative pain, and prevent recurrent subluxation and dislocation than an allogenic graft construct. The double endobutton technique may be a suitable option for addressing AC–CC injuries.

Keywords Acromioclavicular · Coracoclavicular · AC joint · Biomechanics · Translation · Stiffness · Reconstruction

Introduction

Though surgery is considered the mainstay of treatment for types IV through VI acromioclavicular–coracoclavicular (AC–CC) injuries, there is a lack of consensus about a universally preferred technique to repair these injuries. While there are over 60 different repair techniques described in the literature, many authors recommend restoration of only the CC ligaments, with the thought that addressing the AC ligaments may not provide any clinically relevant increase in stability that would warrant their repair [3, 6, 10, 17, 20]. CC interval restoration with suture loops [6, 10], suture

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C. Grantham · N. Heckmann · J. E. Tibone
Department of Orthopaedic Surgery, Keck School of Medicine, University of Southern California, Los Angeles, CA, USA

N. Heckmann · L. Wang · T. Q. Lee (✉)
Orthopaedic Biomechanics Laboratory, VA Long Beach Healthcare System (09/151), 5901 East 7th. Street, Long Beach, CA 90822, USA
e-mail: tqlee@va.gov

S. Struhl
Department of Orthopaedic Surgery, New York University Hospital for Joint Diseases, New York, NY, USA

T. Q. Lee
University of California, Irvine, CA, USA

anchors [3, 20], or hardware fixation with various types of non-absorbable buttons [7, 18, 21] has come into favour because they utilize relatively undemanding surgical techniques and have yielded promising biomechanical [1, 2, 5, 19, 22, 23] and clinical data [3, 6, 7, 10, 17, 20]. However, many of these current techniques are time-intensive, costly, and require the use of novel hardware or devices, making them challenging for orthopaedic surgeons to employ.

The double endobutton technique, which utilizes a standard endobutton CL fixation device (Smith and Nephew, Memphis, TN) and an additional supplementary endobutton to provide fixation across the CC interval, was first described by Struhl [21]. This technique has been shown to yield promising clinical results [25, 27], and a similar triple endobutton technique has also been described [12] with equally promising clinical results [24, 26]. Furthermore, this technique does not use allogenic graft material which is prone to creep. To our knowledge, there are no biomechanical studies that assess the biomechanical properties of the double endobutton technique in the literature. As such, very little is known about the strength of this repair relative to the strength of a repair using a tendon allograft. The purpose of this study was to biomechanically compare the translational properties and load-to-failure characteristic of the double endobutton technique with a traditional coracoid cerclage allograft loop reconstruction of the CC ligaments in an AC dislocation injury. A coracoid cerclage sling (CS) was used as a control because it is the most common reconstruction technique performed by sports-trained surgeons.

Materials and methods

Eight pairs of fresh frozen cadaveric shoulders (two males, six females) with a mean age of 67.4 ± 16.2 years were used. The specimens were stored at −20 °C until the day before testing and thawed overnight at room temperature in preparation for dissection and testing. The specimens were kept moist with 0.9 % saline solution to prevent dehydration during the dissection and testing. The humerus was disarticulated from the glenohumeral joint capsule, and all soft tissues were removed except the AC ligament and CC ligaments. The scapula and clavicle were potted with plaster of paris in an aluminium box and 20-cm-long PVC pipe, respectively. A 2.5-in. wood screw was drilled through the clavicle and pipe to minimize any residual motion.

The shoulder was mounted to a translation plate on a custom shoulder jig such that the articular plane of the AC joint was parallel to the translation plate and the medial end of the clavicle was fixed to a stationary arm on the jig (Fig. 1). This allowed for anterior–posterior (AP) and superior–inferior (SI) translation of the scapula relative to the clavicle in a plane parallel to the ground, allowing the force of gravity to be orthogonal to the applied AP and SI translational forces.

