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REVIEW

Current Biomechanical Concepts of Suture Bridge Repair Technique for Rotator Cuff Tear

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ABSTRACT

Rotator cuff tears are one of the most common disorders of the shoulder and can have significant effects on daily activities as a result of pain, loss of motion and strength. The goal of rotator cuff repair is aimed at anatomic restoration of the rotator cuff tendon to reduce pain and improve the joint function. Recently, arthroscopic repair has been widely accepted for treatment of rotator cuff tears due to its equal or better results than those from open repair. In 2006, a transosseous-equivalent (TOE) or "suture bridge" technique was introduced by Park et al. This technique maximizes the utility of the conventional double-row technique by using the suture limbs to form the media mattress sutures to bridge and compress the repaired tendon. This technique has been proven to provide biomechanical properties that are superior to other arthroscopic repair techniques regarding the initial fixation strength, contact area and contact pressure at the tendon-bone interface. Since suture bridge techniques have been evolving over time, further biomechanical investigations have been carried out. These studies include examination of the effects of dynamic humeral external rotation on the mechanic stability of the repaired tendon construct, the effects of various modifications of the suture bridge configurations on the biomechanical characteristics of the medial mattress suture, biomechanical implications of medial row failure, and biomechanical performance of the repaired constructs over time. In this review, the biomechanical concepts behind the suture bridge technique for rotator cuff repair were reviewed and discussed.

Key words: Suture bridge; Rotator cuff repair; Contact pressure; Contact area; Biomechanics; Transosseous-equivalent

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INTRODUCTION

Rotator cuff tears are identified as one of the most common disorders of the shoulder and can have significant effects on daily activities as a result of pain, loss of motion and strength in adults[1,2]. Although conservative treatment is regarded as first-line therapy for the majority of rotator cuff tears, surgical repair is indicated when non-operative treatment fails. The goal of rotator cuff repair is aimed at anatomic restoration of the rotator cuff tendon to reduce pain, improve joint function and prevent long-term consequences of rotator cuff arthropathy. The evolution of rotator cuff repair has progressed over the past decades. More recently, arthroscopic rotator cuff repair has become increasingly more popular due to the advancement of surgical instruments and increased surgical experience with arthroscopic techniques. Arthroscopic rotator cuff repair could provide a secure biomechanical construct, improve patient satisfaction, and decrease

postoperative complications. Arthroscopic techniques have evolved from a single-row, to a double-row, and finally, to a transosseous-equivalent/suture bridge repair. Although most studies have shown that maintaining rotator cuff repair integrity correlates with improved function and superior rotator cuff power postoperatively[3-5], high rates of healing failure and re-tears have been observed with ultrasound and magnetic resonance imaging after surgery[3,6]. A comparative study reported re-tear rates of 40% for single-row and 22.6% for double-row techniques at 6 months postoperatively (Figures 1 and 2)[7]. Another study reported that the suture bridge technique has been associated with a re-tear rate of 11% on MRI evaluation at a median of 14.6 months, and the rate increases with larger tear size and older age, among other factors (Figure 3)[8,9]. The percentage of revision surgeries has been reported to be as high as 30% for isolated supraspinatus tendon tears and 90% for large to massive tears[10-13]. This suggests that advances in repair techniques are needed to optimize the healing environment after repair in order to facilitate restoration of function. Numerous researches have reported that an ideal rotator cuff repair would have higher initial fixation strength, as well as greater contact area and contact pressure at the tendon-bone interface[1,14,15]; it would also permit minimal gap formation and sustain mechanical stability until healing has been achieved[16]. Initial fixation strength is an essential consideration in optimizing rotator cuff constructs, and therefore, numerous biomechanical studies have focused on elucidating the strongest anchors, knots, and repair configurations for rotator cuff repair[17-26]. Arthroscopic repairs using a single-row technique involves passing sutures through the lateral aspect of the torn tendon and repairs the tendon to the footprint of the greater tuberosity. Biomechanical studies have uncovered potential problems with single-row repair. Specifically, this repair has lower load to failure and restores only 67% of the rotator cuff footprint; in addition, the initial reports demonstrated that single-row construct did not adequately establish the medial-to-lateral footprint[1]. Double-row technique has a greater load to failure and a lower frequency of gap formation than single-row technique[12,27]. As a result, the double-row suture anchor technique was introduced, which uses two rows of suture anchors to maximize the contact area between the tendon and the tuberosity insertion footprint[10,11]. This double- row technique has been shown to increase the footprint contact area, distribute the stress over multiple fixation points, and would theoretically improve the ability of the tendon to heal to bone. A transosseous-equivalent (TOE) or "suture-bridge" configuration was developed by Park *et al* in 2006[13] to maximize the utility of the double-row technique by using the suture limbs to form the medial mattress sutures in order to to span and compress the repaired tendon. Several studies have reported that the suture bridge technique resulted in comparable patient satisfaction, functional outcome, and rate of re-tear; the technique also tended to be better in preserving the cuff tissue repaired to the footprint of the rotator cuff than the single-row technique. The suture bridge technique involves using the medial row of anchors placed at the humeral articular cartilage margin and tying the sutures in a mattress fashion ideally 10 to 12 mm medial to the lateral edge of the torn tendon to secure the cuff tissue. The free ends of the medial suture limbs are preserved and bridged laterally over the bursal surface of the remaining cuff tissue. A suture limb from each medial anchor is fastened with lateral row anchors to compress the repaired tendon. The lateral row anchors are placed 1 cm distal to the lateral edge of the tuberosity in order to create downward pressure and restore the rotator cuff footprint. One or two lateral row anchors can be used depending on the size of the tear. Various knotless suture anchors have been developed for lateral row fixation. The major

