Review Article

# Fixation of Soft Tissue to Bone: Techniques and Fundamentals

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## Abstract

A myriad of orthopaedic injuries require surgical fixation of torn connective tissue to an osseous insertion site with either direct repair or reconstruction with a soft-tissue graft. Numerous factors influence the strength of a soft–tissue-to-bone fixation construct, including tissue quality, implant strength, contact area and pressure, and tensioning. Each fixation technique differs with respect to biologic integration, biomechanical stability, and failure mechanism. Fixation methods may or may not require an implant, such as interference screws, staples, internal buttons, transfixion pins, or suture anchors. Understanding the optimal method of soft-tissue fixation for a given scenario is crucial for successful repair or reconstruction.

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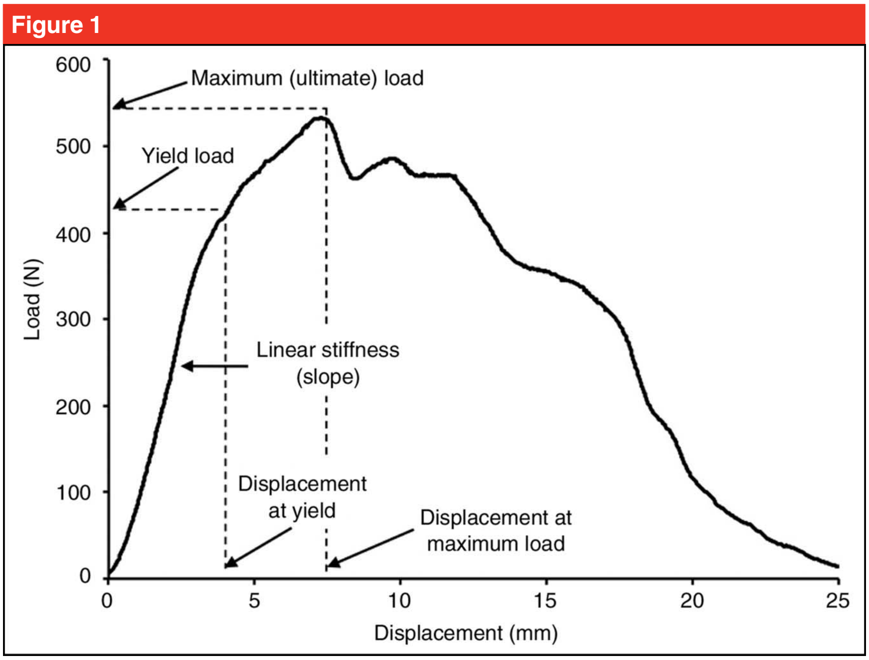
Surgical fixation of torn connective tissue to its bony insertion site using direct repair or reconstruction with a soft-tissue graft is required for management of many orthopaedic injuries. Several factors contribute to the underlying strength of a soft–tissue-to-bone fixation construct, including tissue quality; vascularity; contact area and pressure; tensioning; and implant properties, including material, size, and strength. The goals of fixation are to provide "time-zero" strength (ie, time at initial fixation) to the construct to allow early rehabilitation, to maximize the contact area to facilitate biologic incorporation, and to restore anatomic insertional anatomy. Therefore, failure of fixation is a dichotomy that involves either time-zero mechanical failure, in which fixation is inadequate for an early catastrophic loading event (eg, a fall), or chronic biologic failure, in which healing fails to match the pace at which mechanical fixation weakens under the repetitive stresses of rehabilitation.

Much more is known about the biomechanics of fixation methods than about their clinical consequences, and the two are not always correlated. For some clinical applications, the load-bearing requirement of the repair construct is frequently lower than that afforded by the fixation technique. Thus, novel implants may be of questionable use for procedures with low failure rates. In addition, some anatomic locations, surgical techniques, and exposures may lend themselves to certain fixation methods. Because of climbing healthcare costs, surgeons must consider not only biomechanics, but also the costs associated with an implant relative to potentially equivalent, less costly, and/or implant-free methods.

## Principles

Common biomechanical parameters used to evaluate tendon or ligament constructs include ultimate failure load, yield load, stiffness, displacement, gap formation, and mode of failure[1] (Figures 1 and 2). Two basic methods are used to test

**Figure 1**



Graph demonstrating typical load displacement in a load-to-failure test. The structural properties of a tendon or ligament fixation construct, such as linear stiffness and displacement at yield, can be ascertained from the curve.

biomechanical parameters: prefailure cyclic loading and load-to-failure testing. The former evaluates cumulative microdamage, whereas the latter determines the maximum sustainable force of a construct. Loading orientation, experimental setup, specimen age, and tendon quality are among the challenges to optimal re-creation of the clinical scenario during biomechanical testing. In vitro studies are limited to describing initial rather than long-term in vivo biomechanics. For instance, some constructs are predisposed to gap formation and thus may preclude biologic healing even if they have better time-zero load to failure.[2] In addition, if one fixation device is weaker than another in laboratory testing, but both exceed the clinical requirement for adequate fixation, then such biomechanical comparisons may not be clinically relevant. In general, anatomic graft placement supersedes fixation methodology because nonanatomic repair can subject the tissue to supraphysiologic stress and precipitate clinical failure.[3]

## Fixation Types

Soft–tissue-to-bone fixation constructs can be classified as compression or suspension[4] (Figures 3 and 4). Compression fixation constitutes aperture fixation, which secures the tendon at its point of osseous insertion, whereas suspension fixation requires fixation distant from the actual insertion site.[4] In compression fixation, the orientation of force is transverse to the longitudinal axis of the tendon, and loads are distributed among the bone-screw-tendon interfaces.[4] In suspension techniques, fixation can be suspended from a cortical periosteal surface, a cortical endosteal surface, cancellous bone, or a combination of cortical and cancellous bone. Suspensory fixation may result in tunnel expansion secondary to the windshield-wiper effect in 50% to 100% of cases of anterior cruciate ligament (ACL) reconstruction.[5] The clinical significance of tunnel expansion is unclear. Some authors argue that (1) excessive shearing motion impedes biologic incorporation, (2) bone loss related to tunnel expansion complicates revision surgery, or (3) tunnel expansion is of no consequence.[1]

## Biology of Fixation and Healing

The site of tendon or ligament insertion onto bone is known as the enthesis. Re-creation of this structure relies on adequate biologic healing afforded by adequate initial fixation. The healing pattern associated with direct soft–tissue-to-bone repair, such as rotator cuff repair (RCR), is different from that associated with fixation within bone tunnels, as in ACL reconstruction.[6] The process of tendon healing within osseous tunnels includes the following: at 2 weeks, disorganized inflammatory tissue; at 4

