Original Article

Fixation methods and implants in shoulder stabilization: A historical perspective

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ABSTRACT

Background: Treatment for shoulder instability has changed significantly over the past decade from open procedures to arthroscopic procedures using a variety of different fixation methods and implants. The development of these implants has been highly influenced by the numerous complications that have arisen using early designs. **Methods:** A review of the literature was performed to describe the history of shoulder stabilization. **Conclusion:** As biomedical technology improves, we should continue to see changes to implant design and manufacturing. Having an understanding of the history and evolution of these implants will provide us with context in which to guide future implant design and clinical use. This review article provides a comprehensive overview of the evolution of early shoulder stabilization techniques and implants to the modern implants being used today.

Introduction

Glenohumeral instability is a common shoulder disorder, particularly in young active patients. Instability can be categorized into traumatic unidirectional instability or multidirectional instability (MDI). Multiple soft tissue pathologic processes have been associated with instability and surgical stabilization has been shown to be beneficial in many of them. Initial surgical interventions were performed through open approaches as early as 1906.¹ The first documented use of the arthroscope was by Dr. Severin Nordentoft, who made his own endoscope and presented his work on knee arthroscopy in Berlin in 1912.² Dr. Kenji Takagi, who performed an arthroscopic examination of a tuberculous knee joint in 1919, a time when minimally invasive procedures became a focus of clinical research and practice.³ Dr. Masaki Watanabe made significant contributions to the design and production of arthroscopes, and developed the concept of “triangulation”, involving bringing instruments from multiple portals to treat pathology.⁴

Later, Kreuscher and Burman were the first to publish about arthroscopy in the United States, and used an arthroscope to examine the shoulder.^{5,6} Since then, the arthroscope has evolved to be the primary modality used for surgical interventions of the shoulder. Numerous operative procedures have been described to prevent recurrent instability for these processes. The following review article will highlight the history and evolution of these arthroscopic surgical procedures for shoulder instability.

Staples

Early descriptions of glenohumeral stabilization surgery were through open techniques. The first report of surgical stabilization was by Perthes in 1906 who used staples.¹ In 1923 Blundell Bankart first described the detachment of the antero-inferior labrum from the glenoid (bankart lesion) and his stabilization technique of suturing the anterior capsule to the detached labrum using silk gut sutures.^{2,7} Some surgeons found the Bankart technique technically demanding and in 1931 F. P. Fouche and A. Lewer Allen described their technique of using chisel pointed staples made from bicycle spokes to pin the anterior capsule to the glenoid rim.⁸ Slight modifications of this technique including the use of conical tipped stainless steel staples and staples fashioned from kirschner wires.^{8,9} The first series of staple capsulorrhaphy for anterior instability reported in the US was in 1965 by Boyd and Hunt who used barbed stainless steel staples to prevent hardware migration.¹⁰ Despite advances in these techniques, complications related to stapling persisted including nerve injury, incorrect hardware placement, hardware migration and articular injury, leading to the need for hardware removal.¹¹

Meanwhile, arthroscopic techniques were being developed and by the mid 1980's arthroscopy was shown to be superior to some open orthopedic procedures.¹² In 1983 Matthews performed the first staple capsulorrhaphies as demonstrated in Fig. 1. A postoperative radiograph is demonstrated in Fig. 2. He utilized staples through an arthroscopic

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Fig. 1. A staple used through arthroscopic cannulas.

Fig. 2. Postoperative radiograph after staple capsulorrhaphies.

staple cannula. His results showed 67% good to excellent to results, with 20% of his patients needing further surgery. There was one case of staple loosening and one case of staple impingement resulting in chondral damage.

In 1989, Hawkins published a series using staples on 50 cases. He had a relatively high recurrence rate of 15%, which he attributed to his shorter rehabilitation period. He also had two cases of loose intra-articular staples that required surgery for removal. Furthermore, at least one staple broke during insertion, requiring creation of an additional portal for extraction. In total, 4.3% failed due to hardware loosening.¹³ In 1993, Lane et al reported an even higher rate of hardware loosening of 26%, of which 19% required open revision.¹⁴ Eventually, staple use diminished as it is often inadequate in the thin cortical bone and can dislodge easily with motion, as evidenced by the abundance of hardware complications as described above.

