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Tendon anchoring methods in small animals – literature review

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1. Introduction

In orthopedic surgery, both in human and veterinary medicine, suture anchors play a critical role in procedures requiring secure bone-to-tendon or bone-to-ligament attachment. These bone anchors are widely used for joint stabilization and repair, such as in rotator cuff repairs, labral repairs, and biceps tenodesis. Despite their extensive application, achieving optimal mechanical stability, minimizing bone response complications, and ensuring effective tissue healing remain complex challenges. Factors such as anchor type, material composition, and insertion orientation significantly affect the outcomes of these procedures.

Research highlights various suture anchor types, from traditional metallic and bioabsorbable anchors to newer all-suture designs and emerging composite materials. For instance, Stewart et al. (2020) compared biocomposite push-fit anchors and all-suture anchors, finding that all-suture anchors were associated with less osteolysis, suggesting they may better preserve bone integrity over time (1). Similarly, the study by Bulman, Cotton, and Barnes (2016) evaluated bone integration between Healicoil Regenesorb anchors and biocomposite Corkscrew anchors, observing superior bone ingrowth with Healicoil Regenesorb anchors, which may indicate better long-term outcomes (2).

The choice of anchor material also influences the body's bone response and the fixation stability. Metals like stainless steel and titanium, known for their high mechanical strength, pose issues such as stress shielding, MRI interference, and, in some cases, inflammatory reactions (3). Alternatively, biodegradable polymers such as poly-l-lactic acid (PLLA) and poly-glycolic acid (PGA) are designed to resorb over time, which eliminates the need for removal but may cause complications like osteolysis, cyst formation, and inflammatory responses due to degradation byproducts (4, 5, 3). Recent developments, such as polymer-ceramic composites like PLLA/β-Tricalcium Phosphate (β-TCP), offer the potential for enhanced osteointegration, reducing the risk of adverse reactions, though controlled degradation remains a challenge (3).

In veterinary applications, the biomechanics of anchor placement is of particular concern, given that many orthopedic repairs must withstand high loads and repeated motion. Studies such as those by Balara et al. (2004) and Kunkel et al. (2013) emphasize the importance of anchor orientation and mechanical testing in cadaveric models to optimize fixation in canine bones (6, 7). These findings underscore the need to tailor anchor design and placement strategies to the mechanical requirements of different species and skeletal locations.

This review synthesizes recent research on suture anchors, focusing on bone response, bone preservation, holding power, suture abrasion, and material advancements. By examining the performance and limitations of various anchor types and materials, we aim to provide insights into current best practices and future directions for improving surgical outcomes in both human and veterinary orthopedic applications.

2. Overview of Tendon-to-Bone Fixation

2.1 Knotless SwiveLock anchor system

2.1.1 General

This surgical method is an implant (**Figure 1**) that can fix a tendon. It does not need a knot. The suture can be pulled through the anchor and fixed in place. The anchor is located at isometric points of the stifle. This enables the suture under normal movement to keep a constant tension. The anchor sizes can be selected by weight and activity level (8).

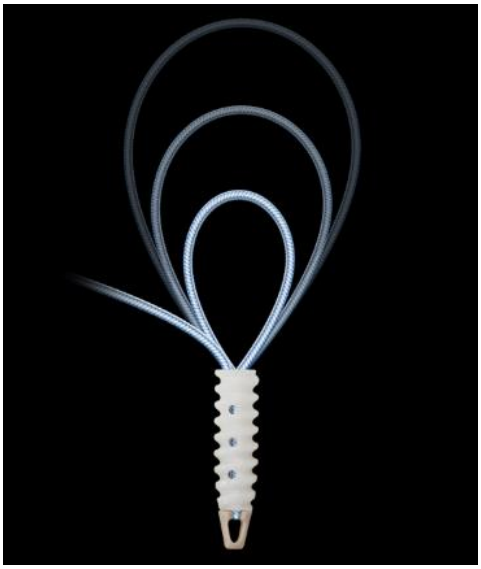

Figure 1: The SwiveLock anchor system from Arthrex (9).

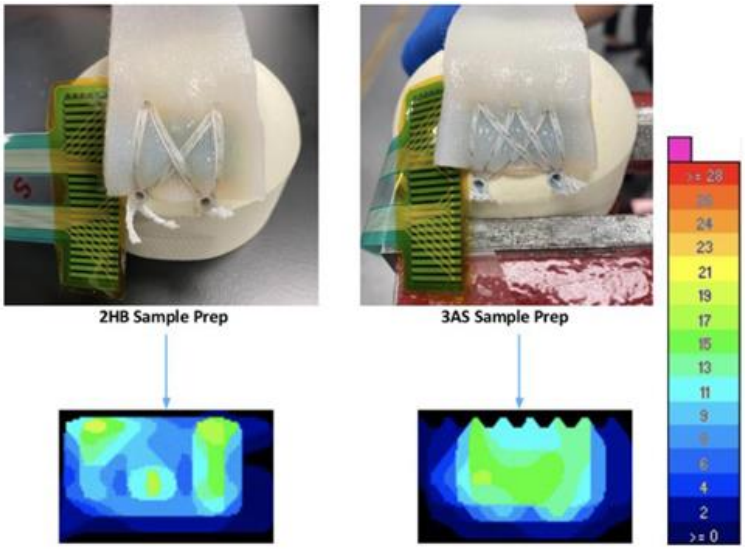

Figure 2: T.R. Hoffman's photograph of the Syndaver model showcasing the contact force setup and comparative pressure maps, with a legend explaining the color-to-force relationship. The setup compares two hard body anchors and three medial all-suture anchors (10).

2.1.2 Advantages

Because it is knotless, it can lead to a more stable and easier Fixation (**Figure 2**). This method allows natural movement. The fixation at isometric points keeps a stable tension through flexion and extension, which lowers the risk of losing the tension with time (8).

2.1.3 Use in cranial cruciate ligament deficient stifle in dogs/ complications

In the study of M. Raske and D. Hulse, they used this method to stabilize the cranial crucial ligament deficient stifles in 41 dogs. They chose the 2mm Fiber Tape, which is a strong multifilament suture with strong resistance and minimal stretch. In these dogs, they strategically placed the suture in two places in femur and tibia at near-isometric points. For this procedure they used arthroscopic assistance to ensure accurate placement. The study utilized a validated owner questionnaire to assess clinical function before and at least six months post-surgery, and results were statistically analyzed. Findings demonstrated significant improvements in clinical function post-surgery across all measured parameters, with most dogs achieving good to excellent outcomes. The study reported 3 major complications (7.3% of cases). Two dogs developed surgical site infections, and one dog sustained a meniscal tear post-surgery. The

surgical site infection rate of 4.9% aligns with general rates for orthopedic surgeries in veterinary practice, suggesting the procedure's safety profile is consistent with similar surgical methods. At the 7-8-week follow-up, 87.8% of cases showed minimal cranial drawer movement of less than 3 mm. No bone anchor pull-out was observed (8).

2.1.4 Use in cranial cruciate ligament deficient dogs

Raske and Hulse concluded that the SwiveLock system provides effective stabilization for cranial cruciate ligament-deficient stifles in dogs, with promising long-term outcomes and a low complication rate. Their findings support the system's efficacy and suggest that isometric suture anchor placement can enhance stability in canine stifle repair procedures (8).

2.2 Arthrex titanium bone anchor

2.2.1 General

For the placement of this implant (**Figure 3**), the lateral approach is used with a limited medial Arthroscopy, which is a small incision on the medial side of the joint to allow exploration of the stifle. The implant is an Arthrex titanium bone anchor (**Figure 3**), which is placed in the distolateral femur. The location should be in the quasi-isometric point approximately 3mm distal to articulation and between the lateral femoral condyle and lateral fabella. As already mentioned in the Knotless Swive Anchor System (**Figure 1**), the isometric points The fixation at isometric points keep a stable tension through flexion and extension movement. A hole is drilled at this point to the femur exiting on the proximal-medial surface of the tibia. The strong suture, for example, FibreWire, is passed through the titanium button and back through the bone tunnel. Afterwards, it is tied in strong knots while enduring stabilization of the joint at the proper anatomical angle (11).

2.2.2 Advantages

The use of the titanium bone anchor and a strong suture material, like FibreWire, ensures a secure and durable repair (11).

2.2.3 Use in cranial crucial ligament deficient stifle in small-to-medium sized dogs

The anchor, shown in Figure 3, was used for 85 dogs with an average age of 7.7 years, ranging from 1-14 years, and an average weight of 8.7 kg, ranging from 2.9 to 18kg. In this study they operated on 47 dogs on the left leg and on 38 dogs on the right leg. 45 dogs had meniscal pathology. Over 63.6 percent had long-term follow-ups with over 6 months later. The complication rate was 30.3 percent, with 17 out of 56 dogs having a complication. 9 of them had minor complications, and 7 of them needed additional surgery because of infection, unstable stifle, or implant failures. And one dog needed to be euthanized because of severe mobility issues. This study showed no correspondence with characteristics of the patient and the complications (11).