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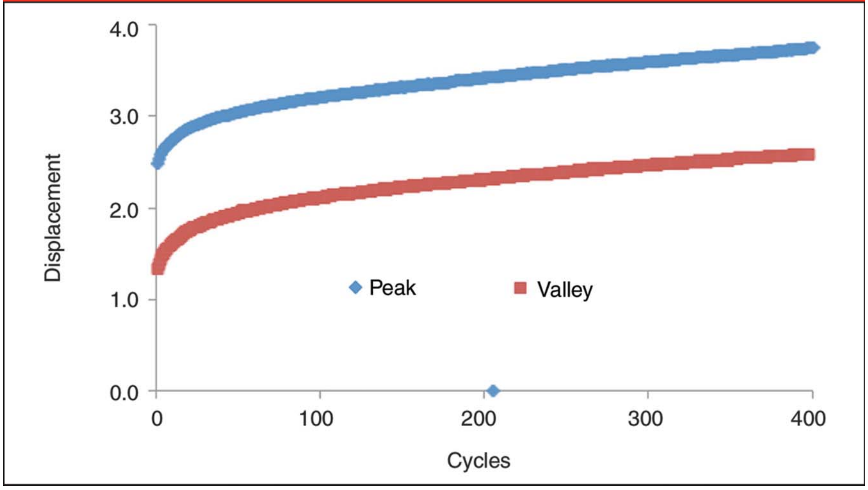
weeks, formation of fibroblast-rich connective tissue matrix; and at 6 weeks, increased type II collagen without complete reformation of the native enthesis.[7] The entire process plateaus at approximately 6 months. With direct repair and despite healing, a discrete margin remains between the tendon and the bone without restoration of the bridging collagen Sharpey fibers or a mineral gradient.[8] At 6 to 14 months, ACL reconstructions performed with suspensory fixation exhibit granulation tissue and extensive new, irregular woven bone without collagen fiber ingrowth between the tendon and the osseous insertion.[9] In contrast, aperture interference fixation yields metaplastic fibrous cartilage with fibers bridging the tendon-bone interface.[9] In a sheep model of ACL reconstruction, interference fixation of an autologous Achilles tendon graft yielded a broad, direct ligamentous insertion with a regular transition zone at 24 weeks.[10]

**Figure 2**



Plot graph demonstrating displacement versus cycle number, which depicts creep response during cyclic testing between two constant load levels. The two individual curves represent the peak and valley displacements corresponding to the peak and valley forces, respectively, at each cycle.

## Fixation Methods

### Transosseous Sutures

Transosseous sutures promote fixation through a direct tendon-bone compression vector resulting from suture tension[11] (Figure 5). In a bovine RCR model, transosseous sutures provided a greater footprint contact area and greater pressure than did suture anchors.[11] In a human cadaver study of distal biceps tendon repair, the failure load of transosseous sutures was similar to that of 2.4-mm suture anchors, lower than that of fixation with an EndoButton (Smith & Nephew), and higher than that of 5.0-mm suture anchors[12,13] (Table 1). Cortical bridge augmentation, using thick, plate-like absorbable poly-L/D-lactide membranes, improves the ultimate tensile strength of transosseous sutures.[25] Failure modes of this fixation technique include suture pullout,[13] breakage,[12,13] and tearing through the bone bridge.[12,13] Its advantages include the lack of an implant and the sole dependence of fixation strength on the strength of the suture and bone. This technique is appropriate for RCR, distal biceps repair, and tendon transfers about the shoulder (Figure 6).

### Looped Figure-of-8 Technique

Looped figure-of-8 techniques are typically used in ulnar collateral ligament reconstruction of the elbow. In a human cadaver study, the figure-of-8 method exhibited a lower failure load than did the docking technique and techniques that used an interference screw or EndoButton.[24] The figure-of-8 method allowed the greatest displacement and failed earliest during incremental cyclic loading.[24] The failure mode was suture pullout from the suture-graft interface. Some drawbacks to this technique are the larger exposure required, which necessitates a longer graft; nonanatomic placement of two tunnels with the soft-tissue attachment point between the two tunnels; and potential difficulty with graft tensioning.[24] The docking technique was introduced to address these concerns. Two drill holes in the ulna and a single medial epicondylar drill hole are used with fixation of the graft via sutures tied over a bone bridge. The ultimate fixation method is a suture, which is used to tie the graft back to itself. Advantages of this technique include the lack of an implant and the ability, with sufficient length, to double the graft.

### Pullout Button

Fixation with a pullout button is implant free; a suture is externally tied over a "shirt button" or nail plate button. In a cadaver study of distal fixation for an avulsion of the flexor digitorum profundus tendon, the pullout button had a higher failure load than did the suture anchor, but both devices had similar gap formation.[2] These parameters were dependent on the suture type, with braided polyester outperforming monofilament suture.[2] The failure mode was suture tearing at the button site.[2] Given the external attachment

