A review of suture anchors

Samena Chaudhry
Kenan Dehne
Faisal Hussain

Abstract

Suture anchors are designed to allow soft tissue to bone healing in cases where inadequate soft tissue stock on bone makes it impossible to perform a direct soft tissue-to-soft tissue repair. Suture anchor fixation is one of the most important innovations in arthroscopic glenohumeral shoulder surgery, optimizing the link between bone and soft tissue at the rotator cuff footprint. Newer developments and techniques have expanded the use of suture anchors to most other musculoskeletal tissues including the hip, elbow, hand, knee foot and ankle.

Their success depends on having an understanding of the biology and biomechanics that affect their use and knowing the factors that may affect the clinical outcome. This review concentrates on the design, insertion technique, composition and evolution of suture anchors in orthopaedic surgery and the ways in which they are utilised in different tissues.

Keywords soft tissue surgery; suture anchor

Introduction

Tissue anchors enable reattachment of tissue to bone in most parts of the body. These anchors are subject to specific stresses depending on the type of tissues they are used to repair and can fail through a variety of mechanisms. Many options exist in terms of anchor selection and it is therefore important for the surgeon to understand how individual anchor characteristics and biomechanics may affect their use. An understanding of the technique and site-specific factors, such as the quality of the local bone and tissue, is crucial.

Open surgical procedures in the shoulder, such as glenoid labrum repairs and rotator cuff repairs, may now be performed as effectively using arthroscopic techniques with suture anchors.[1–4] The literature has been populated with reports and studies demonstrating their success. This has led to newer indications for their use – medial patellofemoral ligament (MPFL) repair and lateral ligament repairs in the ankle are some examples[5–7] Operations such as FDL transfer into the navicular to augment posterior tibial tendon deficiency no longer require such a wide dissection.[8]

Samena Chaudhry *FRCS (Tr&orth) Spr in Knee and Shoulder Arthroplasty and Arthroscopy, Royal Orthopaedic Hospital, Birmingham, UK. Conflict of interest: none declared.*

Kenan Dehne *FRCS (Tr&Orth) Senior Clinical Fellow, Royal Manchester Childrens Hospital, UK. Conflict of interest: none declared.*

Faisal Hussain *FRCS (Tr&Orth) Consultant in Knee & Shoulder Arthroplasty and Arthroscopic Surgery, The Royal Orthopaedic Hospital, Birmingham, UK. Conflict of interest: none declared.*

Basic science

Suture Anchors are very useful devices for fixing tendons and ligaments to bone. They are made up of:

- The Anchor – which is inserted into the bone. This may be a screw mechanism or an interference fit. They may be made of metal or be biodegradable
- The Eyelet – is a hole or a loop in the anchor through which the suture passes. This links the anchor to the suture.
- The suture may be a non-absorbable or absorbable material (Figure 1).

Suture anchors in the shoulder

The rotator cuff

The goal of rotator cuff surgery is to optimize the bone to soft tissue connection at the rotator cuff footprint. The diagram of the individual components involved in a cuff repair (Figure 1) demonstrates the areas which will undergo physiological loading whilst healing takes place.

The repaired rotator cuff can be divided into tissue-suture, suture-anchor and anchor–bone interfaces. As better suture anchors and suture materials have become available, the weakest point is now most usually pull-out of the loaded suture from the tendon.[2] This has been demonstrated in studies evaluating load to failure and modes of failure as well as observations made at revision cuff repair surgery.[2–4] Factors involved, in addition to materials used, include patient factors such as the quality of the tissue and technique (e.g. knot security). It is possible to improve outcomes by doubling the number of fixation points of suture to tendon, thereby reducing the loading of each suture sufficiently to minimize cut out.[1,2,9–15]

Knowledge of a tendon's insertional footprint allows the orthopaedic surgeon to maximize tendon coverage over the healing zone, which promotes tendon-bone healing and decreases the rate of failure associated with, for example, arthroscopic glenohumeral repair.[2]