Spiked washers

Spiked washers were first described for use in open ligamentous repair by Hurson and Sheehan in 198. The concept behind this innovation was to prevent the screw head from cutting through the ligament.¹⁵ They used spiked plastic washers in conjunction with A.O. compression screws to repair various ligament avulsions including

Fig. 3. Cannulated screw and washer.

lateral ankle ligaments, the lateral collateral ligament of the knee, and the labrum in a bankart lesion in the shoulder. In 1986, Robertson et al compared fixation of two and four-pronged staples to spiked circular washers in a cadaveric model.¹⁶ They found that spiked washers coupled to compression screws provided better fixation strength. Additionally, they noted staples tended to tear through capsular and ligamentous tissue during cyclic loading.

In 1988, Wolf et al. described the use of cannulated screws with spiked washers for the arthroscopic shoulder capsulorrhaphy as seen in Figs. 3 and 4.¹⁷ In this technique, a sharp trochar was used to spear the avulsed glenohumeral ligament complex and advance them superomedially on the scapular neck. After drilling through the scapular neck, a kirschner wire was used to preliminarily fix the ligament complex in place; this was followed by final fixation with a 4.5 cannulated screw with a spiked washer. During the 26 month follow up, none of the 23 patients had recurrent instability and there was no evidence of screw migration.

Spiked washers with compression screws continued to be used into the 1990s for both arthroscopic and open shoulder stabilization. In 1998 Takeda et al. described the use of a spiked washer and cancellous screw in a modified open bankart procedure in chronic anterior shoulder instability.¹⁸ However, arthroscopic use of cannulated screws

Fig. 4. Arthroscopic photograph of cannulated screw and washer.

with spiked washers was a technically challenging procedure with concerns for inappropriate screw placement and eventual hardware migration. Furthermore, though spiked washers provide strong initial fixation strength, it was found that soft tissue ingrowth and healing enhanced the overall strength of the construct. In 1991, Bagley et al. have shown that soft tissue attachment via suture technique is stronger than screw and washer fixation at 3 months postoperatively.¹⁹

Transglenoid bone tunnels

Half a century after Blundell Bankart first began repairing labral tissue for recurrent anterior shoulder instability, Morgan et al first described an arthroscopic method using bone tunnels through the glenoid in 1987.²⁰ At that point in time, there were two schools of thought regarding anterior glenohumeral instability: subscapularis buttress via Magnuson type procedures and focusing on anterior capsular structures through a Bankart type repair.

Through anatomic studies published by Turkel et al, the inferior glenohumeral ligament-anterior labral complex were found to be the primary restraint to recurrent traumatic instability. This evidence, along with presence of the pathologic “Bankart lesion”, focus shifted to repairing these lesions through Bankart repairs.²¹

Morgan et al. used the “utility” anterior portal first described by Matthews in 1985 by entering the triangular interval for the majority of the repair.²² After abrading the glenoid rim and scapular neck anteriorly, they passed suture through the bankart lesion, glenoid bone and the anterior capsulolabral tissue using a modified Beath pin thereby creating a single large anterior horizontal mattress suture with tails exiting the scapular neck and skin posteriorly as seen in Fig. 5. Using this technique, they reported excellent results for all 25 patients with full return to pre-injury level of activity.²⁰ However, this technique requires tying suture over muscle and fascia that is often distended with extravasated fluid. In addition, the transglenoid technique risks injury to the suprascapular nerve.

Wolf described the use of antero-superior and antero-inferior portals to improve visualization of glenohumeral labral complex in 1989.¹⁷ Through anatomic studies, he demonstrated the acute angle created when attempting to approach the scapular neck, predisposing the surgeon to skive drills and K-wires when working on the labral complex. The anterior superior portal is located between the coracoid and the

acromion, and the anterior inferior portal is located immediately inferior to the tip of the coracoid.