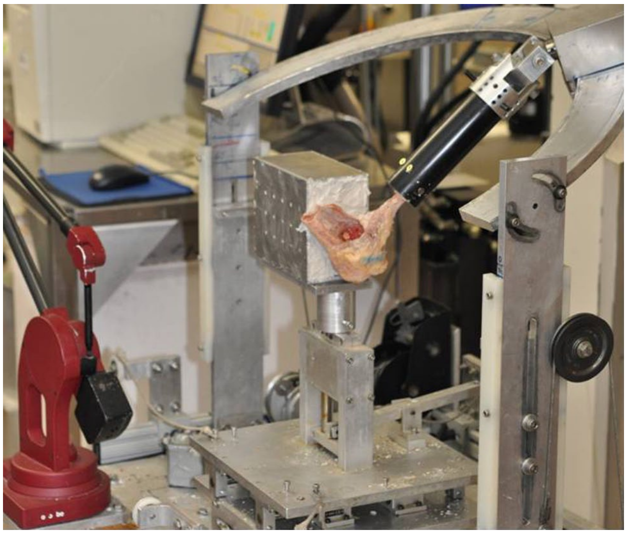

Fig. 1 Custom shoulder-testing system used to test acromioclavicular joint translation

Testing was first performed on each shoulder with the AC and CC ligaments intact. AC capsule translation with an applied load of 5 and 10 N was measured by digitizing the motion of the acromion relative to the clavicle using a Microscribe 3D LX device (Revware, Raleigh, NC, USA). To obtain a reproducible neutral position, two series of translational testing were done: one with a 5 N superiorly directed tension and another with a 10 N superiorly directed tension when measuring AP translation, and similarly a 5 and 10 N anteriorly directed tension was used when measuring SI translation.

Each translational measurement was taken twice with the Microscribe 3D LX to insure reproducibility. If the difference between the two measurements was greater than 1 mm, the data point was re-measured. If the difference between the two data points was less than 1 mm, the measurements were averaged together. The accuracy of the Microscribe 3D LX is ±0.3 mm.

After testing the intact condition, the AC and CC ligaments were transected and randomly reconstructed with either the double endobutton technique or CC sling technique. The same testing procedures were then repeated. Upon completing translation testing, load-to-failure characteristics of the reconstruction were measured by mounting the shoulder onto an Instron material testing machine (model 3365, Instron, Norwood, MA) (Fig. 2). The clavicle was fixed to the Instron crosshead with a fixed load cell, and the specimen was pulled in a superior direction at a rate of 50 mm/min after being cycled from 10 to 20 N for 10 cycles from a 5 N preload.

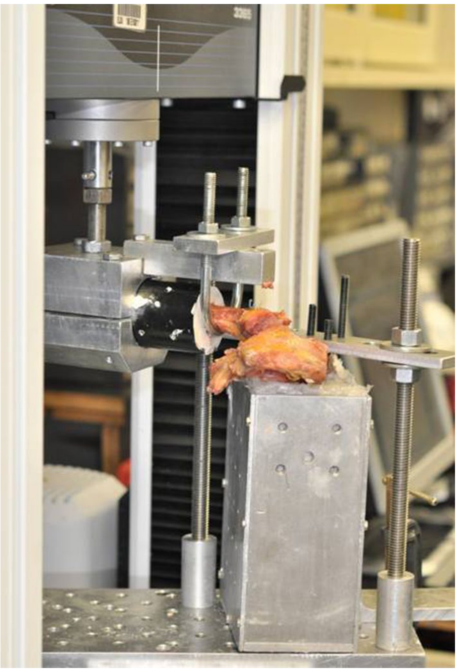

Fig. 2 Potted acromioclavicular joint mounted on the Instron testing system for load-to-failure testing