Tissue anchor selection is an essential part of arthroscopic rotator cuff repair (Figure 2). The cortical thickness of the greater tuberosity is generally thin. Excessive decortication during preparation of the bone surface may compromise the pullout strength of the anchor.[11] Trabecular bone mineral density also varies based on the region of the greater tuberosity, as well as in the presence of pathologic states, which may compromise anchors that predominantly rely on trabecular bone fixation. The proximal portion of the greater tuberosity between the articular surface and the tip of the tuberosity has a higher trabecular bone mineral density than that of the bone distal to the tip of the tuberosity.[10,11]

Labrum

The glenoid labrum enhances stability by substantially increasing the depth, height, and width of the glenoid. Suture anchors provide multiple points of fixation from which capsulolabral tissue can be reconstructed back up onto the surface of the glenoid rim during a stabilization procedure. Unlike the

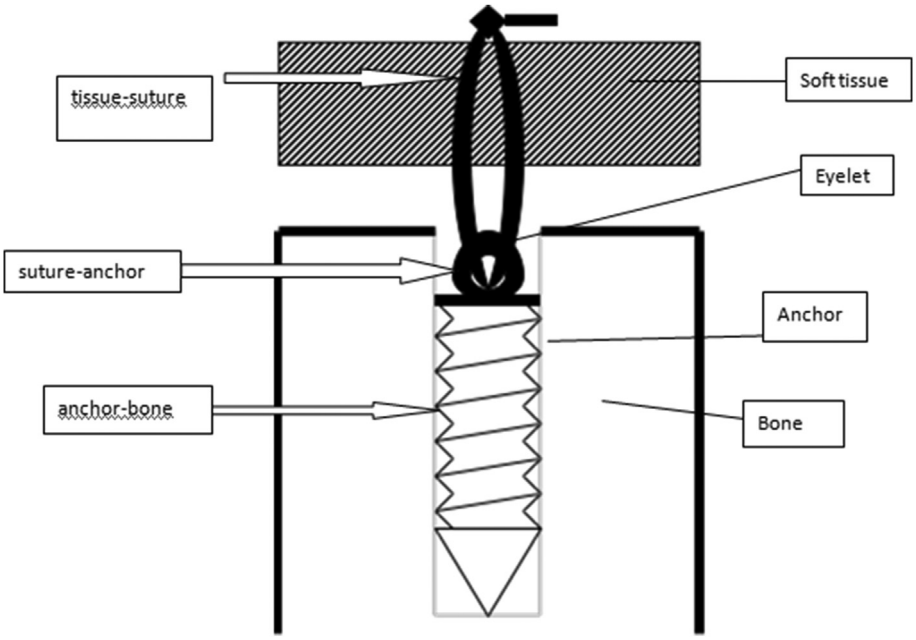

Figure 1 The components involved in attaching tissue to bone *via* an anchor, using the rotator cuff as an example.

proximal humerus, the narrow glenoid rim typically accommodates anchors measuring up to only 4.1 mm in diameter.[12] The amount of bone available for anchor insertion varies based on the position on the glenoid. Cadaveric studies have found that the anteroinferior glenoid has the least amount of bone available for anchor insertion.[13] Other anatomic factors that influence anchor performance include the thickness of the cortical glenoid bone as this correlates directly with fatigue resistance to suture anchor pullout.[2,3,12,13]

Anchors used in arthroscopic glenohumeral repair can be categorized by the method of fixation to the bone. Screw anchors, which have both a major and minor diameter, have threads to enable advancement of the anchor into the bone. The major diameter of the screw encompasses the entire width of the threads, whereas the minor diameter is the width of the screw's inner core.[1,3]

Acromioclavicular joint

Numerous cadaveric studies have explored the AC joint reconstruction using suture anchors after AC joint separations with favourable results.[16] Other biomechanical studies have demonstrated that suture anchors can provide equivalence to reconstructive techniques using the coracoacromial ligament, screw fixation, or suture or synthetic augmentations passed under the base of the coracoid for AC joint separations.[16] Dimakopoulos and colleagues[17] recently reported good clinical results in treating acute complete AC separations with a double-loop suture repair around the base of the coracoid. Other work has shown that similar stability can be achieved for coracoclavicular fixation with suture anchors or with sutures placed around the base of the coracoid.[18]

Elbow

Suture anchor tenodesis of the proximal biceps tendon can be performed for the treatment of proximal biceps tendonitis and rupture. Ulnar collateral ligament reconstruction and distal biceps tendon ruptures too can be successfully managed with suture anchors; conditions in which transosseous suture repair used to be the only surgical option (Figures 2 and 3).[19–23]