Despite these advancements in arthroscopic surgical technique, these procedures were still fraught with complications. A case report by Shea et al. in 1991 described scapulothoracic penetration with a beath pin.²³ While attempting to drive the pin into the glenoid, the pin was lost. Radiographs revealed that the pin had penetrated the anterior glenoid cortex and then skived off the posterior cortex rather than penetrating it, thereby advancing into the scapulothoracic articulation. The flexibility of the modified Beath pin lent to its tendency to follow an undesired trajectory if approached at too oblique of an angle. During that time, the Editor of Arthroscopy stated that “No one but an experienced arthroscopic surgeon should undertake the Arthroscopic Bankart Suture Repair Technique and then only after having had instruction at the hands of someone who has had the necessary experience and knows how to avoid the complications.”²⁰

Though these techniques presented new challenges to shoulder arthroscopists, biomechanical evidence suggested they were superior to older techniques. In a cadaveric biomechanics study, the initial pull-out strength of suture repair was compared to the staple technique.²⁴ The results showed that the initial pull-out strength of the suture repair was more than twice that of the staple repair. This was hypothesized to be due to the staple creating two rents in the capsule which are larger in area than the staple. Interestingly, both of these techniques still had much lower initial pull-out strength compared to native shoulders.

This finding was reflected in clinical studies, as authors continued to have minimal success with this technique in subsequent years.^{25–27} Grana et al. followed short term results for 27 patients undergoing arthroscopic bankart suture repair in 12 patients, and 45% of patients were rated as failed with recurrent instability of the shoulder.²⁵ These failures were associated with shorter immobilization periods, young patients, and those who played contact sports.

Hayashida et al. reported improved results five years later in 1998, though recurrent instability still occurred in 18% of patients.²⁶ Notably, they excluded patients with bony Bankart lesions, which may one of the reasons of the improved results. Patient selection continued to evolve during this time period as authors identified associations with poor outcomes. Like Grana, Hayashida et al. found that patients who played contact sports tended to have higher rates of instability.

Despite new contributions to the technique including the introduction of an inside-out drill guide to avoid neurovascular structures, malposition, and migration by Harryman et al. in 1994, in 1995 Walch et al. reported poor results in 50% of patients, and subsequently concluded that arthroscopic stabilization should only be part of controlled clinical trials.^{27, 28} At this time it was apparent that although the technique had promise, further refinement was necessary before arthroscopic shoulder stabilization could surpass open stabilization as the gold standard of care.

Metallic suture anchors

Previous techniques had inherent limitations in that they did not address the structural damage present in these injuries; specifically, the capsulo-labral detachment and redundancy. The advent of suture anchors allowed for reattachment and repair of the entire capsulo-labral complex, which is believed to yield better results. This allows for a proximal capsular shift to improve tensioning and stability of the capsule.

The next significant development in arthroscopic shoulder stabilization was the use of metallic suture anchors. The first implant in the literature was the Mitek metallic suture anchor (Mitek products Inc., Westwood, MA). These were small metallic implants with two main components: the body, which consisted of titanium, and the arc, which consisted of nitinol (nickel-titanium). The nitinol arc had a memory property which allowed for insertion through a small drill hole, thus enabling the arc to anchor in subcortical bone. Suture is attached to the

Fig. 5. Arthroscopic image of transglenoid suture repair.

implant through a drill hole in the body of the anchor. The first reports of these were in biomechanical studies. In 1989, France et al published a report comparing pullout strength of the Mitek metallic suture anchor to transglenoid bone tunnels in cadavers. They found that the anchor was weaker than the bone tunnels (82.5 N vs 135 N).²⁹ A year later, a 2nd generation suture anchor, which was a double armed device, had comparable strength to bone tunnels.

These metallic suture anchors were used in shoulder stabilization in the early 1990s. Richmond et al. first used them in 1991 during open bankart repair.³⁰ Using Mitek metallic suture anchors, the capsulolabral complex was reattached to the glenoid rim. Of 17 patients, only one had recurrent dislocation. Richmond's research showed favorable results and overall satisfaction with the surgical technique itself. In addition, they found that these devices simplified the procedure.

Following success using metallic suture anchors in open shoulder surgery, Wolf et al described their use in arthroscopic shoulder surgery in 1991.³¹ Using dual anterior and posterior portals, the anterior glenoid rim and scapular neck are prepared and then drilled. Three drill holes were spaced as far away from each other on the anterior glenoid rim, angling 15–20 degrees medially. Generation II Mitek anchors were used to allow the suture to slide within the drill hole. At 12–24 months after surgery, there were no complications and no recurrence of instability or dislocation.