2.2.4 Complication rates

The study of N. Rappa and R. M. Radasch showed a complication rate of 30.3 percent, with most of them not needing surgical intervention. And the need to remove the surgical implant was at 1.8 percent. The functional outcome was favorable for 96 percent of dogs achieving full or acceptable function (11).

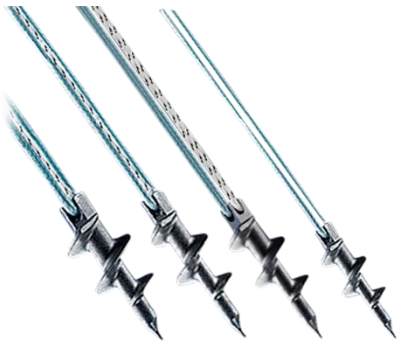

Figure 3: The Arthrex Corkscrew anchor made of titanium (12).

2.3 IMEX suture anchor

2.3.1 General

The IMEX suture anchor (**Figure 4**) is manufactured by IMEX Veterinary. It is used in orthopedic surgery to stabilize ligaments, for example, in case of traumatic joint luxation. By predrilling a hole in the bone, the anchor can be inserted. The anchor is designed to attach the damaged ligament to the bone. By using a locking loop suture pattern, the ligament can be tied to the anchor (13).

2.3.2 Advantages

The locking loop suture ensures more stability (13).

2.3.3 Use for stabilizing the lateral elbow joint after traumatic luxation/ complications

In the study of V. Logothetou et al., 2 dogs were operated on after a traumatic luxation at the elbow joint. They used the lateral approach to the elbow joint. After predrilling with a 2.7mm drill bit, the anchor (**Figure 4**) was placed into the hole in the lateral epicondyle at the insertion of the lateral collateral ligament. With the locking loop suture pattern, the distal part of the ruptured lateral collateral ligament was attached to the anchor. They also used 3 metric polydioxanone suture material to suture the tenotomy of the ulnaris-lateralis-muscle. After surgery, both dogs were hospitalized for a few days and then discharged with pain medicine and restricted activity. 1 dog showed no lameness after 7- and 24-weeks post-surgery and had normal range of motion. The other dog had a relaxation within the 24 hours after surgery, which was managed with revision surgery. After that the elbow remained stable with only occasional mild lameness (13).

The IMEX suture anchor was in the study of V. Logothetou et al. effective for stabilizing the elbow luxation. 1 of them needed revision surgery due to relaxation. But both dogs had good functional recovery with no major long-term complications (13).

Figure 4: IMEX suture anchor by IMEX-Veterinary, used in the study by V. Logothetou et al. (13).

2.4 FASTak anchor (Arthrex)

2.4.1 General

The FASTak Anchor (**Figure 5**) is manufactured by Arthrex. It is a bone anchor method and is also used for stabilizing ligaments in case of traumatic joint luxation. Unlike the IMEX suture anchor, it does not need predrilling before insertion. The anchor was secured and preloaded strong suture material like the FiberWire was used in a locking loop pattern to fix the ligament to the bone (13).

Figure 5: FASTak anchor by Arthrex used in the study by V. Logothetou et al. (13).

2.4.2 Advantages

No pre-drilling is needed, which is less, and it has preloaded suture material (13).

2.4.3 Use for stabilizing the lateral elbow joint after traumatic luxation/ complications

In the study of V. Logothetou et al., one dog was operated on after a traumatic luxation at the elbow joint, and the FASTak anchor was used (**Figure 5**). They used the lateral approach to the elbow joint. The bone anchor was inserted into the lateral humeral epicondyle. The preloaded 3 metric FibreWire was used, and with a locking loop suture pattern, the distal part of the ruptured lateral collateral ligament was attached to the anchor. They used 3 metric polydioxanone suture material for the suturing of the tenotomy of the ulnaris-lateralis-muscle. After surgery, the dog was hospitalized for a few days and then discharged with pain medicine and restricted activity. The dog showed no lameness after 7- and 24-weeks post-surgery and had normal range of motion (13).

2.5 Biocomposite push-fit anchor (Osteoraptor, Smith & Nephew)

2.5.1 General

This anchor (**Figure 6**) is a traditional push-fit design that combines synthetic materials aimed at providing initial stability in the glenoid (shoulder socket). Composed of a bioabsorbable material, biocomposite anchors are designed to gradually degrade while providing temporary support to the labrum during healing. The push-fit mechanism requires a 2.9 mm drill hole, allowing the anchor to be tightly embedded within the glenoid. As it resorbs over time, the biocomposite material should ideally be replaced by bone tissue, though some previous studies have reported osteolytic changes (bone resorption around the implant) in these types of anchors (1).

2.5.2 Use in labral tears requiring shoulder stabilization/ complications

In the study of C. Steward et al., the anchor (**Figure 6**) was used for shoulder stabilization after labral tears in humans. After 3 weeks, the anchor revealed minimal osteolytic response. But after 6 months, the mean grade of pronounces osteolysis was 2.55 (1).

Figure 6: Osteoraptor anchor by Smith & Nephew (14).

2.6 All-Suture anchor (Suturefix Ultra, Smith & Nephew)

2.6.1 General

This anchor (**Figure 7**) is a newer option in labral repair, designed to require a smaller drill hole and theoretically reduce the amount of bone trauma. Unlike solid biocomposite anchors, all-suture anchors use fabric or material that expands to secure the anchor within the bone upon insertion. It is inserted as a collapsed suture material through a smaller, 1.9 mm drill hole. Once inserted, the suture expands to anchor itself within the bone (1).

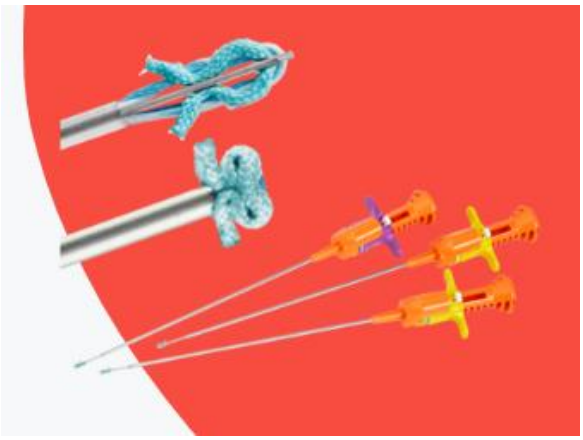

Figure 7: Suturefix Anchorsystem by Smith & Nephew (15).

2.6.2 Advantages

The reduced hole size may help preserve more of the bone structure, which is beneficial for patients who may require revision surgery. This anchor (**Figure 7**) is a more flexible solution, relying on expansion rather than a rigid structure. This anchor design has shown potential for reduced osteolytic activity compared to biocomposite anchors due to its smaller size and flexible integration with bone tissue (1).

2.6.3 Use in labral tears requiring shoulder stabilization/ complications

In the study of C. Steward et al., the anchor shown in Figure 7 was used for shoulder stabilization after labral tears in humans. After 3 weeks, the anchor revealed minimal osteolytic response. And after 6 months, the mean grade of pronounces osteolysis was only at 1.62 (1).

2.7 Healicoil Regenesorb suture anchor (Smith &Nephew)

2.7.1 General

This bone anchor, depicted in Figure 8, is a medical implant developed by Smith & Nephew, Inc., designed for use in orthopedic surgery, particularly in bone and tendon reconstructions. Between the threads of the anchor, material is removed, allowing blood and bone marrow to infiltrate the anchor. It is made from a novel combination of biocomposite materials based on Poly (lactic-co-glycolic acid). These materials also contain ß-Tricalcium Phosphate (ß-TCP)

and Calcium Sulfate, which have osteoconductive properties. The anchor is designed to resorb over time and being replaced by bone (2). The Poly-L-lactic-co-glycolic acid serves as the primary structural element, providing stability over a gradual degradation period of approximately 24 months.

Beta-tricalcium phosphate is a well-documented osteoconductive material that facilitates new bone formation around the anchor, resorbing over roughly 18 months. The Calcium Sulfate degrades within 4 to 12 weeks (16).

Figure 8: Healicoil Regenesorb suture anchor by Smith & Nephew (2).

2.7.2 Advantages

This structure promotes integration with surrounding tissue and supports the healing process. Osteoconductive materials support bone growth by providing a scaffold for new bone tissue to form (2).

2.7.3 Use in bilateral femoral defects in sheep/ complications

In the study of S. Bulman et al. 9 sheep. The implants were screwed in until they were positioned 1 mm below the surface. For each limb, the distal end of the femur was disarticulated at the knee joint, and the femoral cut was made no more than 2 cm above the femoral intercondylar fossa (2). Bone ingrowth was assessed using micro-computed tomography and histological imaging. The Healicoil Regenesorb demonstrated 54.5% of bone ingrowth. After 18 months, 70% of the material resorbed (2).