Hand and wrist

In the wrist and hand, smaller-sized suture anchors are used for a wide range of surgical procedures (Figure 4). In the wrist, suture anchors can be used for scapholunate and lunotriquetral ligament repair, as well as for triangular fibrocartilage repair.[3,24] Suture anchors are also used in the repair of ulnar collateral ligament injuries of the thumb, as well as collateral ligament injuries of the finger metacarpophalangeal and interphalangeal joints.[25] Ruptures of the flexor digitorum profundus tendon are commonly repaired using suture anchors.[26]

Hip

Analogous to labral repairs in the shoulder, suture anchors are also helpful in reattaching the labrum to bone in the hip (Figure 5). Such tears are the commonest pathology identified in this area. However the angle of anchor insertion is even more critical in the hip than it is in the shoulder, to restore the anatomy of the labrum. The acetabular cavity is deeply concave, unlike the shoulder, making the angle of insertion more acute and the avoidance of acetabular penetration somewhat more difficult. However, the procedure is technically challenging due to the restricted angle of anchor insertion, concavity of the acetabular articular surface and relatively narrow column of bone in the anterior and posterior acetabulum.[27] Failure of anchor insertion

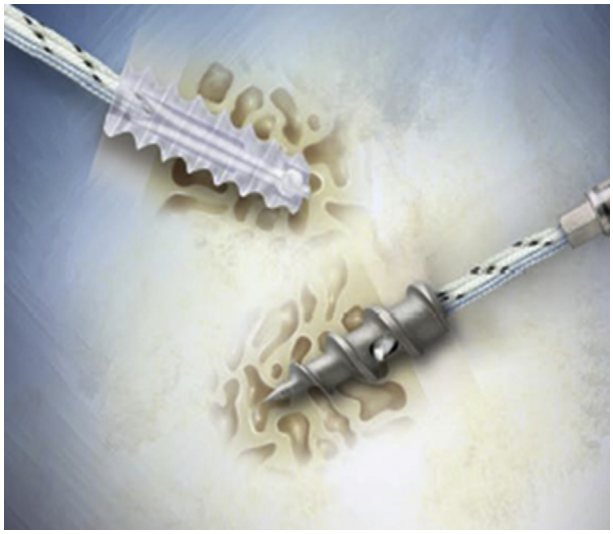

Figure 2 Fully threaded corkscrew and biocorkscrew anchors used in rotator cuff repair.

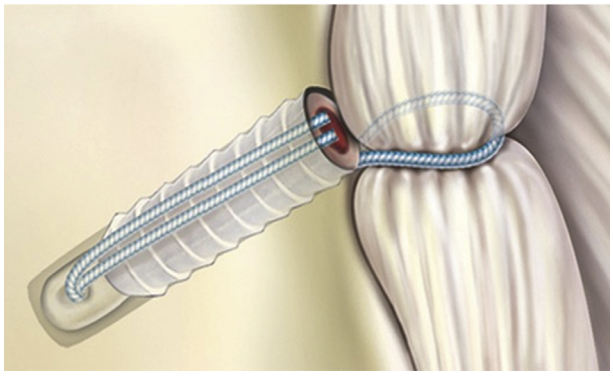

Figure 3 Example of a labral repair.

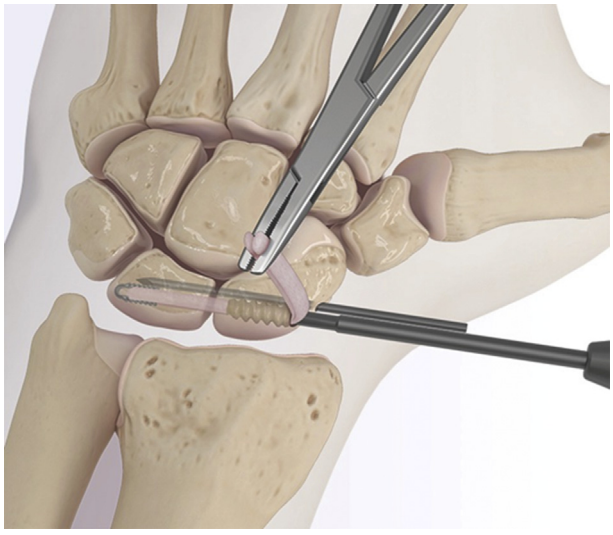

Figure 4 Scapholunate reconstruction using a suture anchor technique.