**Figure 3**

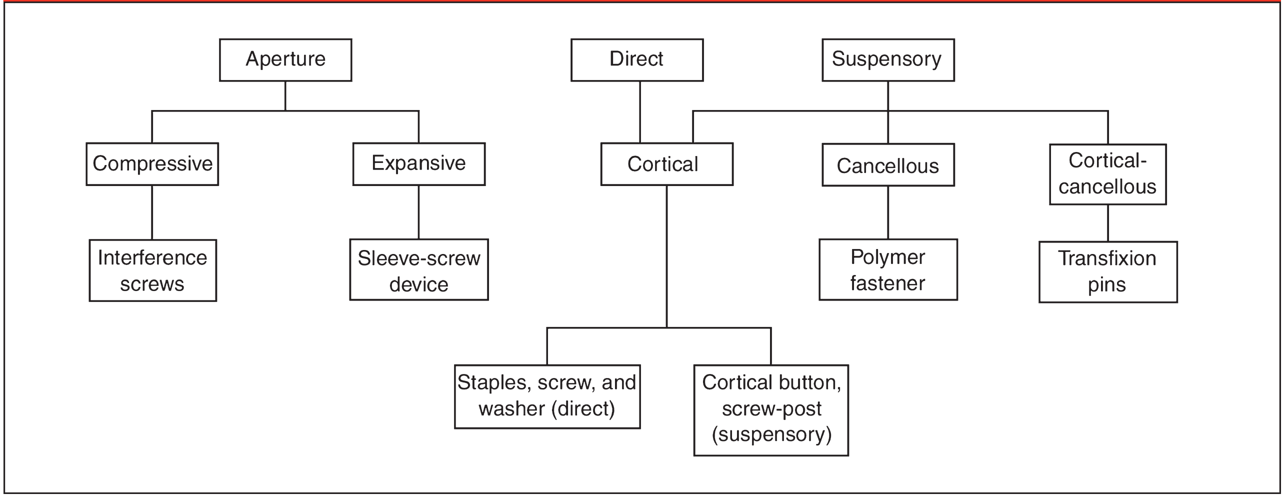
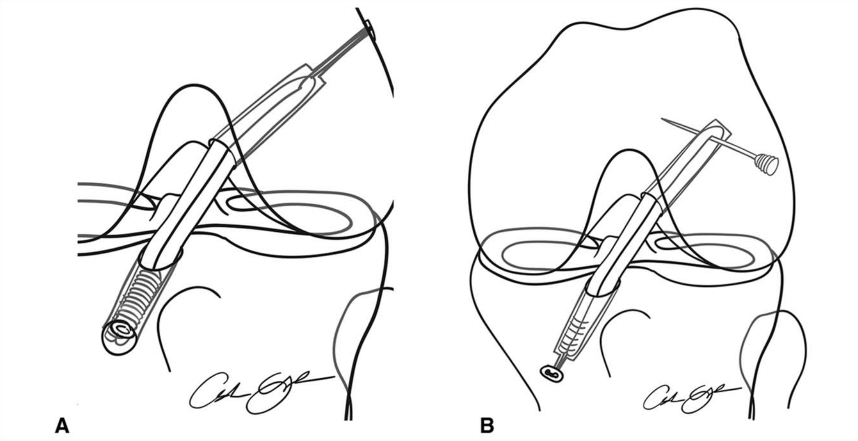


Illustration demonstrating the types of aperture and suspensory fixation mechanisms.

**Figure 4**



Illustrations of the knee joint demonstrating compression fixation of the tibial side and cortical suspension fixation of the femoral side (**A**) and cortical suspension fixation of the tibial side and cortical-cancellous suspension fixation of the femoral side (**B**), which are common fixation mechanisms used in anterior cruciate ligament reconstruction.

of the pullout button, complications include infection and button-related deformity or necrosis caused by pressure against soft tissues, which can be prevented by the use of interposed felt or cast material. However, these materials decrease construct stiffness. The primary advantages of this technique are that it allows precise tunnel placement and removal of all foreign material. This technique is appropriate for repair of the flexor digitorum profundus and pediatric tibialis tendon transfer.

## Interference Screw

Fixation with an interference screw is achieved by engaging the tendon with the screw threads and compressing it against the cortical bone or bone tunnel wall[14] (Figure 7). By anatomically affixing the tendon to bone near the joint line, interference screws improve joint stability. Interference fixation generates increased local pressure around the tendon-cancellous bone interface, which is thought to augment biologic healing.[10]

Determinants of interference screw fixation properties include material properties, geometry, core diameter, pitch or thread height, length, placement, and/or screw insertion torque along with the gap size and bone mineral density.[4,16,17] In an ACL reconstruction study that used a porcine model, metallic and bioabsorbable interference screws allowed greater cyclic elongation than did several expansion and suspension fixation devices.[4] Screw-tendon collinearity should be ensured because divergence can undermine strength and damage the tendon.[3] In patients with suboptimal screw purchase, hybrid fixation with a staple, spiked washer, or suture post used for backup may be considered.[1]

In a porcine model, purely cancellous fixation methods, such as interference fixation, and cortical suspensory devices that have a low contact surface area had the lowest ultimate failure loads.[4] Graft pullout was the most

**Figure 5**

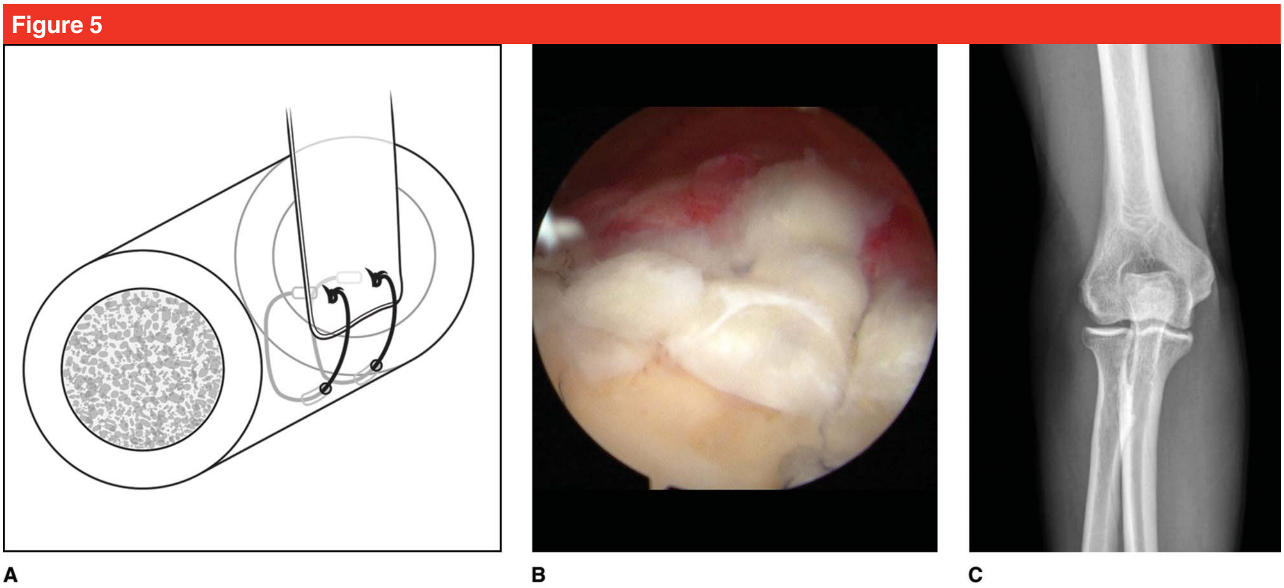


Illustration (**A**), arthroscopic image (**B**), and AP radiograph (**C**) of the elbow demonstrating fixation with radiolucent transosseous sutures.

common failure mode for cancellous fixation constructs, whereas all others failed secondary to implant material properties.[4] The primary failure mode of interference fixation is tendon pullout,[16,17] although other failure modes, including tendon slippage and laceration by the screw threads[16] and fatigue fracture during screw insertion,[20] have also been reported. Fixation with interference screws remains appropriate in many settings, including ACL and posterior cruciate ligament reconstruction, lateral ligament reconstruction of the ankle, proximal biceps tenodesis, and distal biceps repair.