2.7.4 Use in rotator cuff repairs in humans/ complications

The study by J. Vonhoegen et al. included 48 patients who underwent arthroscopic rotator cuff repair. They had Magnetic resonance imaging at an average follow-up of 21 months. Osteolysis was observed in only 2 out of 82 anchors (2.4%). Both cases of osteolysis were limited to diameters smaller than the 5.5 mm anchor diameter, indicating minimal bone degradation around the implant. Resorption analysis revealed that 50% of the anchors had completely degraded and were no longer visible, while 25% were partially resorbed with minimal residual material visible on MRI. Only 12.5% of anchors retained most of their structure, suggesting a controlled and predictable degradation process. Only two cases of tendon retears (4.2%) were documented, with no cases of anchor pull-out (16).

2.8 BioComposite Corkscrew (Arthrex)

2.8.1 General

The biocomposite Corkscrew, which you can see in Figure 9, is a type of suture anchor used in orthopedic surgeries designed for rotator cuff repair. It is described as being made from a biocomposite material, specifically a combination of Poly-L-Lactic Acid and ß-Tricalcium Phosphate. The corkscrew design refers to the shape of the anchor, which is typically designed to be screwed into bone to provide secure fixation for tendons or ligaments during reconstruction or repair procedures. The anchor is designed to resorb over time and being replaced by bone (2).

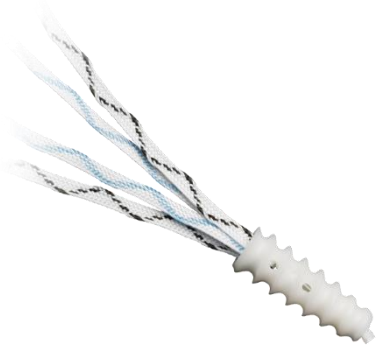

Figure 9: A BioComposite Corkscrew anchor by Arthrex (17).

2.8.2 Advantages

The materials have osteoconductive properties, meaning they support bone growth and help integrate the anchor into the bone (2).

2.8.3 Use in bilateral femoral defects in sheep/ complications

In the study of S. Bulman et al. 9 sheep. The implants were screwed in until they were positioned 1 mm below the surface. For each limb, the distal end of the femur was disarticulated at the knee joint, and the femoral cut was made no more than 2 cm above the femoral intercondylar fossa. Bone ingrowth was assessed using micro-computed tomography and histological imaging. The anchor showed 29.8% of bone ingrowth. After 18 months, 57% of the material resorbed (2).

2.9 JuggerKnot long soft anchor (Zimmer Biomet)

2.9.1 General

The JuggerKnot anchor (**Figure 10**) uses the suture material's expansion within the bone to achieve a strong, secure hold. This fixation method offers biomechanical benefits (e.g., low cyclic displacement) while preserving bone structure, making it ideal for surgeries where maintaining bone integrity is essential (18).

Figure 10: JuggerKnot anchor by Zimmer Biomet (19).

2.9.2 Advantages

The JuggerKnot Long Soft Anchor (**Figure 10**) is a highly effective choice for procedures like hip labral repairs, primarily due to its bone-conserving design. Unlike traditional anchors, the JuggerKnot requires only a small drill hole, reducing bone trauma and preserving the structure, especially in revision surgeries or cases with low bone density. This minimal bone impact allows surgeons to place multiple anchors in a limited area without risking structural integrity. In terms of performance, the JuggerKnot provides strong fixation comparable to larger anchors, with high resistance to cyclic loading, meaning it holds steady even under repetitive stress. This stability minimizes "anchor creep," or loosening, which is crucial for durable repairs. The anchor's load is evenly distributed across the suture rather than concentrated at a single point, reducing stress on the bone and lowering the risk of fractures. Its simple suture-based expansion ensures a secure fit, making placement straightforward and effective across various procedures (18).

2.9.3 Use in hip labral repair procedures in humans/ conclusions

These anchors were subjected to tests simulating hip labral repair procedures, examining both cyclic displacement and ultimate failure strength. Cyclic displacement measures the extent of movement of the anchor under repetitive load, and maintaining low displacement is essential for stability. The JuggerKnot Long Soft Anchor required 73% less bone surface area for placement compared to competing anchors. This feature allows for additional fixation points during labral repairs, offering potential benefits for patients with low bone density or where the conservation of bone is critical (18).

2.10 BioWick SureLock (Zimmer Biomet)

2.10.1 General

The suture anchor implant is an all-suture anchor construct with braided ultra-high-molecular-weight polyethylene suture fibers and a polyether ether ketone anchor component that houses and protects the scaffold and suture components. The scaffold component is a porous, aligned fiber matrix composed of 1-mm diameter poly-L-lactide-co-glycoside fibers produced using electrospinning techniques (20).

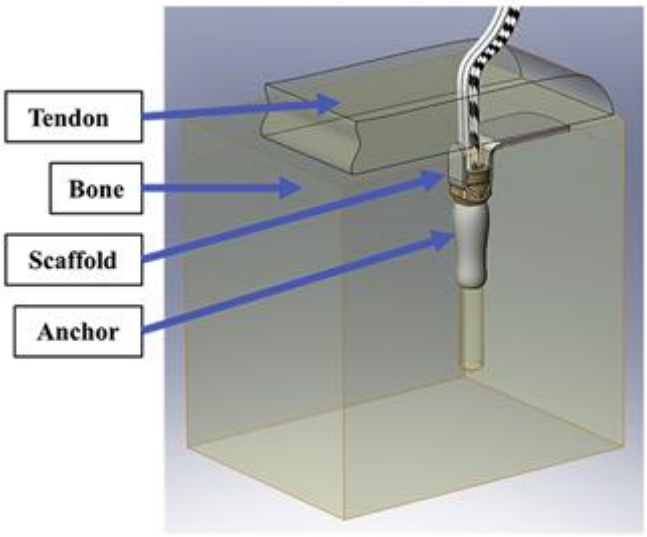

Figure 11: Model of the BioWick SutureLock with the new scaffold (20).

2.10.2 Advantages

The BioWick Anchors use a bioresorbable scaffold attached to the vented suture anchor, which promotes tendon-to-bone healing. These enhanced cellular processes are critical for tissue repair and can lead to faster and more efficient wound healing, which leads to more stable implants, with less complications. In the study "A prospective study comparing tendon-to-bone interface healing using an interposition bioresorbable scaffold with a vented anchor for primary rotator cuff repair in sheep" conducted by Jeremiah Easley et al. in 2020, both groups of test subjects displayed mild inflammation, but the treatment group had lower inflammation scores compared to controls, particularly at 12 weeks. No adverse immune responses or negative effects were observed with the PLGA scaffold, supporting its biocompatibility (20).

2.10.3 Use in primary rotator cuff repair in sheep/ results

In a detailed experimental study published in the Journal of Shoulder and Elbow Surgery, Easley et al. (2020) investigated the efficacy of a novel bioresorbable scaffold attached to a vented suture anchor in promoting tendon-to-bone healing in a rotator cuff repair model in sheep. The study aimed to determine if using a scaffold-integrated suture anchor would improve biomechanical strength and tissue integration at the tendon-bone interface compared to standard anchors. The experiment involved 56 skeletally mature female Columbia Cross sheep, with the sample divided into two groups: The Treatment Group underwent rotator cuff repair using a

vented suture anchor with an integrated bioresorbable scaffold made of poly lactic-co-glycolic acid. While the Control Group received rotator cuff repairs using a similar vented anchor but without the scaffold. The bioresorbable PLGA scaffold was designed as an aligned fiber matrix produced through electrospinning techniques, a process that allows for small-diameter fibers conducive to cell migration and tissue integration. The purpose of this scaffold was to enhance the biological response at the repair site, ideally supporting fibroblast activity and tissue ingrowth to strengthen the tendon-bone attachment over time. The study was divided into two euthanization time points, 7- and 12 weeks post-surgery, allowing researchers to assess healing progress over time. The sheep's infraspinatus tendon was sharply detached from the humeral footprint and then reattached using a double-row suture anchor technique. Animals were randomly assigned to one of the two groups and euthanized at either the 7-week or 12-week mark to evaluate the outcomes at early and later stages of healing (20).

The study by Easley et al. concludes that the PLGA scaffold attached to a vented anchor provides a favorable histologic environment for tendon-to-bone healing, with increased fibroblast activity, tendon-bone integration, collagen III deposition, and new bone formation. These findings suggest that the scaffold could offer long-term benefits for rotator cuff repairs by creating a biological environment that supports healing and integration (20).