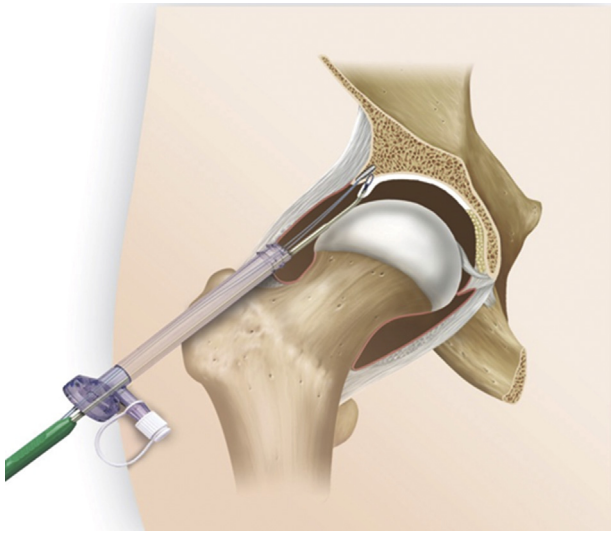

Figure 5 Labral repair of the hip.

can occur by penetration of the intra or extra-articular acetabulum.

Knee

Achieving an anatomic meniscus root repair is one of the important factors in normalizing femorotibial force pressure.

Kim et al. reported on arthroscopic suture anchor repair of posterior root tears of the medial meniscus compared with pullout suture repair.[28] For the suture anchor technique, they passed the suture anchor through a high posteromedial portal for anchor placement in a more vertical position. The International Knee Documentation Committee, Lysholm, and Hospital for Special Surgery scores showed statistically significant postoperative improvements in pain, locking, and giving way.

The JuggerKnot 1.4 anchor (Biomet) is a low-profile soft anchor that is often used in cases of glenoid labral repair. A biomechanical study has also shown that the mean pullout force of the JuggerKnot anchor is at least three times greater than the mean tension in the repaired medial meniscus root and is rigid enough to be used for a longitudinal tear of the lateral meniscus.[2]

Patella tendon and quadriceps tendon repairs can be successfully managed using suture anchors. Here the key technical tip is the insertion point of the anchors – approximately 2 mm from the articular surface. Placing them too superficially would increase the joint reactive force and lead to abnormal patellofemoral joint mechanics[29,30] The chances of penetrating the articular surface and injuring the intact tendon are greatly diminished by the low-profile nature of the anchor. Moreover, the traditional technique of passing sutures through obliquely oriented bone tunnels can theoretically create abnormal patellar tilting and force distribution. Suture anchors, however, do not have this risk. Excessive tendon shortening does not occur because the tendon edges do not penetrate into the long tunnels. The most likely mode of failure is cutting of suture through the tendon, counteracted by a strong Krackow stitch, which affords greater force dispersion.[31]

Other important and emerging uses include anatomic MPFL reconstruction, and major ligament repairs and reconstructions.[6,32]

Foot & ankle

For achilles tendon repair, refractory achilles tendinopathy or even after a Haglands deformity resection, suture anchors have become an effective means of reattachment. McGarvey et al.[34] found FHL augmentation into the achilles insertion with suture anchors improved the AOFAS score from 42 to 90/100.[33] More recently a soft all-suture knotless anchor system has been developed to eliminate the possibility of loose bodies in the joint and reduce the amount of bony resection.

A modification providing more versatility than the original technique of lateral ankle stabilization has helped enhance repair of the ATFL, CFL and anterior capsule.[34] The placement of the suture anchor at the footprints of the ATFL and CFL allows one to address each of the ligaments individually and provides the ability to repair them anatomically. Secondly, using anchors with sutures that are tied to the distal aspects of the ligaments provides the opportunity to tighten the lateral ankle structures more effectively in primary repair. Adding a third suture anchor approximately 1 cm above the ATFL insertion site helps tighten the confluence of the proximal aspect of the ATFL ligament with the lateral ankle capsule, resulting in an anatomic reinforcement of the repair without compromising ankle motion.[35]

Anchors

The past decade has seen a proliferation in the designs and types of suture anchors available, and this often presents a confusing plethora of options for the orthopaedic surgeon. . Each anchor has individual characteristics that influence the appropriateness of its usage including size, shape, composition, and holding strength.