## Staples

Like interference screws, fixation with staples is achieved through compression[14] (Figure 8). In a study of ACL reconstruction with several tibial fixation methods, staples had less fixation construct stiffness than did interference screws.[14] Staple fixation allowed greater displacement than did interference screws but had less displacement than did suture-post fixation, with all three methods exhibiting a similar yield. In another study, barbed staples afforded a lower failure load than did suture, screw and washer, and screw and plate constructs.[15] The most common modes of staple failure were pullout and soft-tissue tearing. High recurrent instability rates have been noted with staple fixation of the glenoid labrum, although this situation differs from ligamentous fixation in the knee because glenoid staples were nonmetallic and the failures were secondary to the implant itself, not the technique.[26] Complications associated with this fixation device include staple head-related pain and bursa formation.[15] Staples remain useful for ACL and medial collateral ligament reconstruction and are often used as a backup to suture-post fixation.

## Suture-post Technique

In this technique, suture is passed through the tendon and distally tied around a post or a staple. A variation is to use a screw with a washer positioned against the tendon, which augments stiffness through direct compression (Figure 9). The angle of screw insertion determines whether screw tightening causes increased or decreased tension within the tendon,[1] which can make tensioning challenging. The knot at the screw post theoretically limits the rigidity of tendon fixation.

In a study of the structural properties of several tibial fixation methods for ACL reconstruction, bovine tendons were used and, at 500 N of load, the suture-post technique had significantly greater construct slippage than did a screw-washer device and tandem plastic spiked washers; however, slippage was similar to that of double staples, interference screws, and spiked metal washers.[14] Similarly, the suture-post fixation construct had a markedly lower stiffness than constructs that used an interference screw, a screw-washer device, tandem washers, staples, or spiked metal washers. However, the tandem washer construct provided the highest yield load of all of the constructs. Overall, the authors concluded that, of the six methods evaluated in this biomechanical study,

**Table 1**

**Summary of Biomechanical Studies of Fixation Methods Categorized by Clinical Application**

| Study | Model; Tendon | Loading Protocol | Fixation Methods Compared (Product; Manufacturer) |
|---|---|---|---|
| **Anterior Cruciate Ligament Repair** | | | |
| Milano et al[4] | Porcine; ACL femoral fixation (doubled lateral extensor of toes) | Cyclic<br>(1,000 cyc at 30 cyc/min) | IS (BioScrew; Linvatec)<br>IS (RCI screw)<br>TFP (TransFix; Arthrex)<br>TFP (Bio-TransFix; Arthrex)<br>TFP (Rigidfix; DePuy Mitek)<br>CB |
| Kettler et al[12] | Human; distal biceps repair | Load-to-failure, linear (parallel) | TO<br>CB<br>SA (2.4-mm)<br>SA (5.0-mm) |
| Magen et al[14] | Bovine; ACL tibial fixation (gracilis or semitendinosus) | Cyclic<br>(frequency, duration not given) | IS<br>WL<br>SP<br>St<br>W<br>W-Ta |
| Robertson et al[15] | Human; femoral fixation of various tissues (tendinous tissue) | Cyclic<br>(5 cyc at 2 cyc/min) | St (barbed)<br>St (stone)<br>Suture techniques<br>Sc + W<br>Sc + Pl |
| Kousa et al[16] | Porcine; ACL femoral fixation (quadrupled semitendinosus-gracilis) | Cyclic (1,500 cyc at 30 cyc/min) and load-to-failure, linear (parallel) | CB<br>TFP<br>BMS<br>IS (SmartScrew; Bionx)<br>IS (BioScrew)<br>IS (RCI) |
| Ahmad et al[17] | Porcine; ACL femoral fixation (extensor digitorum communis) | Cyclic<br>(1,000 cyc at 60 cyc/min) | IS<br>CB<br>TFP (Rigidfix)<br>TFP (Bio-Transfix) |
| Steiner et al[18] | Human; ACL tibial and femoral fixation (semitendinosus-gracilis) | Load-to-failure | SP<br>W |
| **Rotator Cuff Repair** | | | |
| Klinger et al[13] | Bovine; infraspinatus repair | Load-to-failure, linear (orthogonal) | TO<br>SA |
| Salata et al[19] | Human; supraspinatus repair | Cyclic<br>(100 cyc at 1 mm/s) | TOE<br>TO<br>ATO |
| **Biceps Repair** | | | |
| Mazzocca et al[20] | Human; distal biceps repair | Cyclic<br>(3,600 cyc at 30 cyc/min) | TO<br>SA<br>IS<br>CB |
| Golish et al[21] | Human; subpectoral proximal biceps tenodesis | Cyclic<br>(100 cyc at 0.5 mm/s) | IS<br>SA |
| Spang et al[22] | Human; distal biceps repair | Cyclic<br>(1,000 cyc at 60 cyc/min) | CB<br>SA |
| Berlet et al[23] | Human; distal biceps repair | Cyclic (parallel)<br>(3,600 cyc at 60 cyc/min) | TO<br>SA (DePuy Mitek)<br>SA (Statak) |
| **Ulnar Collateral Ligament Reconstruction** | | | |
| Armstrong et al[24] | Human; UCL reconstruction (palmaris) | Cyclic (valgus)<br>(200 cyc at 30 cyc/min) | CB<br>IS<br>LFE |
| **Flexor Digitorum Profundus Repair** | | | |
| Latendresse et al[2] | Human; FDP repair | Cyclic<br>(500 cyc at 10 cyc/min) | PB<br>SA |

ACL = anterior cruciate ligament, ATO = arthroscopic transosseous sutures, BMS = Bone Mulch Screw, CB = cortical button, cyc = cycle, displ = displacement, elong = elongation, FDP = flexor digitorum profundus, IS = interference screw, LFE = looped figure-of-8 technique, max = maximum, PB = pullout button, Pl = plate, RCI = round cannulated interference, SA = suture anchor, Sc = screw, SP = suture-post, St = staples, TFP = transfixion pins, TO = transosseous sutures, TOE = transosseous-equivalent, UCL = ulnar collateral ligament, W = washer, WL = Washerloc, W-Ta = tandem washer