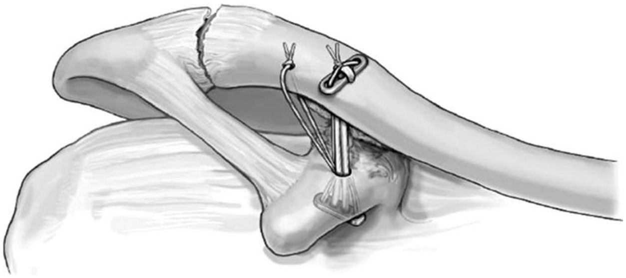

Fig. 3 The double endobutton repair (Struhl [21])

Double endobutton

The double endobutton technique described by Struhl [21] was performed on one side of all eight pairs tested (Fig. 3). Two clavicle tunnels were created using a guide pin and reamer—a 4.5-mm tunnel approximately 3-cm medial to the AC joint and halfway between the width of the clavicle and spanning the entire height of the clavicle, CC interval, and coracoid process, and a 2.5-mm tunnel through the clavicle only approximately 1-cm anterolateral to the first tunnel. The distance between the superior clavicle and inferior coracoid was then measured to determine the appropriate endobutton size to use.

The endobutton, along with its associated sutures, was pushed through the top of the clavicle through the previously drilled hole and through the coracoid hole. The loop stitch was then pulled up, locking the endobutton onto the underside of the coracoid. One of the two pairs of suture tails was pulled out of the interval between the coracoid and clavicle. A free endobutton is held with a suture holder and is now slid into the protruding loop so that it sits centred under the loop. The suture tails are then passed through the endobutton holes and tied down over the button, recreating the conoid portion of the CC ligaments. The remaining suture tails that were brought out of the coracoclavicular space were retrieved, and 1 tail was passed through the second (2.5 mm) drill hole and tied. This recreates the trapezoid portion of the CC ligament.

Coracoclavicular sling

On the contralateral shoulder, the CC sling was performed. Two 5-mm clavicle tunnels approximating the insertion positions of the conoid and trapezoid ligament were again created with a guide pin and reamer—one in the posterior half of the clavicle 45 mm from the distal end, and the other 10 mm lateral to the first tunnel and halfway between the anterior and posterior clavicle edges.

An anterior tibialis allograft was trimmed to an average diameter of 5 mm and prepared with the assistance of a graft preparation station. The graft was whipstitched with sutures (No. 2 FiberWire; Arthrex, Naples, FL) at each end and tensioned to 15 N to remove any subsequent creep. The graft was then looped around the coracoid process to form a sling that rested against the inferior aspect of the coracoid. A generous amount of soft tissue was left along the coracoid to prevent slippage of the graft along the coracoid in the AP direction. The two ends of the graft were then crossed within the CC interval to form an “X”-shaped configuration and then passed superiorly through the two clavicular tunnels. The two graft ends were then sutured together using a modified Bunnell stitch and simple interrupted sutures using No. 2 FiberWire (Arthrex, Naples, FL).

Statistical analysis

A paired Student’s *t* test was used to compare the differences between intact and reconstructed state, and between the two reconstructions. Data for each translational and joint tension (5, 10 N) load combination were compared. For load-to-failure testing, the linear stiffness, yield load, ultimate load, and energy absorbed at yield and ultimate load were calculated. Data for load-to-failure testing were also compared using a paired Student’s *t* test. A *p* value of less than 0.05 was used for statistical significance. In order to detect a 50 % difference in translation between the two reconstruction techniques, four specimens in each of the two groups were required to reach 80 % power.