2.11 Interference screws

2.11.1 General

In the study by Borjali et al. (2021), interference screws (visible in Figure 11) are discussed as the "gold standard" for anterior cruciate ligament reconstruction. Interference screws function by pressing the tendon graft against the walls of a drilled bone tunnel, creating high friction that stabilizes the graft within the tunnel. The screw is inserted into the tunnel parallel to the graft under tension, embedding the graft within the bone and maintaining fixation. The threads of the screw grip both the graft and the tunnel walls, enhancing fixation strength and stability. This configuration minimizes graft motion and supports early healing by keeping the graft in close contact with bone tissue (21).

2.11.2 Advantages

According to Borjali, Interference screws offer high fixation strength by pressing the graft tightly against the bone tunnel walls, reducing slippage and enhancing stability, especially under

cyclic loading conditions. This strong fixation supports early biological healing by keeping the graft in close contact with the bone, allowing for faster integration and enabling earlier load-bearing during rehabilitation. Their extensive clinical use also provides a proven track record, making them a reliable choice for ligament reconstruction with predictable outcomes (21).

2.11.3 Study in rabbits to test the effect of a new material (Titanium) for interference screws

A study from Pei-I Tsai from 2018 investigates the effectiveness of a newly designed porous titanium interference screw in enhancing bone-tendon fixation, using rabbits as animal models. The objective was to improve the performance of bone implants, especially in anterior cruciate ligament reconstruction, by using additive manufacturing to create a titanium alloy interference screw with a rough, porous surface structure. Twenty-seven New Zealand white rabbits were selected as the animal model. These rabbits were divided into three groups, each corresponding to one of the postoperative time points: 4, 8, and 12 weeks. Using computer-generated randomization, one stifle joint of each rabbit received a traditional stainless steel interference screw as control, while the other joint was implanted with the additive-manufactured titanium screw (the experimental group). This randomized bilateral implantation allowed for direct within-animal comparisons between the titanium and control screws across the study period (22).

The study included three main analysis methods to assess the effectiveness of the titanium screws. First, biomechanical testing was performed using a material testing machine to evaluate ultimate failure load. Second, micro-computed tomography scans assessed the bone-screw integration and quantified new bone growth around the implant. And histological, revealing the degree of bone ingrowth and the quality of bone-tendon integration at each time point (22).

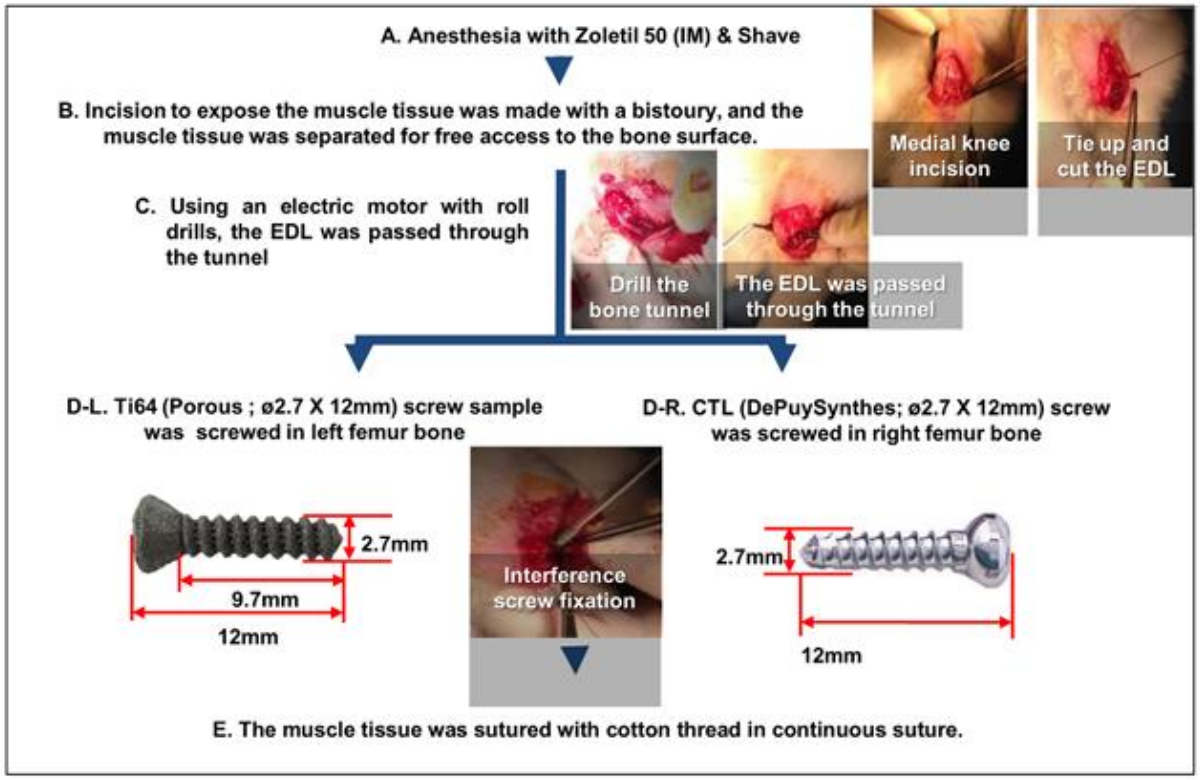

Figure 12: A description of the procedure in the study by Pei-I Tsai which compares a controlled interference screw with an additive-manufactured porous interference screw (22).

Results: The titanium screws showed higher ultimate failure loads in biomechanical tests at all time points (4, 8, and 12 weeks). Micro-computed tomography scans revealed greater bone formation around the titanium screws, with closer bone-screw contact and reduced gaps compared to the control screws.

Histological analysis supported these findings, showing closer bone-tendon integration and minimal gaps between the bone and titanium screws (22).

2.12 BASHTI - Bone and Site Hold Tendon Inside

2.12.1 General

The BASHTI (Bone and Site Hold Tendon Inside) technique is an organic, implant-free method developed as an alternative to traditional fixation techniques, like interference screws. A core bone plug is first harvested from either the tibia or femur, creating a bone tunnel. The tendon graft is then positioned within this tunnel, and the core bone plug is reinserted and hammered back into place, holding the graft tightly without using any metal or biodegradable implants.

This process creates a secure bone-to-bone interface that promotes faster healing due to better biological compatibility and reduced inflammation (21).

Figure 13: A graphic used by Narges Ghias in his 2022 paper on BASHTI, showing how a bone fragment is used instead of a metal or polymer implant (23).

2.12.2 Advantages

According to Borjali et al. (2021), This technique provides several advantages in ligament reconstruction by using the patient's own bone to secure the graft, eliminating the need for synthetic implants. This approach reduces the risks of inflammatory reactions, implant-related complications, and imaging interference. BASHTI also promotes faster healing through a bone-to-bone interface, enhancing biological integration and potentially lowering costs compared to traditional fixation methods like interference screws (21).

2.12.3 Comparison of BASHTI to Interference screws, Study by Borjali et al. (2021)

Borjali et al. (2021) conducted a study to compare the two aforementioned techniques, BASHTI (**Figure 13**) and Interference screws. The study showed that Bashti offers advantages over interference screws (**Figure 12**) by eliminating synthetic implants, thus reducing risks of inflammatory reactions, complications from degradation, and imaging interference. It also promotes faster healing through a bone-to-bone interface and is generally more cost-effective. However, the technique provides lower fixation strength than interference screws, relying on friction without threads, which increases the risk of graft slippage (**Figure 14**) during cyclic

loading and may limit early rehabilitation. Additionally, its effectiveness depends on the patient's bone density, making it less reliable in individuals with lower bone quality (21).

Fixation Technique	Tendon Diameter (mm)	Slippage Failure (%)	Tearing Failure (%)
Interference screw	8	0	100
Interference screw	9	0	100
BASHTI	8	100	0
BASHTI	9	100	0

Figure 14: Table depicting the different occurring modes of failures in Borjalis study (21).

2.13 Arthrex Bio-Tenodesis interference screws

2.13.1 Advantages to anchors

A study by Lee Jeys from 2004 compared the biomechanical performance of two fixation methods: MiTek GII anchors and Arthrex Bio-Tenodesis interference screws in porcine models. The results showed that interference screws provided significantly higher failure load (227 N vs. 114 N for anchors) and lower elongation at failure (22% vs. 37%), indicating stronger and more stable fixation. Cyclic preloading also improved performance by increasing failure load and reducing elongation. The findings suggest that interference screws may be more effective in clinical applications than bone anchors (24).

3 Comparison of tendon to bone fixation

3.1 Insertion/ use

A study by J.L. Robb et al. compared the Cortical Screws, Cancellous screws, BoneBiter suture anchor, and the IMEX anchors with 4.7mm and 4.0 mm, both with 18-gauge wire and the TwinFix 5.0mm. The Insertion was described as user-friendly except for the BoneBiter, which was the hardest to insert (25).