The positive early results of suture anchors generated interest and led to development of new implants. Biomechanical studies supported the clinical success seen with metallic anchors in shoulder stabilization surgery. By 1993 there were at least five devices. Carpenter tested pull-out strength to failure of five anchors and showed that the Mitek GII (Mitek Surgical Products, Norwood, MA) and Statak (Zimmer, Warsaw, IN) were the strongest with mean loads to failure at 82.5 and 90.2 N, respectively.³² They also found that the anchors performed better when inserted further from and parallel to the joint surface.

Just as previous implants suffered from hardware migration into the glenohumeral joint, metallic suture anchors were prone to the same problems. One case report outlined interarticular migration of the anchor ultimately leading to significant articular cartilage erosion.³³ In addition, there were reported cases of localized osteolysis around the metallic implants, even one case that went on to subsequent infection requiring revision.³⁴

Biocompatible anchors

Eventually, development of new anchor systems shifted to bio-compatible materials. The rationale was to implant devices that had lower rates of implant migration, loosening, and potential need for future removal.³³ The first description of their use was in 1995 by Barber et al with the Arthrex Expanding Suture Plug (Arthrex Inc, Naples, FL).³⁵ This anchor was threaded with non-absorbable No. 2 braided polyester sutures. The anchor itself was composed of poly-L-lactic acid (PLLA) and was implanted in an animal model. Though there was a decrease in osteoblastic activity, there was no evidence of a foreign-body reaction in the 12 week period of study. Later, Ono et al may have been the first to describe the use of these anchors to repair soft tissue to bone in a rabbit model.³⁶ The other commonly used bioabsorbable anchor was composed of polyglycolic acid (PGA), however degradation occurred within 3–4 months, and thus PLLA became the predominant material used.³⁷

Strength testing of these new bioabsorbable anchors that flooded the market in the 1990s fared well compared to their metallic predecessors.³⁸ Eventually they were described for use in open bankart repair. One randomized study comparing metallic to bioabsorbable anchor for open bankart repair showed no differences 24 months postoperatively.³⁹ In 2003, Barber et al published results of the BioAnchor (Linvatec Corp, Largo, FL) in arthroscopic bankart repair.⁴⁰ This was the first series to report the arthroscopic use of PLLA anchors in the human body. Fifty-seven patients were followed for a mean of 2

Fig. 6. Biocompatible anchors seen on magnetic resonance imaging.

years after arthroscopic bankart repair. There were no adverse reactions to the anchors seen in follow up radiographs.

Several years later, Tan et al performed a prospective randomized study comparing the G II absorbable anchor (DePuy Mitek, Raynham, MA) to non-absorbable suture anchors. 124 patients completed the study. There were no differences in rate of recurrence or clinical scores between the two groups. However, this was a relatively short mean follow-up of 2.5 years, and radiographs were not taken so there was no information regarding cystic bony changes, anchor position or anchor migration.⁴¹

During the mid 2000s, there was a major shift away from metallic suture anchors towards bioabsorbable anchors.⁴² This was largely due to the decreased complication rates with bioabsorbable implants. The absorption over time minimized the risk of implant migration and minimized interference with revision surgery. In addition, the implants are generally radiolucent, and due to their composition were less likely to interfere with magnetic resonance imaging of the shoulder, as is demonstrated in Fig. 6.⁴³

Of course, even these implants have their own source of unique complications. In 2007, Barber published a case report which outlined a complication related to the implant.⁴⁴ In one case, a patient who underwent bankart repair using three Bio-SutureTake anchors (Arthrex, Naples, FL) loaded with No. 2 Fiberwire suture (Arthrex) described increasing pain with overhead activities and an “audible squeaking” with shoulder motion. Magnetic resonance imaging (MRI) demonstrated no loose anchors. However, repeat arthroscopy showed a 1.5 x 0.5 cm area of grade 4 chondromalacia with a segment of suture buried in the bone, which was determined to be the polyester suture eyelet. The problem in this case example was the combination of non-absorbable suture with absorbable anchors. This could be theoretically mitigated by using anchors with a slower degradation profile, ensuring the anchor eyelet is not protruding into the joint, or by using a implant made of the same material.