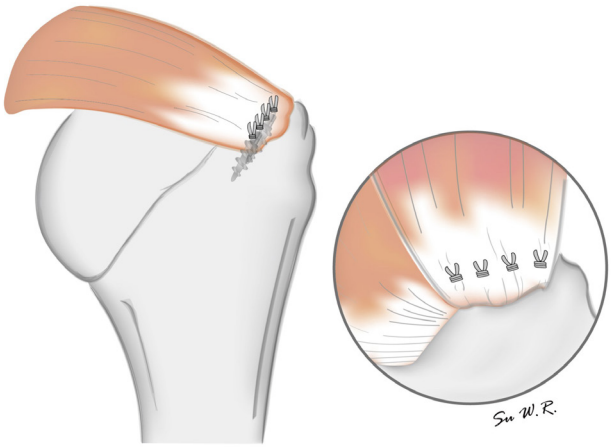

Figure 1 Single-row suture technique.

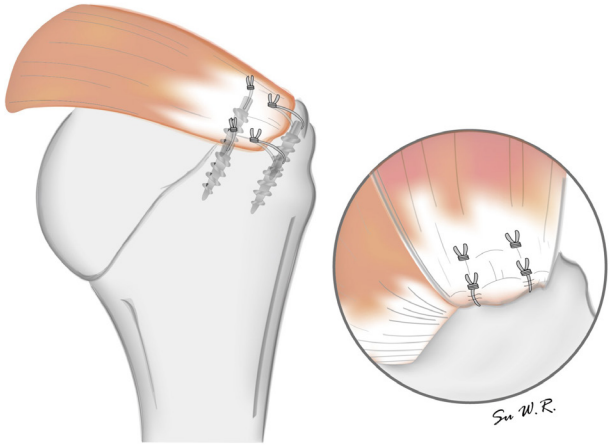

Figure 2 Double-row suture technique.

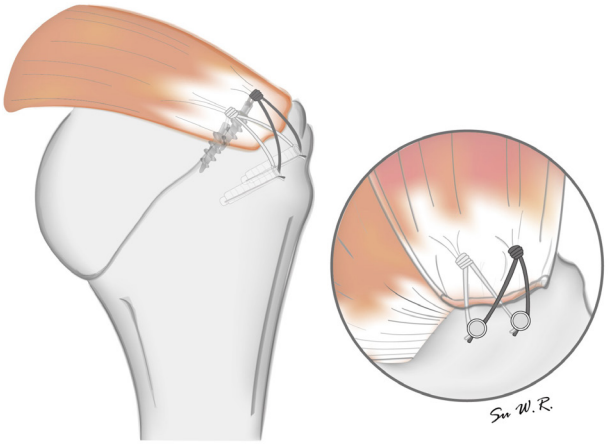

Figure 3 Suture bridge technique.

differences between the suture bridge fixation and conventional double-row fixation techniques are the presence of the suture bridge over the tendon and the more distal fixation points for the lateral row. The suture bridge is correlated with the interconnection between fixation points, which connects the medial and lateral rows, as well as the anterior-posterior rows, allowing a steady and homogenous pressure distribution throughout the entire footprint[13]; this is in contrast to the double-row construct that is based on separate fixation

points. In addition, the suture-bridge technique provides a better compression vector by placing the lateral row of anchors orthogonal to the rotator cuff-loading vector; a compression vector over the tendon is created to increase pressure at the footprint. This greatly increases the contact pressure along the repaired tendon in the suture-bridge repair compared to the double-row repair. These biomechanical advantages of the suture-bridge repair would lead to a higher healing potential between the repaired tendon and tuberosity. In addition, the suture-bridge technique has advantages over double-row repair in that it may allow quick and firm fastening of the compromised tendon with reduced surgical steps and also reduce the likelihood of knot impingement in the subacromial space. In this review, the biomechanical concepts behind current suture bridge techniques for rotator cuff repair will be reviewed and discussed.