Another study evaluated the acute load to failure and cyclic load to failure of three veterinary and one human suture anchor in canine femoral condyles, with the anchors being placed in the cranial and caudal aspects of the femoral condyle. Results showed no significant difference in acute load to failure for any anchor type in the cranial aspect. Still, all veterinary anchors exhibited a higher acute load of failure in the caudal aspect of the femoral condyle. So, it concluded that veterinary anchors provided a higher acute load of failure in the caudal compared to the cranial aspect of the femoral condyle (26).

3.2 Complication Rates

The Knotless SwiveLock Anchor (**Figure 1**) was used in a study involving 41 dogs with cranial cruciate ligament deficiency. The complication rate was 7.3%, with three major complications reported: two cases of surgical site infections and one meniscal tear post-surgery. This suggests a relatively low complication rate consistent with general orthopedic procedures (8).

The IMEX suture anchor also had relatively low complication rates. In a study involving two dogs with traumatic elbow luxation, one dog required revision surgery due to relaxation of the suture. However, both dogs showed good functional recovery with no major long-term complications (13).

In this same study, the FASTak Anchor (**Figure 5**) was used on a dog with elbow luxation, and it showed good functional recovery post-surgery. No complications were detailed, suggesting a low complication rate for this anchor (13).

The JuggerKnot Long Soft Anchor (**Figure 10**) showed excellent results in terms of bone conservation and strength under cyclic loading, with no major complications like anchor pull-out or fractures. The anchor demonstrated strong fixation and minimal cyclic displacement, indicating a low risk of complications (18).

Arthrex Titanium Bone Anchor (**Figure 3**): In a study of 85 dogs, the complication rate was at 30.3%. Of the 17 dogs with complications, 9 had minor issues, 7 required additional surgery due to infection, implant failure, or unstable stifles, and 1 dog had to be euthanized due to severe mobility issues. Despite this, 96% of dogs achieved good to excellent functional outcomes (11).

BioWick SureLock (**Figure 11**): In a study on rotator cuff repairs in sheep, the BioWick SureLock showed favorable outcomes with lower inflammation and no adverse immune responses. This suggests a low complication rate, especially in terms of inflammatory reactions and tissue healing (20).

3.3 Bone response

The study by Stewart et al. (2020) aimed to compare the bone response of two suture anchor types in humans biocomposite push-fit anchors (Osteoraptor, Figure 6) and all-suture anchors (Suturefix Ultra) commonly used in arthroscopic labral repair surgeries. The study followed 17 patients with a total of 37 unique anchors who underwent shoulder stabilization procedures due to labral tears. Using MRI scans at 3 weeks and 6 months postoperatively, researchers assessed osteolysis as a measure of bone response (**Figure 15**) (1).

MRI scans at 3 weeks revealed minimal osteolytic response for both anchor types.

There was no significant difference in osteolysis levels between the two anchor types at this early time point, suggesting similar initial bone responses for both anchors.

At the 6-month follow-up, the bone response diverged significantly between the two anchor types. Biocomposite anchors showed a mean grade of 2.55, indicating more pronounced osteolysis. All-suture anchors had a mean grade of 1.62, reflecting lower osteolytic changes. (**Figure 15**) The difference in osteolysis between the two anchor types was significant at this point ($p = 0.040$), suggesting that all-suture anchors cause less bone degradation over time.

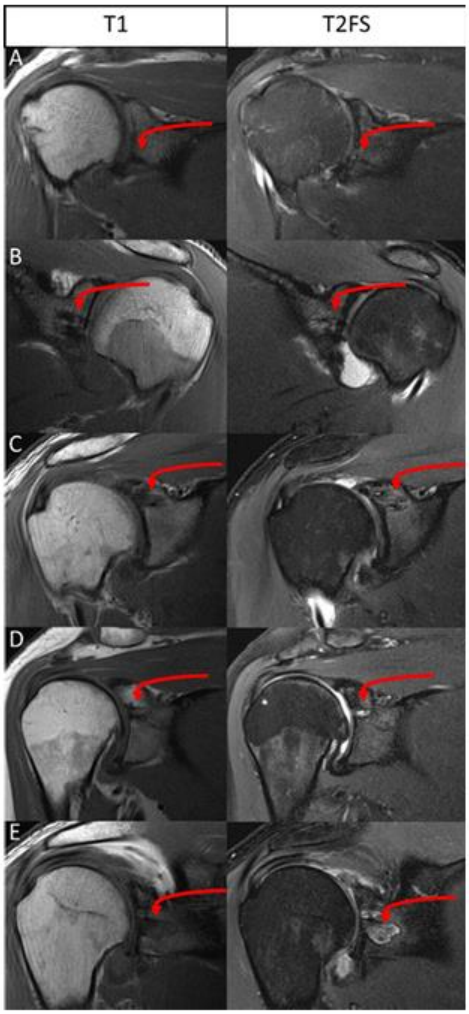

Figure 15: The examples of each grade, as included in the training resource provided to the raters in the study of Stewart, are shown. Each anchor is visualized using coronal T1- and T2-weighted fat-suppressed magnetic resonance images, which assign a grade to the suture anchor based on the bone response. (A) Grade 0, (B) Grade 1, (C) Grade 2, (D) Grade 3, and (E) Grade 4. Anchors being highlighted by red arrows (1).

The study indicates that all-suture anchors may have an advantage over biocomposite anchors by preserving bone integrity better over time. Lower levels of osteolysis around the all-suture anchors (**Figure 15**) suggest that they may offer more stable support for labral repairs and reduce complications associated with bone loss (1).

In the study of S. Bulman et al., the comparison between the Healicoil Regenesorb Suture anchor (**Figure 8**) and the biocomposite Corkscrew (**Figure 9**) showed significant differences. Both anchors are designed to resorb with time. The Bone Integration after 18 months showed that the Healicoil Regenesorb anchor had significantly better bone ingrowth compared to the

Arthrex BioComposite Corkscrew. Also, the Healicoil Regenesorb demonstrated 54.5% of bone ingrowth, compared to 29.8% in the Arthrex anchor (2). The resorption rate of the Healicoil Regenesorb was faster, with 70% of the material resorbed after 18 months, compared to 57% for the Arthrex BioComposite Corkscrew (2). Histological and with micro-computed tomography scans, the study showed that bone grew into areas where the implant had resorbed, suggesting effective integration and bone healing in the regions of the anchor (2).

The Healicoil Regenesorb suture anchor showed superior bone ingrowth, faster resorption, and better clinical outcomes for rotator cuff repairs when compared to traditional anchors in this preclinical study in sheep (2).

The study by J. Vonhoegen et al. on arthroscopic rotator cuff repair with the Healicoil Regenesorb suture anchor found minimal osteolysis, with only 2.4% of anchors showing bone degradation. Resorption analysis revealed 50% of anchors had fully degraded, and 25% were partially resorbed. Only 12.5% retained most of their structure, indicating predictable degradation. The study reported a low incidence of tendon retears (4.2%) and no anchor pull-outs, suggesting stable bone integration and favorable long-term outcomes (16).

The study of H. Haneveld et al. showed the osseous reaction after arthroscopic double-row rotator cuff repair when using bio-absorbable poly-L-lactic acid and non-absorbable polyetheretherketone suture anchors, which are the more traditional anchors in comparison to the Healicoil Regenesorb suture anchors. Both materials in this study lead to osseous reactions like tunnel widening. The Peri-implant fluid was pronounced when using the poly-L-lactic acid anchors (5).

Also, the study of Sean Hoon Kim et al. showed the common complications after the use of bioabsorbable anchors. They used polylactic acid enantiomers, poly-D, L-lactide from L-lactide and D-lactide. The common complications were Osteolysis and cyst formation. Cyst formation happened in 46.4%. The healing of the impaired tendon was successful in 62.7% (4).

3.4 Bone Preservation

A study conducted by Jason Hurst, M.D., in collaboration with Biomet Sports Medicine's R&D team, evaluates the biomechanical properties of the JuggerKnot Long Soft Anchor (**Figure 10**) in cadaver hip bone models. The aim was to assess cyclic displacement and maximum load-bearing capacity in comparison to other commonly used suture anchors. The paper tested the performance of the JuggerKnot Long Soft Anchor against other anchors, such as the Biocomposite PushLock (Arthrex) Knotless Anchor and Bioabsorbable Bioraptor (Smith &

Nephew) Anchor. These anchors were subjected to tests simulating hip labral repair procedures, examining both cyclic displacement (**Figure 16**) and ultimate failure strength. In the load-to-failure tests, all anchors displayed comparable maximum resistance. The lack of statistically significant differences in load capacity among the JuggerKnot, PushLock, and Bioraptor anchors suggests that each can withstand similar maximum forces before detachment under testing conditions. Moreover, the JuggerKnot Long Soft Anchor required 73% less bone surface area compared to the other anchors (**Figure 16**), an advantageous design feature for preserving bone and allowing for multiple fixation points if necessary. This study thus highlights the JuggerKnot Long Soft Anchor's potential, offering reduced cyclic displacement, competitive load resistance, and minimized bone impact, which collectively make it a strong option for surgical applications requiring stable, reliable fixation points (18).