**Table 1 *(continued)***

**Summary of Biomechanical Studies of Fixation Methods Categorized by Clinical Application**

| Single-cycle Failure/Yield Load (N) | Cyclic Failure/Yield Load (N) | Stiffness (N/mm) | Elongation or Displacement (mm) |
|---|---|---|---|
| | 407.2 ± 145.4 | 121.4 ± 40.7 | 11.8 ± 5.83 (max) |
| | 392.5 ± 122.2 | 392.5 ± 122.2 | 8.62 ± 4.6 (max) |
| | 1,469.7 ± 315.5 | 206.7 ± 29.7 | 2.75 ± 1.45 (max) |
| | 1,491.6 ± 87.6 | 210.1 ± 67.9 | 2.62 ± 1.39 (max) |
| | 994.4 ± 233.6 | 138.4 ± 20.8 | 4.62 ± 1.13 (max) |
| | 850 ± 189.8 | 112.5 ± 9.7 | 4.19 ± 1.32 (max) |
| 210 ± 66 | | | |
| 270 ± 22 | | | |
| 134 ± 97 | | | |
| 57 ± 22 | | | |
| | 776 ± 155 | 476 ± 251 | 0.72 ± 0.42 (500 N) |
| | 821 ± 193 | 429 ± 269 | 0.81 ± 0.61 (500 N) |
| | 830 ± 187 | 70 ± 19 | 4.87 ± 1.59 (500 N) |
| | 705 ± 174 | 174 ± 92 | 3.31 ± 1.29 (500 N) |
| | 930 ± 323 | 192 ± 61 | 3.52 ± 2.14 (500 N) |
| | 1,375 ± 213 | 420 ± 180 | 1.23 ± 0.53 (500 N) |
| | 13.4 | | |
| | 4.5 | | |
| | 15.8 | | |
| | 39.8 | | |
| | 53.5 | | |
| 1086 ± 185 | 781 ± 252 | 79 ± 7.2 | |
| 868 ± 171 | 768 ± 253 | 77 ± 17 | |
| 1112 ± 295 | 925 ± 280 | 115 ± 28 | |
| 794 ± 152 | 842 ± 201 | 96 ± 20 | |
| 589 ± 204 | 565 ± 137 | 66 ± 28 | |
| 546 ± 174 | 534 ± 129 | 68 ± 15 | |
| | 539 ± 114 | | 3.06 ± 2.07 (100 cyc) |
| | 864 ± 164 | | 1.23 ± 0.98 (100 cyc) |
| | 737 ± 140 | | 5.04 ± 2.42 (100 cyc) |
| | 746 ± 119 | | 0.62 ± 0.50 (100 cyc) |
| 335 ± 87 | | 16 ± 16 | 26 ± 12 |
| 519 ± 165 | | 18 ± 5 | 20 ± 10 |
| 201.4 ± 14.4 | | 107.7 ± 6.5 | |
| 223.8 ± 15.2 | | 113.6 ± 7.9 | |
| | 558.4 ± 122.9 | 56.9 ± 11.8 | 5.9% ± 3.3% (elong); 5.10 ± 0.89 (displ) |
| | 325.3 ± 79.9 | 59.4 ± 7.0 | 13.7% ± 7.4% (elong); 6.67 ± 2.13 (displ) |
| | 291.7 ± 57.9 | 56.7 ± 16.1 | 14.3% ± 8.9% (elong); 8.19 ± 1.85 (displ) |
| | 310.7 | | 3.55 (3,600 cyc) |
| | 381.0 | | 2.33 (3,600 cyc) |
| | 232.0 | | 2.15 (3,600 cyc) |
| | 439.6 | | 3.42 (3,600 cyc) |
| | 169.6 ± 50.5 | 34.1 ± 9.0 | |
| | 68.5 ± 33.0 | 19.3 ± 10.5 | |
| | 274.8 ± 98.6 | 80.1 ± 29.6 | 2.58 ± 1.72 (1,000 cyc) |
| | 230.0 ± 86.5 | 72.1 ± 24.8 | 2.06 ± 0.71 (1,000 cyc) |
| | 307 ± 142 | 44 ± 10 | |
| | 220 ± 54 | 18 ± 4 | |
| | 187 ± 64 | 23 ± 5 | |
| | 52.5 ± 10.4 | | 1.7 ± 0.7 (20 N) |
| | 41.0 ± 16.0 | | 1.5 ± 1.0 (20 N) |
| | 33.3 ± 7.1 | | 3.0 ± 0.9 (20 N) |
| | 47.1 ± 4.51 | | 1.66 ± 1.67 |
| | 28.5 ± 4.03 | | 2.00 ± 0.36 |

ACL = anterior cruciate ligament, ATO = arthroscopic transosseous sutures, BMS = Bone Mulch Screw, CB = cortical button, cyc = cycle, displ = displacement, elong = elongation, FDP = flexor digitorum profundus, IS = interference screw, LFE = looped figure-of-8 technique, max = maximum, PB = pullout button, Pl = plate, RCI = round cannulated interference, SA = suture anchor, Sc = screw, SP = suture-post, St = staples, TFP = transfixion pins, TO = transosseous sutures, TOE = transosseous-equivalent, UCL = ulnar collateral ligament, W = washer, WL = Washerloc, W-Ta = tandem washer

**Figure 6**

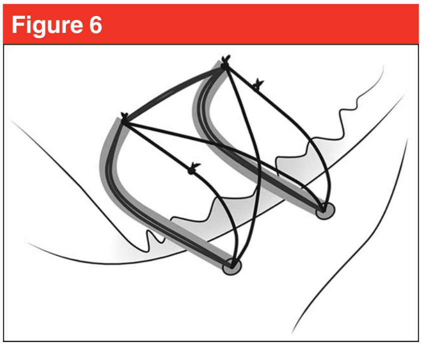


Illustration of a transosseous suture repair used for a rotator cuff tear.

the screw-washer device, tandem washers, and interference screws provided the most optimal fixation. Suture-post fixation failure is the result of suture-tendon stretching, post pullout, and suture rupture.[18] Conventional screws may require removal, although newer designs feature a lower profile and flatter head to avoid prominent instrumentation.[1] The suture-post is particularly relevant for backup fixation in ACL and medial collateral ligament reconstruction.