Results

Translation testing

For both reconstruction techniques, AP translation increased after reconstruction compared to intact. The double endobutton only had a significantly higher increase from the intact state with a 5-N applied translational load and 10-N superior tension (2.8 ± 1.3 to 4.4 ± 1.9 mm, $p = 0.046$). The CS reconstruction had a significantly higher increase from the intact state with a 5-N applied load and 5-N tension (3.2 ± 1.7 to 14.8 ± 4.0 mm, $p = 0.0001$), 10-N applied load and 5-N tension (4.9 ± 2.2 to 18.3 ± 4.3 mm, $p = 0.0001$), 5-N applied load and 10-N tension (2.7 ± 1.4 to 11.9 ± 2.9 mm, $p = 0.0001$), and 10-N applied load and 10-N tension (4.3 ± 1.9 to 16.4 ± 3.2 mm, $p = 0.0001$). The CS technique demonstrated a significantly greater increase in AP translation than the double endobutton technique across all loading conditions—5-N load with 5-N tension (CS +11.5 ± 3.9 mm vs. DEB +1.3 ± 2.0 mm, $p = 0.0001$), 10-N load with 5-N tension (CS +13.4 ± 4.3 mm vs. DEB +1.7 ± 2.3 mm, $p = 0.0001$), 5-N load with 10-N tension (CS +9.2 ± 3.0 mm vs. DEB +1.7 ± 1.9 mm, $p = 0.0003$), and 10-N load with 10-N tension (CS +12.1 ± 3.1 mm vs. DEB +1.7 ± 2.2 mm, $p = 0.0001$) (Fig. 4 a, b).

SI translation increased after reconstruction with the CS technique across all loading conditions compared to intact (5 N/5 N 2.9 ± 1.2 to 7.3 ± 4.4 mm, $p = 0.019$; 10 N/5 N 4.8 ± 1.6 to 9.4 ± 4.4 mm, $p = 0.014$; 5 N/10 N 2.3 ± 1.0 to 7.3 ± 4.7 mm, $p = 0.014$; 10 N/10 N 4.0 ± 1.5 to 9.4 ± 4.6 mm, $p = 0.0099$), but decreased with the double endobutton technique for all but one loading condition (5 N/5 N 2.6 ± 1.1 to 1.3 ± 0.4 mm, $p = 0.031$; 10 N/5 N 4.1 ± 1.1 to 2.5 ± 0.5 mm, $p = 0.013$; 10 N/10 N 4.1 ± 1.1 to 2.5 ± 0.7 mm, $p = 0.023$). As such, the CS technique demonstrated a significantly greater increase in SI translation than the double endobutton technique across all loading conditions—5-N translational load and 5-N tension (CS +4.4 ± 4.1 mm vs. DEB −1.3 ± 1.3 mm, $p = 0.0086$), 10-N load with 5-N tension (CS +4.6 ± 4.0 mm vs. DEB −1.7 ± 1.4 mm, $p = 0.0059$), 5-N load with 10-N tension (CS +5.0 ± 4.3 mm vs. DEB −1.0 ± 1.3 mm, $p = 0.0077$), and 10-N load with 10-N tension (CS +5.3 ± 4.3 mm vs. DEB −1.5 ± 1.5 mm, $p = 0.0044$) (Fig. 5a, b).

Load-to-failure testing

The double endobutton technique had a greater stiffness (DEB 41.3 ± 15.2 N/mm vs. CS 20.8 ± 6.0 N/mm, $p = 0.005$), yield load (DEB 190.6 ± 67.7 N vs. CS 107.5 ± 57.3 N, $p = 0.002$), ultimate load (DEB 448.4 ± 191.0 N vs. CS 226.9 ± 86.2 N, $p = 0.026$), and