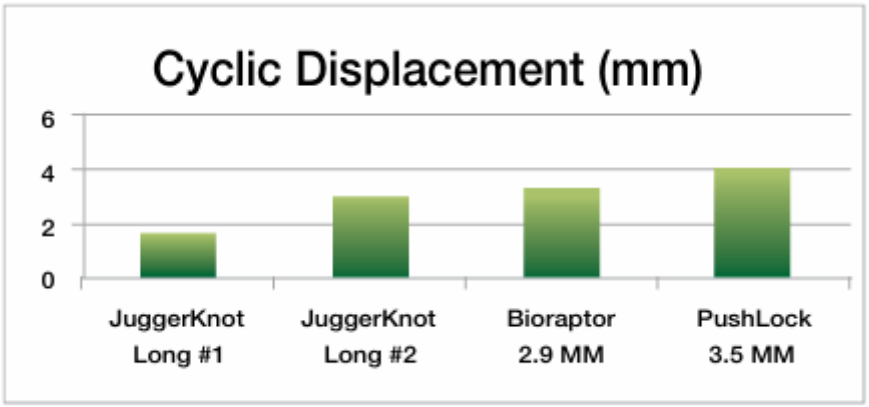

Figure 16: Results by Hurst, depicting the cyclic displacement of certain Anchors (18).

3.5 Holding Power/ load of failure

The study by J.M. Balara et al. evaluated the mechanical performance of a veterinary bone anchor in canine humeri under static and cyclic loads. Using cadaveric humeri from six skeletally mature dogs, anchors were tested for their holding strength in both longitudinal and perpendicular orientations. In the longitudinal direction, the screw-type anchor had an initial holding power of 385 N. After 1200 cycles of loading at 50% of the failure load, its strength remained stable at 335 N (no significant change). In the perpendicular direction, the anchors exhibited higher holding power, reaching 514 N after 1200 cycles of cyclic loading at 100% of the longitudinal strength, with failure occurring due to suture breakage. The study found that the anchor's strength is orientation-dependent, with perpendicular loading providing higher holding strength. Longitudinal cyclic loading did not compromise the anchor's holding power,

suggesting the bone anchor is reliable for use in the proximal humerus of large-breed dogs, withholding strengths around 385 N longitudinally and 514 N perpendicularly (6).

The study of K. A. R. Kunkel et al. also focused on the comparison of different orientations. This study evaluated the acute load to failure and suture abrasion of a novel screw-type mini-anchor design, tested at two orientations (0° and 90°) in synthetic bone. The results showed that the mini-anchor had a mean acute load to failure of 431.8 ± 70.8 N at 0° and 683 ± 48.7 N at 90°, with the 90° orientation significantly outperforming 0° in terms of load to failure. But there were no significant differences in yield strength and stiffness between the two orientations (7).

A study by Robb et al. compared the ease of insertion, load to failure, and failure modes of various bone anchors cortical and cancellous screws, BoneBiter, IMEX, and TwinFix in canine tibial metaphyseal bone. A single investigator inserted the anchors into cadaveric tibias and assessed the ease of placement. The anchors were then loaded to failure, and failure modes were recorded.

In terms of load to failure, cancellous screws (711 ± 193 N) had the highest strength, followed by IMEX 4.7 mm and 4.0 mm wires (661 ± 163 N and 661 ± 165 N, respectively), cortical screws (635 ± 184 N), BoneBiter #5 Kevlar suture (393 ± 109 N), and TwinFix 5.0 mm #2 polyester suture (267 ± 73 N). No significant difference in load to failure was found between the cortical and cancellous screws and the IMEX anchors, all of which were significantly stronger than BoneBiter and TwinFix.

Failure modes varied by anchor type. Screws primarily failed by pullout, while IMEX anchors showed pullout or wire breakage. BoneBiter and TwinFix anchors failed due to suture or wire breakage.

Cortical and cancellous screws, along with IMEX anchors (**Figure 4**), demonstrated significantly greater load to failure compared to BoneBiter and TwinFix. The failure modes were influenced by the anchor design and suture material. Based on their superior performance, ease of use, and cost-effectiveness, IMEX anchors may offer advantages over other soft tissue fixation devices in veterinary practice (25).

S. Raymond Golish et al. conducted a study to compare the biomechanical effectiveness of two fixation methods for subpectoral proximal biceps tenodesis: the Bio-Tenodesis screw and the Bio-Corkscrew suture anchor (**Figure 9**), both by Arthrex. Using nine pairs of cadaveric shoulders, the researchers assessed each method's performance by measuring load-to-failure

and stiffness. Results showed that the Bio-Tenodesis screw had a significantly higher load-to-failure (169.6 N vs. 68.5 N) and greater stiffness (34.1 N/mm vs. 19.3 N/mm) than the Bio-Corkscrew anchor. These findings suggest that the Bio-Tenodesis screw provides stronger and more stable fixation, indicating it may be more effective for clinical applications (27).

3.6 Suture abrasion

The study of K. A. R. Kunkel also tested for suture abrasion. The anchors with #5 and #2 Fiberwire survived significantly more cycles than those with 30 lb and 40 lb nylon leader line (NLL) at 90°. At 0°, 30 lb NLL survived fewer cycles than Fiberwire. The orientation of the suture within the anchor eyelet did not significantly affect suture abrasion for Fiberwire sutures (7).

Another tested the acute load to failure (ALF) and cyclic load to failure of three veterinary and one human suture anchor in canine femoral condyles. They used two different suture materials: 5 USP Fiberwire and 27 kg test nylon leader line. Except for one anchor in which the nylon leader line performed better, the Fiberwire and nylon leader line both had a similar cyclic performance with each veterinary anchor type. But Fiberwire was significantly stronger than the nylon leader line in post-cycling acute load to failure testing (26).

3.7. Material and design differences

3.7.1 Materials – Metals

Stainless steel: Traditional material known for high mechanical strength.
Complications with stainless steel include high rigidity, which leads to stress shielding, which can impair natural load transmission and cause surrounding bone weakening. Stainless steel screws also interfere with MRI and CT imaging, making post-operative monitoring challenging. Secondary surgery is often needed to remove the hardware due to long-term interference with surrounding tissue and the risk of infection or implant loosening (3).

Titanium and titanium alloys: Lighter and more resistant to corrosion compared to stainless steel, with reduced MRI interference.

Complications: Although less problematic with imaging, titanium screws may cause osseointegration, that's when they become integrated into the bone, making removal difficult and potentially causing bone damage. Titanium particles can lead to localized inflammation, with risks of sinus formation, osteolysis and hypersensitivity reactions. There's also potential for particle buildup due to wear, leading to inflammatory responses (3).

A study by Pei-I Tsai (2018) investigated the use of porous titanium interference screws in rabbits for anterior cruciate ligament reconstruction. The titanium screws showed higher ultimate failure loads, better bone-screw integration, and reduced gaps compared to stainless steel screws. These findings suggest that the porous titanium screws offer enhanced bone-tendon fixation (22).

3.7.2 Materials – Biodegradable polymers

Poly-l-lactic acid (PLLA): A slow-degrading polymer with high crystallinity and reduced inflammatory response. PLLA is commonly used for its stability and compatibility with graft.
Complications: PLLA screws degrade slowly, sometimes over several years, which can lead to tunnel widening in the surrounding bone due to the accumulation of acidic byproducts from degradation (**Figure 17**). The slow degradation also causes localized inflammatory reactions, osteolysis, and occasionally cyst formation. Patients may experience fluid effusion (fluid collection around the joint) due to the inflammatory response triggered by PLLA degradation.

Poly-glycolic acid (PGA): This material degrades faster than PLLA and is sometimes used in combination with other materials to adjust the degradation rate.
Complications: PGA's rapid degradation leads to an early loss of mechanical stability, increasing the likelihood of screw breakage and instability in the early postoperative phase (**Figure 17**). It may cause inflammatory responses, tissue irritation, and effusion as it degrades quickly, making it less suitable for high-load applications in ligament fixation.

Poly-lactic-co-glycolic acid (PLGA): Combines PLLA and PGA properties, providing a more controlled degradation rate and biocompatibility.
Complications: PLGA's degradation products (lactic and glycolic acid) can accumulate locally, causing acidity that may induce inflammatory responses, tissue irritation, and foreign body reactions (**Figure 17**)**.** These reactions can result in osteolysis, bone tunnel widening, and in

some cases, sterile abscess formation. The variable degradation rate also makes PLGA less predictable in long-term applications.