## Cortical Button

Implantable metal buttons that are placed either on the opposite cortical surface or in the medullary canal function similar to pullout buttons (Figure 10). They are available as fixed- or adjustable-length loop devices that are tightened intraoperatively. Fixed-length devices have demonstrated a higher failure load and lower cyclic displacement than have adjustable-length devices.[27] In a porcine femoral-side ACL reconstruction model, the yield load during cyclic loading was highest for the EndoButton CL, Bone Mulch Screw (Arthrotek), RigidFix (DePuy Mitek), and SmartScrew ACL (Bionx), followed by the BioScrew (Linvatec) and a titanium interference screw.[16] The EndoButton had the lowest stiffness.

In a human cadaver study of distal biceps tenodesis, all fixation techniques provided comparable stiffness, but the EndoButton had a higher failure load during cyclic loading than did the suture anchor, transosseous tunnel, and interference screw.[20] In another study that used a similar model, EndoButton fixation provided greater stiffness during cyclic loading but had a similar ultimate tensile load and final displacement relative to suture anchors.[22] The EndoButton effectively resists displacement because it is cortically anchored.[17] Residual displacement is likely the result of deformation of the continuous polyester loop.[16] Because resistance vectors are oriented toward the cortex-implant interface, the load concentration is inversely proportional to the implant contact surface area.[4] As a result, the failure load and stiffness increase with the implant diameter and number of contact points. Failure modes include the button pulling through bone,[17] implant migration and breakdown,[4] and tearing of the tendon loop or continuous polyester loop.[16] This technique remains an option for ACL reconstruction, proximal biceps tenodesis, distal biceps repair, pectoralis tendon repair, syndesmotic fixation, and acromioclavicular reconstruction.

## Transfixion Pins

These devices achieve fixation via cross-pins that traverse the bone tunnel[17] (Figure 4, B). In ACL reconstruction, the pins either skewer the four-strand graft, or are encircled by the two-strand graft to establish a quadrupled graft.[17] Transfixion devices facilitate independent tensioning.[1] Fixation properties depend on the press-fit of the tendon and pin placement, which, if errant, unevenly distributes loads across the bone-tendon interface.[4] In a study that used a porcine model to examine the mechanical properties of several femoral fixation devices, the failure load was lower for the interference screw than for the Rigidfix, Bio-Transfix, and EndoButton, whereas slippage was highest with the Rigidfix device.[17] In an animal model, cross-pins had the highest failure loads and stiffness among all compression, expansion, and suspension fixation devices tested.[4] Transfixion pins fail secondary to cross-pin breakage,[17] tendon slippage, and partial tearing.[16] Metallic and bioabsorbable pins tend to fail secondary to implant migration and breakdown, respectively.[4] Residual displacement is likely the result of progressive pin deformation.[16] Risks associated with the use of transfixion pins include pin migration, pin-related irritation, and potential neurovascular injury at the insertion site. Transfixion devices are appropriate for ACL reconstruction.

## Suture Anchors

Suture anchors, most of which essentially function as hollow headless screws that are preloaded with suture through an eyelet at the base, allow tendon fixation at the cortical surface (Figure 11). They are now available in radiolucent materials, including polyetheretherketone and other biocomposite polymers (eg, partially composed of β-tricalcium phosphate, hyaluronic acid), and ultra-high–molecular-weight polyethylene.[28]

Suture anchor design has rapidly evolved. Some biocomposite anchors, such as those containing β-tricalcium phosphate, promote osteoconductivity.[28] A distal crossbar eyelet facilitates the use of double- or triple-loaded anchors.[28] Suture-based anchors possess a narrow sleeve with suture woven into or passed through the sleeve.[28] Anchor thread design has also evolved to include fully threaded constructs that allow simultaneous cortical-cancellous fixation. In addition, the interface between the anchor and the insertion handle has been modified to better

**Figure 7**

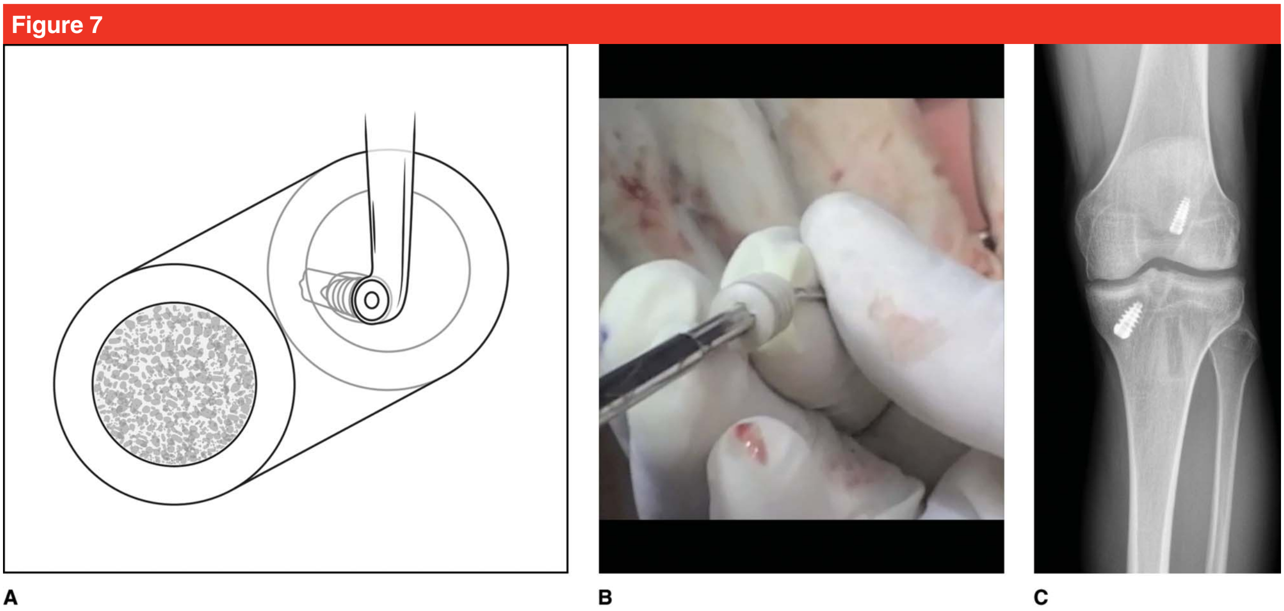


Illustration (**A**), clinical photograph (**B**), and AP radiograph (**C**) of the knee demonstrating fixation with interference screws.