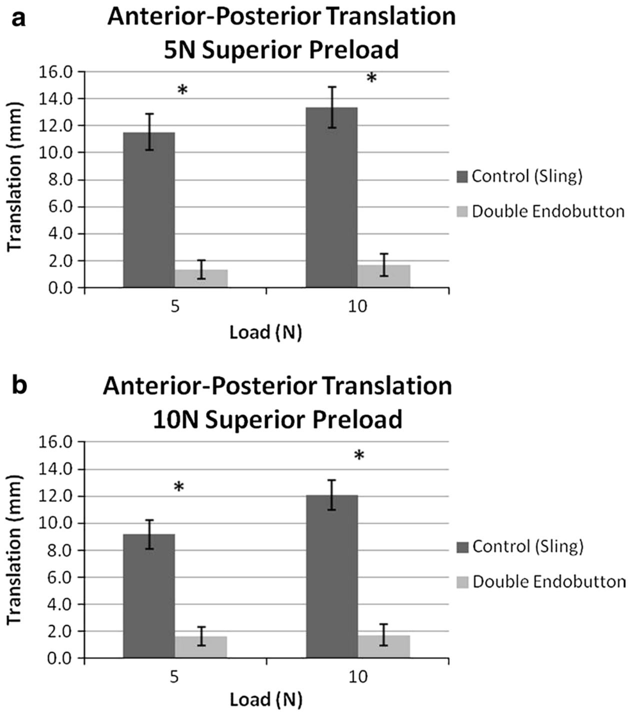

Fig. 4 Anterior–posterior translation with 5 N (**a**) and 10 N (**b**) of superiorly directed tension. *$p < 0.05$ control (coracoid sling) versus double endobutton

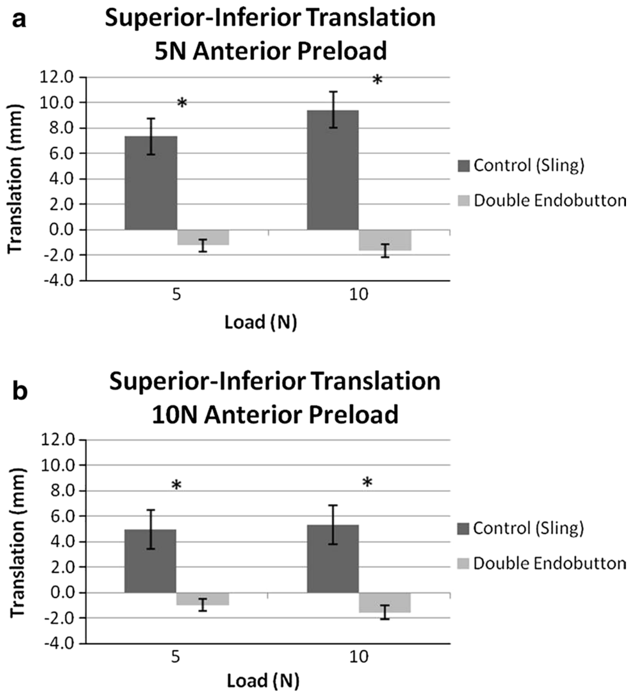

Fig. 5 Superior–inferior translation with 5 N (**a**) and 10 N (**b**) of anteriorly directed tension. *$p < 0.05$ control (coracoid sling) versus double endobutton

energy absorbed at yield load (DEB 3682.0 ± 2758.4 Nmm vs. CS 2634.0 ± 1994.5 Nmm, $p = 0.032$) when compared to the CS technique. Modes of failure for the double endobutton group all involved the coracoid, with five coracoid fractures and three coracoid pull-throughs. The failure of the CC sling was by tearing of the graft at the graft–suture interface along the superior aspect of the clavicle in all eight specimens.

Discussion

The double endobutton technique showed better biomechanical characteristics than the CS reconstruction by more closely restoring the translational value to the intact state. The double endobutton was also found to be stiffer and have higher yield and ultimate loads than the CS technique suggesting that the double endobutton technique may be less prone to failure than the CS technique.

In our study, AP translation increased from the intact condition for both the double endobutton construct and the CS. However, the amount of AP translation increased significantly less with the double endobutton than with the CS, presumably because the double endobutton technique utilizes drill holes in both the coracoid and clavicle that prevents the construct from migrating in the AP directions. Also, the lack of soft tissue structures such as the deltoid and trapezius muscle fibres, which are thought to act as dynamic stabilizers of the AC joint, were removed in this study, which may explain why we saw such large values in anterior posterior translation [13]. Further studies comparing the amount of AP translation to a construct addressing both the AC and CC ligaments could determine whether there is any statistically significant increase in AP translation in the double endobutton when compared to a repair technique that addresses both the AC joint and CC ligaments.