Due to the complications associated with absorbable anchors, alternative materials were developed. Specifically, the development of polyetheretherketone (PEEK) led to an array of products with an inert, stable structure that is resistant to degradation.⁴⁵ Furthermore, these materials tend to be less inductive of an inflammatory response.

Alternatively, anchors can be constructed using a combination of a bioabsorbable polymer which ultimately resorbs, and a bioceramic such as porous calcium phosphate. These biocomposites allow for partial absorption and breakdown into calcium and phosphate substrates which provide a biologic habitat for in vivo bone formation. One prospective study published in 2014 by Randelli et al demonstrated

Fig. 7. Cyst formation following absorption of biocompatible anchors.

Fig. 8. Illustration of suture-anchor deployment.

excellent biological efficacy while magnetic resonance imaging showed reformation of normal glenoid trabecular bone at a mean of 29 months after transplantation.⁴⁶ In this case series, anchors made of 70% polylactic co-glycolide (PLGA) and 30% β -tricalcium phosphate were used in Bankart repair and subsequently imaged. Despite the composition of these biocompatible anchors, degradation or incorporation of the implant material lead to inflammatory changes or cyst formation in a number of cases as demonstrated in Fig. 7.

All-suture anchor systems

The most recent development in arthroscopic shoulder stabilization is the advent of the all-suture anchor. These function by expansion of the suture implant in bone when pulling on both suture ends as depicted in Fig. 8. One theoretical advantage of an all-suture anchor is uniform implant construction, which would mitigate problems related to differential absorption of its constituents. Furthermore, many of these implants require a smaller pilot hole than their bioabsorbable counterparts, thereby removing less bone. Thus more of these anchors may be used for fixation, which has been shown to improve results. A study by Boileau et al. analyzed risk factors associated with recurrent instability after surgery for bankart repair.⁴⁷ One key finding in their series of ninety-one patients was increased risk of recurrent instability if fewer than three anchors were utilized for repair.

In 2012, Mazzocca et al compared an all-suture anchors system to a

bioabsorbable suture anchor. The JuggerKnot (Biomet, Warsaw, IN), an all-suture anchor performed comparably to the a classic suture anchor (the 2.4 mm biocomposite sutureTak: Arthrex, Naples, FL) in an in vitro labral repair model. There was no statistical difference in ultimate load to failure. However, they found that greater load was required to create 2 mm labral displacement in the bioabsorbable anchor group.⁴⁸ Similarly, Swyer et al showed no difference in load to failure between an all-suture anchor (Y-Knot, ConMed Linvatec, Largo, FL) and a bioabsorbable anchor (Bio Mini-Revo, ConMed Linvatec). They did note that the all-suture anchor had inferior fixation, early displacement, and greater laxity. However, pre-tensioning to 60 N eliminated this behavior.⁴⁹

There is currently a paucity of clinical data regarding these new all-suture anchor systems, despite their frequent use. To date, the only published clinical series is by Agrawal et al focused on triple labral tears. In their series of eighteen patients, they treated these panlabral tears with 1.4 mm JuggerKnot Soft Anchors (Biomet, Warsaw, IN). The anchors were placed 5–10 mm apart and an average of 11.5 anchors were used per case. Overall results showed significant improvement, and all contact athletes returned to their pre-injury level of sports activity.

Conclusion

The long history of implant development in shoulder stabilization is fascinating, from open procedures employing bicycle spokes for fixation in the early 1900s to advanced bioabsorbable and all-suture anchor systems that are being used today. As biotechnology continues to improve, we should see parallel advancements in implants and devices, which in turn, we hope, will lead to improved clinical outcomes for our patients.

However, the device industry's continued expenditures in anchor design, manufacturing, and marketing will inevitably lead to increased costs for the health care system. As the health care sector continues to shift focus towards cost-effectiveness, we need to be cognizant of the economical effects of using new, potentially costly implants, particularly when these implants have not necessarily undergone comparative trials demonstrating their clinical efficacy. Having an understanding of the history, evolution, and design of these implants will provide us with context to which we can apply to future implant design and utilization.

Disclaimer

None.

Conflicts of interest

None.

Authors contribution

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