prevent anchor breakage caused by high-torque insertion into hard bone. Knotless anchors eliminate a potentially irritating knot, and recent designs allow direct implant insertion (without the need for punching, tapping, or predrilling) with the use of a self-embedding tip as well as independent fine-tuning and tensioning of individual sutures. Open-architecture anchors abolish the traditional solid core, possibly facilitating interdigitation of the bone with anchor threads for secure fixation. Anchor placement also plays a role in fixation characteristics; for example, in the transosseous-equivalent suture-bridge (TOE/SB) technique, two rows of anchors enhance tendon-to-bone compression and achieve footprint restoration in RCR.[29]

Suture anchors produce tension throughout the tendon-bone interface.[11] The size and placement of the implant in cortical or cancellous bone determine fixation strength.[30] Screw-type anchors generally confer stronger fixation than do punch-in anchors, although the latter have more varied insertion methods, such as transtissue and suture-first insertion.[30] Compared with fixation using knotted anchors, knotless anchor fixation provides comparable strength and displacement.[28] In a human cadaver RCR model, TOE/SB repair demonstrated a higher failure load than did traditional transosseous sutures and arthroscopic transosseous sutures using a simple or X-box

**Figure 8**

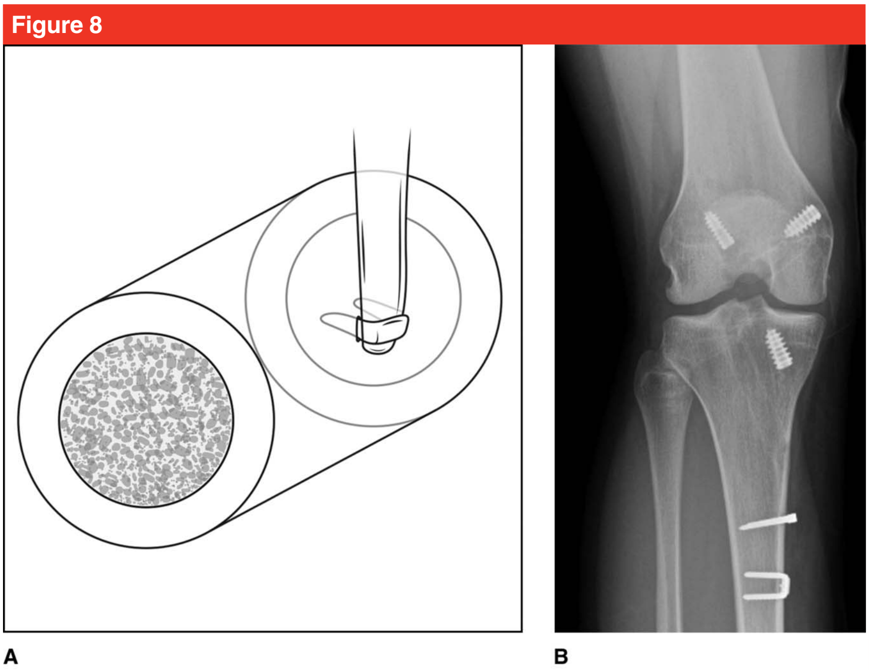


Illustration (**A**) and AP radiograph (**B**) of the knee demonstrating fixation of soft tissue to bone with staples.

**Figure 9**

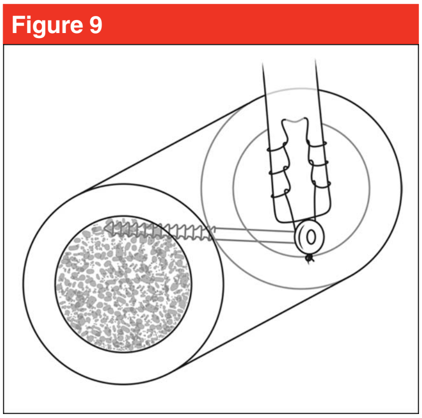
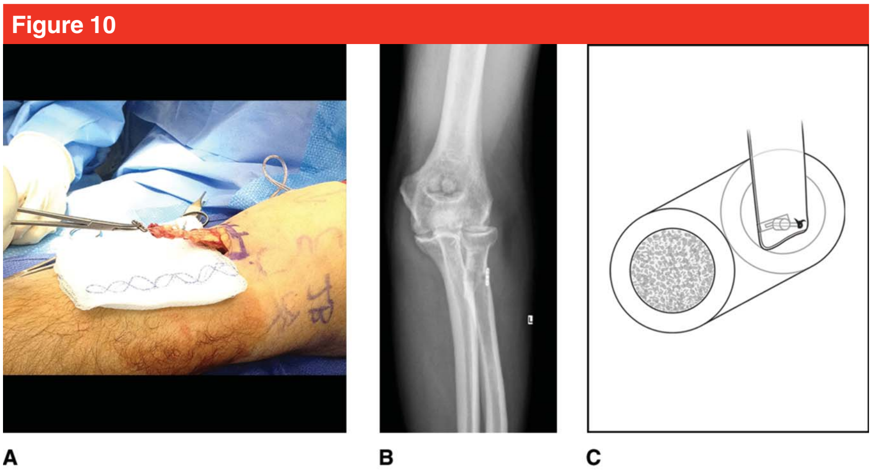


Illustration demonstrating suture-post fixation with a screw and washer placed against the tendon to augment stiffness.

**Figure 10**



**A,** Clinical photograph of a cortical button. **B,** AP radiograph of the elbow demonstrating fixation with a cortical button. **C,** Illustration of a cortical button placed on the opposite cortex.

suture configuration.[19] Stiffness and cyclic elongation were similar across the techniques.

Modern suture anchor constructs typically fail at the tissue-suture interface[30] because of knot breakage or suture pulling through the tendon,[13] although failure patterns differ by anatomic location.[28] Knotless anchors fail secondary to suture slippage around the anchor, whereas bioabsorbable anchors can fail secondary to eyelet breakage.[30] The type of suture material also influences the failure mode.[30] The use of ultra-high–molecular-weight polyethylene suture predisposes metal and bioabsorbable anchors to fail through anchor and eyelet pullout, respectively, rather than through suture failure.[31]

## Clinical Applications

Although these techniques have a wide variety of clinical applications in all orthopaedic surgery subspecialties, several of the more common clinical applications include ACL reconstruction, RCR, proximal biceps tenodesis, and distal biceps repair. Surgeons should be aware of all the surgical options available to develop new procedures and have more tools for reconstruction when primary techniques fail.