Superior–inferior translation increased from intact values with the CS repair but decreased with the double endobutton construct. The amount of SI translation was significantly less for the double endobutton technique when compared to the CS repair alone. This is consistent with previous studies that compare various suture fixation techniques with tissue grafts. Beitzal et al. [1] compared a CC reconstruction using an Arthrex GraftRope with a modified Weaver–Dunn technique and found that the GraftRope construct had significantly less superior translation than the intact shoulder, whereas the modified Weaver–Dunn group was not statistically significant from the intact group.

In this study, the double endobutton construct was shown to have an ultimate load in excess of the soft tissue construct. However, it failed to reach the ultimate load of the intact CC ligament (i.e., 500–725 N) as reported in the literature [4, 9, 15]. This was caused by endobutton–cortical–bone interface which distributed the force focally, causing the graft to fail by fracturing the coracoid process, and not at the substance of the endobutton CL construct. Traditional procedures such as the modified Weaver–Dunn have been shown to be much weaker than the native ligaments [1, 8, 22], which may explain the frequently observed loss of reduction that follows these types of procedures, and also highlight the need for a non-soft tissue or augmented soft tissue repairs that have been shown to be capable of withstanding the same forces as the native CC ligaments [1, 15, 22].

There remains an ongoing debate regarding the need to reconstruct the CC ligaments as a single bundle or as two individual bundles that replicate the native conoid and trapezoid ligamentous anatomy [1, 14, 23]. The CC ligaments consist of the individual conoid and trapezoid ligaments, which insert along different points of the clavicle providing a three-dimensional structure that some investigators have. The conoid ligament is the primary restraint to anterior and superior loading, while the trapezoid is a restraint to posterior loading [1]. Walz et al. [23] published a study in which the individual components of the CC ligament were reconstructed with two Arthrex tightropes. They found that the two tightrope techniques showed similar biomechanical properties when compared to the native ligaments in both the superior and anterior directions. Beitzal et al. [1] compared a single bundle technique using one tightrope with a double bundle technique using a double button twin tail tightrope and found no statistically significant differences between the two reconstructions for in both the superior and AP directions.

In selecting an appropriate repair construct, it was important to choose a material that could withstand the same forces that the native CC ligament withstands. Biomechanical studies have shown that the CC ligaments in isolation can withstand anywhere from 500 to 725 N [4, 9, 15], while the combined acromioclavicular joint and coracoclavicular ligament complex can withstand anywhere from 815 to 1,331 N [8, 22]. We determined that the endobutton CL was suited to withstand these high forces, as previous biomechanical knee studies have shown the endobutton CL can withstand anywhere from 1,086 to 1,365 N [11, 16].

Biomechanical studies of this nature have limitations with regard to their application to clinical cases. The shoulder is a complex joint with many different directional forces and muscle attachments that were not accounted for in this cadaveric study. The weight of the arm places constant deforming force on the fixation construct during biologic healing. Cadaveric studies are done with all soft tissue removed and fail to account for the many deforming forces placed on the reconstruction by the shoulder and arm. The specimens in this study are also tested at a “time zero point” which would be analogous to applying forces to a patient directly following surgery, before adequate time is given to allow for soft tissue healing and graft or construct incorporation into the bone and surrounding tissues. This lack of healing response may significantly alter the strength of the constructs and may account for discrepancies in a clinical setting.

Despite these limitations, this study provides clear biomechanical data to support the use of this reconstruction technique when addressing AC–CC injuries. Further clinical studies are warranted to assess clinical outcomes.

Conclusion

The double endobutton technique better restored native AC–CC translation than the CC sling. The double endobutton underwent significantly less translation than CC sling in all directions. SI translation increased from intact with the CC sling but decreased with double endobutton. The double endobutton technique also had a significantly greater stiffness, yield load, energy absorbed at yield load, and ultimate load when compared to the CC sling.

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