Anchors can be divided into different groups based on composition and morphology, consisting of metal screw anchors, nonmetal bioabsorbable and biocomposite anchors, mini-anchors, plastic suture anchors as well as newer anchor designs that have not yet been tested in comparative biomechanical studies, such as all-suture knotless and vented anchors.[36,37]

Screw and impaction anchors

Compared with impaction devices of a similar size, screw threads have better holding strength because of the increased area of contact with the surface of the bone.[10,11] The amount of bone displaced by a screw anchor is also less than that of an impaction anchor of similar size. A screw anchor usually requires a hole that matches its inner diameter, whereas an impaction anchor generally requires a hole that can accommodate the combination of its shape, resilience (of the anchor material), and bone quality for fixation strength once the anchor is seated into place.

Impaction anchors can be further categorized by mechanism of fit (e.g. wedging or press-fit); this may include use of barbs or plastics that expand when the anchor is advanced into bone. Impaction anchors can be made of various plastics that expand after impaction through a cortical hole with a slightly smaller diameter than that of the anchor.[1,4]

Toggling anchors

Another mechanism locking the anchor into the bone is toggling or tilting. This mechanism is similar to that used in tent guy line fixation. The anchor is inserted into a predrilled hole in the bone. The suture eyelet is located asymmetrically to the line of loading so that when the suture is mechanically loaded it exerts a tilting force on the anchor. This blocks the anchor within the drill hole. The usefulness of these anchors is that they can also find purchase in poor quality bone where even if they are tilted by 90° on being pulled back by the loaded suture to the inner cortical surface of the bone the anchor is held in position similar to a button in a button hole.[1,2,4]

Expanding anchors

Expanding-type anchors are an older mechanism in which, after insertion of the anchor into bone, a pistol-like handle is activated to shorten and expand the anchor which then effectively blocks the drill hole. These anchors require complex insertion instrumentation and use up a large amount of material, which then has to be disposed of. Another of this type of anchor becomes locked in the bone when the suture is loaded, a process which results in expansion and blockage of the anchor.[1,4]

Anchor materials

Anchor materials may be biodegradable or non-biodegradable. Typical non-biodegradable materials are metal (steel or titanium alloys) and polymers such as polyethylene. Biodegradable anchors may be made of polyglycolic acid (PGA) co polymers or other polymers.[1,4]

Non biodegradable anchors are advantageous in that they have high mechanical stability, even in small sizes, while the advantage of the biodegradable types is that they are replaced with bone over time. Moreover, there is the option of over-drilling the anchor deeper in the bone if the suture fails during knot tying and a new anchor has to be inserted. In this situation a metal anchor would have to be left in place whilst a second new anchor would have to be placed at a different, perhaps suboptimal, site. Biodegradable polymers also have problems, however, such as the generation of pH changes in the surrounding bone and inflammatory responses to the degradation products. Many studies have shown that these acidic degradation products are only problematic if the anchor is not entirely surrounded by bone.[1–4]

Metal anchors

The suture anchors originally used in shoulder surgery were made of metal because at that time most other orthopaedic implants that were metal were proven to be effective, with a long track record of stable fixation. Standard radiographs could be used to assess for anchor migration and potential treatment failure. Both stainless steel and titanium anchors were used in labral and rotator cuff repairs.[2,3] These metals have minimal osseous integration. Stainless steel becomes encapsulated by a fibrous layer, and titanium induces a minimal inflammatory response. Most of these designs now are self-drilling and self-tapping. The use of a longer screw-type anchor can be advantageous for rotator cuff repair in an older population where bone quality may be poor.[1,24,28]

The distortion of imaging modalities by metal does, however, make the postoperative assessment of both rotator cuff and labral repairs difficult. Furthermore, previously metal anchors may complicate placement of new anchors during the revision

procedure. Anchor loosening and fatigue failure leading to chondral damage have been associated with the use of metal anchors. These drawbacks have resulted in bioabsorbable options for suture anchor materials that allow resorption of the anchor material following soft-tissue repair.[24,27,38]