BIOMECHANICAL CHARACTERISTICS OF SUTURE BRIDGE REPAIR TECHNIQUES

In biomechanical studies, the suture-bridge technique has been described as being more effective for obtaining high initial fixation strength and increasing the contact area and the contact pressure at the tendon footprint interface compared to the former techniques[14,15,23,28]. Park *et al* compared the contact characteristics between a 4-strand suture bridge, a 2-strand suture bridge and a standard double-row repair using a pressure-sensitive film placed at the tendon-footprint interface. The mean contact area for the 4-suture bridge, 2-suture bridge, and double-row was 124.2 mm^2, 99.7 mm^2, and 63.3 mm^2, respectively. The mean interface pressure exerted by the 4-suture bridge, 2-suture bridge, and double-row was 0.27 MPa, 0.22 MPa, and 0.19 MPa, respectively. The 4-suture bridge group clearly had the best contact area and pressure over the footprint compared with the other 2 groups. The authors also compared the initial biomechanical properties between the suture bridge rotator cuff repair and conventional double-row repair[14]. They reported that the ultimate load to failure was significantly higher in the suture bridge group (443N) compared with the double-row group (229 N). However, gap formation and stiffness were not found to be significantly different between the two groups[15].

EFFECTS OF DYNAMIC HUMERAL ROTATION ON THE REPAIRED TENDON CONSTRUCT

Traditional rehabilitation following rotator cuff repair has emphasized early passive motion of the shoulder to prevent excessive stiffness. However, excessive rotation can cause tendon motion at the tendon-bone interface which may influence the biomechanics of different repair techniques and result in a compromised healing process of the repaired tendon. Park *et al* also established a supraspinatus loading model which allows cyclic dynamic external rotation of the humerus in order to quantity the effects of external rotation at a repaired rotator cuff footprint[29]. The authors compared a suture bridge construct with a conventional double-row construct. They reported that the suture bridge construct had a significantly higher yield load than the double-row construct but that there was no overall significant difference in gap formation, stiffness, ultimate failure load, and energy absorbed to failure between constructs. However, the authors did find that external rotation produced greater gap formation and tendon strain at the anterior region of the suture bridge construct compared with the posterior repaired footprint (1.62 mm and 0.68 mm, respectively), but this was not observed in the double-row construct. The authors assumed that this might be attributable to the placement of the anchor; in the double-row construct, there is an anchor placed directly at the anterolateral edge of the footprint, while the anterolateral anchor for the suture bridge construct is placed further distal-lateral. This study also highlights the possible need for reinforcing anterior fixation with the suture bridge construct and limiting external rotation postoperatively[30]. In response, Garcia *et al*[31] conducted a biomechanical comparison study to evaluate the potential benefit of adding an anterior augmentation anchor to the standard suture bridge construct by using a dynamic humeral external rotational model. The authors reported that there was a decrease in anterior gap in the augmentation repair group compared with the standard suture bridge group. However, there were no significant biomechanical advantages with the addition of an anterior suture augmentation for a standard suture bridge construct regarding stiffness, yield load and ultimate failure load between the two groups[31].