Polylactide carbonate (PLC): A co-polymer of poly-DL-lactide and calcium carbonate, which provides mechanical strength and osteoconductivity.

Complications: PLC screws have shown synovitis (inflammation of the synovial membrane) and knee swelling in some cases, likely due to irregular degradation rates. Clinical reports have indicated excessive foreign body reactions and synovial fluid buildup, especially when degradation is uneven (**Figure 17**). Patients may experience significant swelling, pain, and implant migration if the screws break down unevenly.

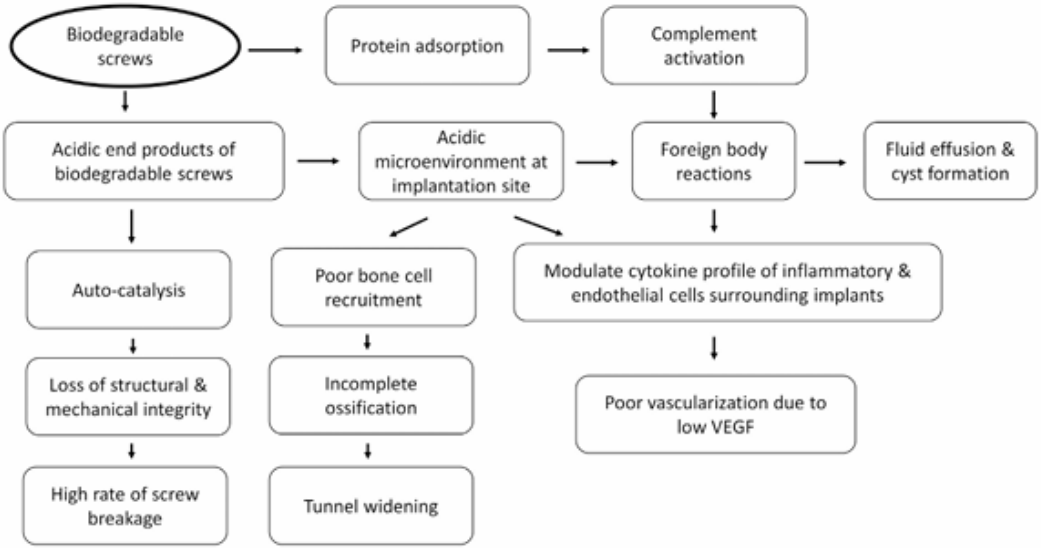

Figure 17: Ramos' proposal for complications occurring with biodegradable screws (3).

3.7.3 Materials - Polymer-Ceramic Composites

PLLA/β-Tricalcium Phosphate (β-TCP): Combines PLLA with β-TCP to enhance osteoconductivity, encouraging bone growth and reducing acidic byproduct effects.
Complications: While adding β-TCP improves osteointegration, the composite can still elicit inflammatory responses, especially if degradation rates are not well-controlled. In rare cases, bone tunnel enlargement and sterile abscesses have been reported, though these are typically less severe than in pure polymeric screws.

PLLA/Hydroxyapatite (HA): HA promotes bone ingrowth, reducing foreign body reactions. The composite gradually resorbs, offering better stability and minimal tunnel widening over time.
Complications: The incorporation of HA reduces inflammatory responses, but complications like bone tunnel widening, cyst formation, or osteolysis may still occur if the degradation is not well-matched to tissue healing. HA also has a brittle nature that can lead to screw breakage during insertion, although it generally promotes better bone in-growth than PLLA alone.

PLGA/β-TCP or HA: A composite that offers both controlled degradation and improved osteointegration by combining PLGA with osteoconductive ceramics like β-TCP or HA.
Complications: The composite offers better osteointegration and controlled degradation, but inflammatory reactions can still occur, particularly with the rapid breakdown of PLGA. Patients may experience sterile effusion, cyst formation, or inflammatory responses if the acidic byproducts accumulate faster than the tissue can neutralize them.

Poly (propylene fumarate) (PPF): PPF provides good mechanical reinforcement and degrades into biocompatible byproducts. It's cross-linkable, which enhances mechanical stability but may hinder cell migration in some scaffold forms.
Complications: Although PPF is biocompatible, its structure may impede cell migration, potentially reducing tissue healing around the implant. In some applications, its degradation products, like fumaric acid, can lead to localized inflammatory reactions or osteolysis if not properly managed.

3.7.4 Materials – Emerging Materials

Magnesium-Based Screws: Magnesium and its alloys are used for their biocompatibility, bone-like mechanical properties, and ability to biodegrade without acidic byproducts. Magnesium-based screws are a promising alternative to both polymers and metals.
Complications: Magnesium's rapid degradation in chloride-rich environments like body fluids can cause early loss of mechanical integrity. This rapid degradation can result in excessive hydrogen gas production, which can form gas pockets, causing localized swelling, discomfort, and compromised fixation if the material degrades too quickly

Polyetheretherketone (PEEK): A bio-inert polymer that is resistant to chemical and thermal degradation, easy to image, and mechanically robust, with minimal inflammatory response.
Complications: While generally bio-inert, PEEK does not degrade and may require secondary surgery for removal, similar to metal screws. There is also potential for implant loosening due to lack of natural integration with bone, and localized stress shielding can still occur, though to a lesser extent than with metal screws (3).

4. Conclusion

Suture anchors are a cornerstone in both, human and veterinary orthopedic surgeries, playing an essential role in stabilizing joints and facilitating tendon and ligament repairs. These devices are designed to attach soft tissues to bones, making them critical in treating conditions such as rotator cuff tears, ligament reconstructions, and joint dislocations. As such, the choice of suture anchor, considering factors like material, design, and biomechanical properties, has become a focal point of research aimed at improving surgical outcomes.

Recent studies have investigated various aspects of suture anchor technology, particularly focusing on material types, anchor design, biomechanical performance, and biological integration. Traditional metallic anchors have been largely replaced by bioabsorbable alternatives and, more recently, by all-suture anchors, which are a newer category offering certain advantages. For example, bioabsorbable anchors, made from materials like poly-L-lactic acid (PLLA), are designed to degrade over time, reducing the need for removal and minimizing the long-term complications associated with metallic implants. However, these anchors have

limitations, including slower degradation rates, reduced strength over time, and the potential for foreign body reactions, which can complicate healing.

Studies like those by Stewart et al. (2020) have highlighted the differences between traditional biocomposite push-fit anchors and all-suture anchors, noting that the latter may reduce the risk of osteolysis, a condition where bone is resorbed due to anchor-induced inflammation (1). This study found that all-suture anchors preserved bone integrity better than their biocomposite counterparts, suggesting they could offer a safer alternative in cases requiring high bone preservation (1). Similarly, Bulman et al. (2016) compared the bone integration properties of different types of anchors, such as Healicoil Regenesorb and Corkscrew anchors, focusing on their osteointegration capabilities. The study concluded that the Healicoil Regenesorb anchors promoted superior bone ingrowth, potentially resulting in better long-term anchorage and fewer complications (2).

While bioabsorbable anchors show promise, they also come with challenges. Ramos (2020) discusses the complications often associated with metallic anchors, such as osteolysis, stress shielding, and delayed healing due to the non-absorbable nature of these materials (3). In response to these issues, many researchers are turning to composite materials like PLLA combined with β-tricalcium phosphate (TCP), which aim to offer better mechanical properties and facilitate enhanced osteointegration. Such advancements may help to minimize adverse reactions and improve the healing process, particularly in high-load environments such as in weight-bearing joints.

The biomechanics of anchor placement are also a key factor in their success. Balara et al. (2004) and Kunkel et al. (2013) explored various anchor types' mechanical properties and performance in canine models, emphasizing the importance of anchor orientation, bone density, and load distribution when designing anchors for veterinary patients. These studies have shown that the success of anchor placement depends not only on material choice but also on how well the anchor is integrated into the bone, as well as the forces acting on the joint (6. 7). For instance, Kunkel et al. (2013) demonstrated that screw-type anchors exhibit higher load-to-failure strengths compared to other designs, making them preferable for areas subject to high mechanical stress (7).

Another significant aspect of anchor technology is the strength of the suture used in conjunction with the anchor. Suture abrasion is a well-documented concern, with some anchors experiencing significant wear on the suture due to mechanical forces, leading to premature failure. Golish et al. (2008) and Hurst (2013) examined this issue and found that materials like the Bio-Tenodesis

screw and JuggerKnot Long Soft Anchor exhibit superior suture retention and less abrasion, leading to higher load-to-failure thresholds and increased durability (27, 18). These findings are critical for improving the longevity and reliability of the suture anchor systems, especially in high-stress surgical applications such as rotator cuff repairs and ligament reconstructions.