Bioabsorbable anchors

These are polymer-based implants. Polymers are solid, nonmetal materials which are plastics composed of small repeating chemical units.[1–3] Degradation of bioabsorbable anchors is dependent on their composition, molecular weight and crystallinity. The earliest, commonly used bioabsorbable anchor was composed of polyglycolic acid but time to anchor degradation was only 3–4 months and the anchors were associated with early loss of fixation, resulting in osteolysis, loose body formation and glenohumeral synovitis.[30] Bioabsorbable suture anchors are now made either solely of poly-L-lacticacid, poly-L/D-lactic acid (PLDLA), poly (lactide-co-glycolide), or a combination of these polymers.[24] This combination has been shown to slow *in vivo* resorption of anchors for up to 7–10 years in some implants and is not associated with significant bone ingrowth.[31]

Biocomposite

Biocomposite anchors were developed to bridge the gap from initial fixation to eventual bone formation at the anchor placement site without inducing osteolysis or synovitis. These anchors are composed of a bioabsorbable polymer (e.g. hydroxyapatite) and an osteoconductive bio-ceramic such as β-tricalcium phosphate. The bioabsorbable polymer allows for resorption of a portion of the anchor, and the bioceramic provides calcium and phosphate substrates as byproducts of breakdown, which help to provide an excellent basis for bone formation and mineralization.[2] Few inflammatory reactions or complications have been observed with use of these implants (Figure 6).[36,37]

Knotless types of anchors

Tacks: one type of nail-like device is stuck through the soft tissue into the bone where the soft tissue is intended to re attach. The head of the tack holds the soft tissue to the bone and prevents the nail shaft from slipping through the soft tissue. There is no requirement for knots or stitching. However this concept is difficult to put into practice effectively and inflexible when the bone under the soft tissue to be repaired is not strong enough.[1,27]

Parachute: a parachute anchor is a screw-type anchor with an attached suture, which passes through a small plate through which a screwdriver is inserted into the anchor body. The anchor is passed through the soft tissue into the bone. As the anchor passes deeper, the plate comes to lie on the soft tissue, tightening it to the bony substrate.[1]

Knotless anchor: this consists of an anchor with a suture sling and a slot on the anchor tip aligned with the insertion direction. The sling is threaded through the soft tissue to be repaired and inserted into a slot on the anchor tip. The anchor is driven into the bone whilst tightening the suture sling until it allows the soft tissue to sit snugly to the bone (e.g. see Figure 7).

Sutures

A typical suture anchor has a suture eyelet through which a suture is threaded and may be used to suture the soft tissue to the bone where the anchor is inserted. Arthroscopic reconstructions and repairs require appropriate suturing and knotting techniques. The knots should slide freely through the eyelet without friction, which could either damage the anchor or prevent snug seating of the knot. Care has to be taken that the suture is not compressed and sheared between the drill hole and anchor eyelet resulting in damage caused by sharp bone edges.

Suture materials

Braided polyester sutures (e.g. Ethibond) were widely used in the past, but improved, stronger suture materials, such as Fiberwire (Arthrex) (Figure 8), made of ultra–high molecular weight polyethylene (UHMWPE) are now available. The Orthocord suture (Depuy Mitek) is made of a UHMWPE sleeve and a polydioxanone (PDS) core with polyglactin 910 coating. The

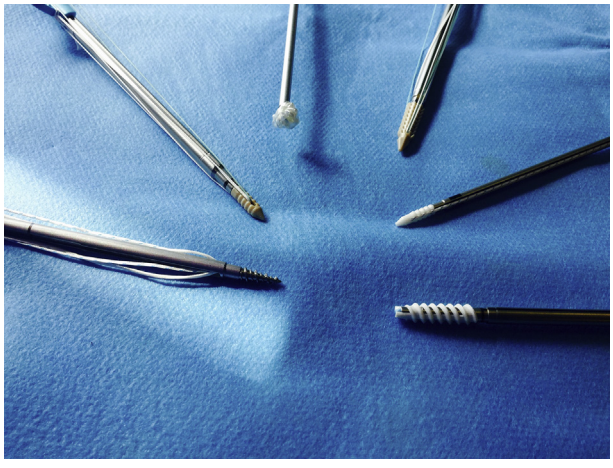

Figure 6 A variety of suture anchor types (Arthrex).