BIOMECHANICAL CHARACTERISTICS OF MEDIAL MATTRESS SUTURE ON SUTURE BRIDGE CONFIGURATIONS

Many studies have addressed an issue regarding whether tying of the medial-row sutures provides additional stability after a suture bridge rotator cuff repair[32-34]. A systematic review by Mall *et al* indicated that most authors reported that the biomechanical properties in terms of ultimate failure load, stiffness, gap formation, and contact area are significantly improved when medial knots are tied as part of a suture bridge construct when comparing with knotless constructs[35]. These studies indicated that the medial horizontal mattress stitches are biomechanically recommended for suture bridge repair of rotator cuff tendons. To address the importance of the medial row knots in a suture bridge configuration, different suture bridge configurations of the medial row have been introduced. Pauly *et al*[36] conducted a biomechanical comparison of four different suture bridge configurations, each of which differ by modifying the medial row suture grasping configuration (i.e. single-mattress, double-mattress, cross-stitch and double-pulley techniques). The authors reported that modification with the double mattress technique has significantly better biomechanical construct stability and higher resistance to suture cutting through the repaired tendon. Maguire *et al*[37] also evaluated the biomechanical properties of four variants of the suture bridge repair via modifications of medial row stitches (i.e. knotted standard suture bridge, knotted double suture bridge, untied suture bridge with medial anchor screw, and untied suture bridge with PushLock screw (Arthrex)). The authors found that the knotted double suture bridge technique has the greatest failure load, highest footprint contact area and least gap formation compared to the other techniques; these findings also demonstrate compatible results with that of Pauly's study. The superior biomechanical properties of the quadruple knotted double suture bridge construct may be related to the utilization of all four mattress stitches medially across tendon repairs which results in a more equal distribution of the tensile load and provision of a more secure grasping of the tendon.

BIOMECHANICAL IMPLICATIONS ON FAILURE OF THE MEDIAL ROW

However, many recent studies have reported that failure of repaired rotator cuff tendons along the medial row of horizontal mattress stitches have developed after arthroscopic double-row repair[38] and

suture-bridge repair[39]. Based on a study of finite element analysis, stress concentration occurs around the medial suture-tendon interface in the double-row repair model[40]. Furthermore, tensile testing has shown that specimens fail primarily at the suture–tendon interface of the medial row of horizontal mattress stitches, with mattress sutures pulling through the tendon medial to the repair site[21,28]. These clinical and biomechanical studies suggest that horizontal mattress stitches on the medial-row suture anchors can be a risk factor for medial cuff failure after arthroscopic rotator cuff repair, even though these sutures improve biomechanical properties of the repaired tendon. Despite the controversy of the medial row of sutures, the contribution of bite size at the medial mattress stitch is not well understood. Tamboli *et al*[41] investigated the effects of bite size at the horizontal mattress stitch on the biomechanical factors of the repaired construct. The results showed that a 4-mm bite secured the tendon more tightly, whereas a 10-mm bite had greater ultimate strength. The authors concluded that for suture-bridge rotator cuff repair, large stitches are beneficial since the repaired construct would have greater strength to prevent the suture from pulling through the tendon.

BIOMECHANICAL PERFORMANCE OF THE REPAIRED CONSTRUCTS OVER TIME

Although the suture bridge technique has been proven to provide superior fixation strength initially, further studies have been done regarding the suture loosening over time, which may compromise the repaired cuff construct. There are many possible causes of the suture loosening after immediate suture fixation, such as tightening of the mattress at the medial row, slippage of the suture at the lateral screw-bone interface, creep of the suture, or creep of the tendon tissue, due to the viscoelastic properties of the repaired construct. Mazzocca *et al*[42] conducted a biomechanical evaluation to look at different repair constructs over time. The authors tested the single-row, double-row, suture bridge, and suture-chain suture bridge techniques. All repaired constructs had decreased footprint contact pressure, force, and area after 160 minutes; however, the suture bridge construct with medial knots had the highest contact pressure and force initially and persisted better over time. This study suggests that creep is a likely factor for suture bridge repairs. A recent study investigated the loosening of suture limbs after cycling the suture bridge constructs with the aim of simulating a real environmental dynamic loading condition after tendon repair. The study demonstrated that all suture limb loosening occurred after being cyclically loaded with 100 N for 1000 cycles. However, this did not affect lateral tendon stability which indicates that all suture limbs retained most of their tension achieved during the initial tying fixation[43].

Biomechanical studies are limited in that these are only time zero characteristics, yet the healing of repaired rotator cuff tendon is likely associated with a combination of biomechanical and biological factors. Although biomechanical studies can test some of the factors that may improve the likelihood of tendon-to-bone healing, there are many other factors that cannot be tested.

CONCLUSION

The goal of rotator cuff repair is to achieve high initial fixation strength, reduce gap formation, maintain mechanical stability during cyclic loading, and optimize the biological environment for healing. In this review, the biomechanical properties of the suture bridge technique for rotator cuff repair was analyzed, and confirmation was obtained regarding mechanical improvement in the repaired construct in terms of the initial fixation strength, contact area and contact pressure at the tendon-bone interface. However, there was no conclusive evidence demonstrating that improved biomechanical properties would necessarily lead to integrity of the repaired tendon at the time of follow-up in clinical studies. Further clinical studies are required to determine whether or not these biomechanical results would translate into better clinical outcome.

CONFLICT OF INTERESTS

There are no conflicts of interest with regard to the present study.

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