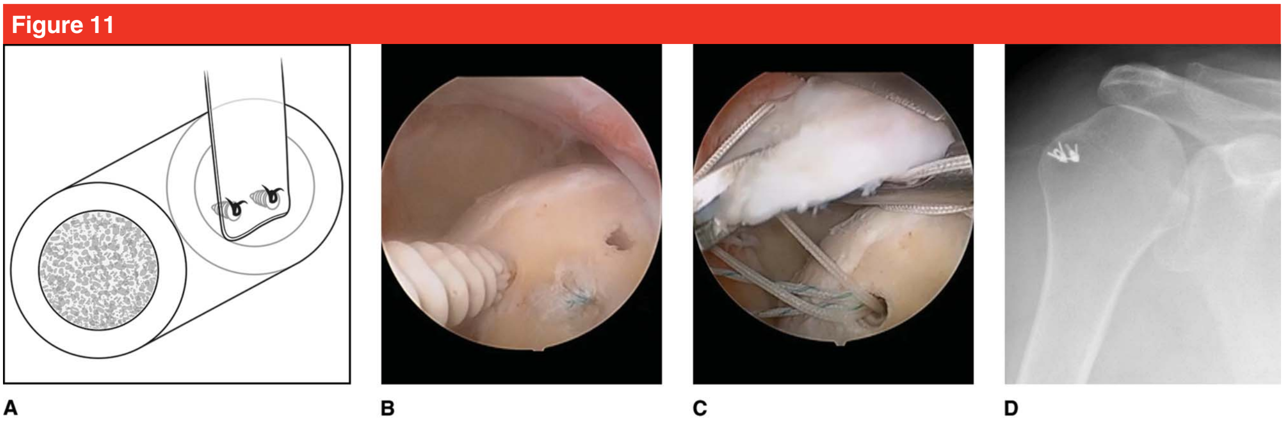
### ACL Reconstruction

ACL reconstruction is perhaps the most widely studied bone-tendon fixation construct in the orthopaedic literature. With respect to graft choices for ACL reconstruction, only hamstring, tibialis, quadriceps, and Achilles (in part) grafts require fixation of soft tissue to bone. Bone–patellar tendon–bone grafts use incorporated bone blocks on both ends of the graft, and fixation and healing are bone-to-bone; thus, the concepts within this review do not apply. Interestingly, soft-tissue grafts remain among the most popular options for ACL reconstruction,[32] and despite extensive study in several meta-analyses and systematic reviews,[33,34] no single graft has been identified as definitively superior with regard to clinical outcomes and failure rates. Various soft-tissue fixation techniques have been used for the femur (eg, interference screws, expansion devices, suspensory fixation devices) and tibia (eg, interference screws, staples, suture posts, tandem washers). On the femoral side, soft-tissue fixation with fixed-loop cortical suspension devices has been shown to be biomechanically superior to adjustable-loop devices,[35] even when incorporating retensioning of the adjustable-loop devices. Some authors suggest that hybrid fixation that incorporates suspensory fixation with an interference screw has superior biomechanical properties.[36] On the tibial side, interference screw fixation has been shown to have biomechanical properties similar to those of combined screw and sheath devices.[37] To date, the fixation construct of choice remains unclear because clinical evidence is limited by variability in surgical technique and outcomes reporting. The preferred technique of the senior authors (B.J.C., N.N.V., and B.R.B.) is either interference screw fixation or suspensory fixation on the femoral side with interference screw fixation on the tibial side.

### Rotator Cuff Repair

RCR is among the most commonly performed shoulder procedures. Surgical management of rotator cuff tears has been revolutionized by the

**Figure 11**



**A,** Illustration of a suture anchor. Arthroscopic images (**B** and **C**) demonstrating the placement of suture anchors. **D,** AP radiograph of the shoulder demonstrating placement of two suture anchors.

introduction of suture anchors. However, despite this advancement, rates of structural healing have improved only marginally and clinical outcomes have not improved.[38] Biomechanical evidence suggests that TOE/SB repairs provide the highest load-to-failure and the largest footprint.[19] Clinical evidence suggests that double-row suture anchor repairs provide the highest rates of clinical healing; however, it remains unclear whether higher rates of structural healing influence clinical outcomes. The authors' preferred technique depends on the size and configuration of the tear. For small tears, in particular, suture anchors placed in a single row are often sufficient. For large tendon tears, a TOE/SB repair is preferred and provides the highest likelihood of structural healing.

## Proximal Biceps Tenodesis

Proximal biceps tenodesis is among the most commonly performed shoulder procedures. Several studies have demonstrated that interference screw fixation has the highest load-to-failure rate, excellent clinical outcomes, and a low complication rate.[39,40] However, the load-to-failure rate of many fixation techniques (eg, suture anchor, interference screw, endosteal cortical button, bone bridge), may exceed the physiologic stress placed on the repair, and no clinical evidence exists to suggest that any single fixation technique is superior. No clinical study has demonstrated a difference in clinical failure among fixation types. The senior authors (B.J.C., N.N.V., A.A.R., and B.R.B.) prefer to use either suture anchors or interference screws for fixation.

## Distal Biceps Tendon Repair

Distal biceps tendon repair is another commonly performed procedure that relies on soft–tissue-to-bone fixation. Options for fixation vary, and the surgical approach dictates which fixation constructs are feasible; two-incision approaches typically use bone tunnels or (less commonly) suture anchors, whereas one-incision approaches use cortical buttons, suture anchors, interference screws, or a combined approach.[41,42] In a biomechanical study of four distal biceps tendon repair techniques, Mazzocca et al[20] found cortical button fixation to be superior to suture anchor fixation, interference screw fixation, and bone tunnel (two-incision) fixation. Overall, current evidence suggests similar clinical outcomes regardless of the technique or fixation construct used and lower complication rates with cortical buttons than with bone tunnels, suture anchors, and interference screws.[42] Fixation with a cortical button with or without interference screws is the technique preferred by the senior authors (B.J.C., N.N.V., A.A.R., and B.R.B.).

## Summary

Achieving successful healing of soft tissue to bone requires a thorough understanding of all aspects of the fixation construct. Optimal fixation devices should confer immediate stability, resist gap formation, promote biologic healing, and restore the anatomic footprint of the native tendon or ligament. Although biomechanical data guide the choice of fixation methods, these methods should be corroborated by randomized controlled trials that incorporate both objective and subjective outcome measures.

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*Evidence-based Medicine:* Levels of evidence are described in the table of contents. In this article, references 5, 33, and 41 are level II studies. Reference 34 is a level III study.

References 26, 29, 38, 40, and 42 are level IV studies. References 1, 3, 6, 7, 15, and 32 are level V expert opinion.

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