Figure 7 Fiberwire and fibertape.

Figure 8 A vented suture anchor.

Figure 9 A vented suture anchor.

introduction of stronger suture materials has changed the mode of failure of the anchor/suture construct. Instead of suture breakage, the metal anchor fails by pulling out of bone, whereas the bioabsorbable anchor fails at the level of the anchor eyelet.[1,3] Suture knot configuration has been studied too, as it is an essential part of the fixation construct. Although a static surgeon's knot provides security, a sliding knot with the addition of three reversing half-hitches on alternating posts can also provide adequate fixation for clinical use.[36,39]

Practical considerations

The appropriate angle of insertion

The angle of insertion of a suture anchor relative to the surface of the bone is an important consideration. The bone should be prepared as per specific technical requirements of the suture anchor that will be inserted (e.g. pre-drilling of the bone).[4]

In 1995, Burkhart introduced the 'deadman's angle' theory, proposing by trigonometric calculation that anchors should be inserted 45° from the insertion surface to increase the pullout strength[39] Recent researches have shown that deadman's angle does not necessarily yield the strongest pullout strength. Strauss et al. reported that the stress distribution on the anchor was lower in anchors inserted at 90° to the surface compared to a 'deadman's' 45° insertion, when assessed using a three dimensional finite element method model. This suggests that inserting the anchor 90° to bone surface may result in higher pullout strength compared to inserting the anchor 45° as a result of stress distribution occurring around the loaded threads.[40]

Suture anchors should be inserted to the appropriate depth (as per manufacturer recommendations) in order to avoid excessively proud or excessively deep suture anchors. It is important to pretest the anchor, by a tensile load *via* the attached sutures, to confirm anchor security within bone.[2,3]

An ability to managed the associated sutures and avoid inadvertent off-loading from the anchor are skills needed to facilitate subsequent steps in the overall surgical procedure (suture passage and knot tying).[41]

Improper direction of the suture anchor relative to the surface of the bone can result in damage to the adjacent articular cartilage or subsequent failure of the anchor (due to inadequate bone purchase). The shaft of the anchor inserter should be perpendicular to the cortical surface. A proud anchor can cause direct damage to opposing articular surfaces and soft tissue structures. A deep anchor may be associated with suboptimal fixation (since cancellous bone is weaker than cortical bone).[36]

Soft tissue reattachment relies not only the strength of the suture and anchor, but more importantly the quality and strength of the soft tissue. Catching a sufficient bite of good quality tissue and knot integrity are important.

Newer designs

Suture anchor designs continue to evolve for use with arthroscopic techniques. Recent innovations in anchor design and application include the use of poly etheretherketone (PEEK) as the anchor material and the addition of multiple high-strength sutures with the development of "knotless" designs that may be used for the lateral row of a dual-row rotator cuff technique,[2,3] PEEK is a radiolucent but not biodegradable plastic suitable for a variety of implants that has the advantages of possessing high strength, facilitating good postoperative imaging if needed and facilitating revision surgery because it is soft enough to be drilled through. High-strength sutures made in part, or entirely, of ultrahigh—molecular weight polyethylene (UHMWPE) have implications for the associated anchors because the increased suture strength places greater demands on the suture-anchor fixation point ("eyelet") at loads associated with failure that are unique to that design.[1,14]

Anchor designs that do not require an arthroscopically tied knot ("knotless") facilitate secure repair fixation but as yet the long term results are available[9,10] Other recent trends in anchor development include the increased use of biodegradable materials.[13,14]

As suture anchor technology develops, older anchors and techniques are replaced with newer ones; the newest generation include vented suture anchors which promote bone marrow flow and bony in growth.[15,23] (Figure 9).

Conclusion

Suture anchors have been available since the early 1990's and are now essential to any orthopaedic surgeon's armamentarium. As with any other implant, the orthopaedic surgeon should be thoroughly educated on the characteristics of the anchor being used and the technique necessary for correct insertion of the anchor. With so many different types of new anchors and sutures available, one must develop wisdom in the selection and use of the most appropriate material and device for the procedure and body part in question. ◆

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