Biomechanical testing of suture anchors in veterinary medicine, where the forces acting on joints are often greater than in humans, further highlights the need for anchors to be both strong and flexible. Studies like those by Robb (2005) and Stewart et al. (2020) emphasize that anchors must be able to withstand not only the mechanical load but also the physiological stresses imposed on joints during rehabilitation (25, 1). Robb's study, for instance, tested the performance of cortical and cancellous screw anchors in canine tibial bone and found that while screw-type anchors performed well under cyclic loading, their performance was influenced by the bone type and anchor material (25). This underscores the importance of tailoring suture anchor designs to different species' unique anatomical and mechanical demands.

In conclusion, the current research on suture anchors for both human and veterinary orthopedic applications underlines the importance of choosing the right anchor material, design, and placement technique. While bioabsorbable anchors and all-suture anchors offer several advantages, their limitations, such as degradation rates, material strength, and potential for foreign body reactions, remain areas of active research. Furthermore, the choice of suture material, anchor strength, and biomechanical testing all play crucial roles in determining the success of the surgery. As research continues to evolve, innovations in anchor design and materials will likely lead to improved outcomes in tendon and ligament repairs, enhancing both the safety and effectiveness of these critical procedures.

5. Discussion

Many studies have already been conducted comparing various anchor systems or methods to reconnect bones and tendons, and many of these studies come to different conclusions, as numerous factors can play a significant role. For example, it's not just about the maximum load an anchor can withstand but also the angle of the load, the frequency of the load, or the likelihood of complications that may arise when using different materials. All of these variables can be highly individualized and differ from patient to patient. Therefore, before every

procedure, it is essential to carefully assess which method to apply, considering all aspects, in order to achieve the best possible result.

Another point to consider is that, although many of these studies were conducted on animals, they are often experimental studies for humans, as human medicine is much more advanced. In terms of movement patterns and load profiles, studies should perhaps be tailored to animals, as these can differ significantly from those of humans. Furthermore, human clinical trials often only collect isolated data and do not provide a comprehensive view of the procedures. Human medicine is more advanced than veterinary medicine due to having far more resources for research and development. The market for human medicine is much larger since every person potentially needs medical care, leading to a high demand for innovative treatments. This demand facilitates extensive research, development of new therapies, and clinical trials. In contrast, veterinary research focuses on specific animal species, which limits the market and available resources. As a result, most of the research is conducted in the field of human medicine, rather than veterinary medicine. And this may be because it is too expensive. This also leads to the fact that the most advanced and modern designs and materials are often too costly to be widely used in veterinary medicine, resulting in less interest in funding and conducting these studies. However, clinical relevance is also very important for animals, just as it is for humans. Additionally, animals present the complication that many species need to be treated, each with very different characteristics in terms of aspects such as bone composition, healing processes, movement patterns, or maximum loads. Just because an anchor works well, is well accepted, and causes no complications in one species, it does not mean this will be true for other species. Therefore, many more studies specific to animals need to be conducted to make more definitive conclusions. Currently, there are only indications.

Another point is that there is very limited long-term data, as many studies focus on short-term outcomes. Many more studies need to be conducted that follow patients over a period of several years in order to observe the healing processes as a whole rather than just isolated aspects. For example, in a study investigating the maximum load of an anchor using synthetic bone models, an anchor may withstand a tremendous load until failure, making it seem better suited than competing products. However, it could be that either the material or the shape leads to more complications during the healing process, which can significantly reduce the anchor's performance. Additionally, it has been noticed that there is no standardization in the studies found. Different methods often yield different results because the parameters of the studies were fundamentally different. There should be more Studies conducted according to a standardized protocol to be able to make a more meaningful comparison.

Some differences in methods cannot be overruled by standardized protocols, because the use of a bone anchor requires surgical insertion. This procedure is performed by human hands, and even a very well-trained surgeon cannot guarantee that every procedure will be identical. Bone anchors are also most commonly used after trauma, and these traumas are never standardized. They require individual procedures that are more difficult to compare.

In conclusion, while many studies have compared various anchor systems for bone-to-tendon reconnection, results often vary due to individual factors such as load limits, surgical techniques, and patient differences. The challenges of applying human research to veterinary medicine, along with the lack of standardized protocols, complicate the interpretation of findings. To achieve the best outcomes, treatment methods must be tailored to each case. More long-term studies and species-specific research are essential for improving both human and veterinary treatments. Ultimately, ongoing research and collaboration between fields will be crucial for advancing these medical procedures.

6. Summary

The comparative analysis of suture anchors, materials, and bone response highlights several key considerations for both human and veterinary orthopedic applications. Studies demonstrate that anchor design, orientation, and material composition significantly influence clinical outcomes, particularly in terms of bone preservation, integration, and mechanical performance.

All-suture anchors appear advantageous for long-term bone integrity, exhibiting lower osteolytic changes and better preservation of bone structure than biocomposite and metal-based anchors (1). Notably, newer anchors such as the JuggerKnot Long Soft Anchor show effective load resistance while requiring minimal bone contact, making them suitable for procedures where bone preservation is a priority (18).

Material selection further affects performance and complication rates. Metals like stainless steel and titanium offer strength but come with drawbacks such as stress shielding, imaging interference, and inflammatory responses (3). Meanwhile, biodegradable polymers (PLLA, PGA, PLGA) provide an alternative with resorption capabilities, though their degradation products can cause adverse reactions, including osteolysis, tunnel widening, and cyst formation (5, 4, 3). Emerging materials like magnesium and polymer-ceramic composites present a

promising middle ground, balancing biodegradability with improved bone integration, though issues such as rapid degradation and localized inflammation remain challenges (3).

In veterinary applications, studies on anchor orientation and suture abrasion underscore the importance of mechanical alignment for durability, particularly under cyclic loading. Orientation-dependent differences in load-to-failure rates suggest that optimizing anchor positioning is critical for maximizing holding power and minimizing the risk of failure in high-stress regions (6, 7, 25).

Overall, advances in anchor design and material science are moving toward achieving stable, reliable fixation with minimized impact on bone health.

7. References

1. Christopher M.B. Stewart, MRes, Haseem Raja, MBChB, Emma Torrance,PhD,Lennard Funk. *In Vivo Randomized Controlled Study of the Bone Response of All-Suture Anchors and Biocomposite Anchors.* Wilmslow : The Orthopaedic Journal of Sportsmedicine, 2020.

2. Bulman, Sarah, Nick Cotton, PhD und George Barnes, PhD. *HEALICOIL™ REGENESORB-Fadenanker: Knochenbildung im Vergleich zu einem soliden Ankerimplantat beim Schaf nach 18 Monaten.* s.l. : Smith & Nephew; Bone&JointScience, 2016.

3. Daisy M. Ramos, Ramya Dhandapani, Anuradha Subramanian, Swaminathan Sethuraman, Sangamesh G. Kumbar,. Clinical complications of biodegradable screws for ligament injuries. *Materials Science and Engineering.* s.l. : Elsevier, 2020, p. Volume 109.

4. Kim SH, Oh JH, Lee OS, Lee HR, Hargens AR. *Postoperative imaging of bioabsorbable anchors in rotator cuff repair.* s.l. : Am J Sports Med, 2014.

5. *Arthroscopic double-row repair of the rotator cuff: a comparison of bio-absorbable and non-resorbable anchors regarding osseous reaction.* Hendrik Haneveld, Konstantin Hug,Gerd Diederichs, Markus Scheibel, Christian Gerhardt. 2013, Knee Surgery, Sports Traumatology, Arthroscopy, pp. 1647-1654.

6. *Mechanical Performance of a Screw-Type Veterinary Suture Anchor Subjected to Single Load to Failure and Cyclic Loads.* Balara, J.M., McCarthy, R.J., Boudrieau, R.J. and Kraus, K.H. 2004, Veterinary Surgery, pp. 615-619.

7. *In Vitro Acute Load to Failure and Eyelet Abrasion Testing of a Novel Veterinary Screw-Type Mini-Anchor Design.* Kunkel, K.A.R., Rusly, R.J., Basinger, R.R., DesJardins, J.D. and Gerard, P.D. 2013, Veterinary Surgery, pp. 217-222.

8. Mathew Raske, Don Hulse. *SwiveLock Bone Anchor Stabilization of the Cranial Cruciate Ligament Deficient Stifle in Dogs: Clinical Outcome.* Austin : Open Journal of Veterinary Medicine, 2013.

9. Arthrex. *Arthrex-Knotless SwiveLock-Fadenanker.* [Online] 11 24, 2024. https://www.arthrex.com/de/schulter/knotenloser-swivelock-fadenanker?currenttab=products.

10. *Three Medial All Suture Anchors Improves Contact Force Compared to Two Hard Body Anchors in a Biomechanical Two-Tendon Rotator Cuff Tear Model.* Tammy R. Hoffman, Joseph D. Lamplot, M.D., Sarah J. McClish, Cassie Payne, Patrick J. Denard, M.D. 2022, Arthroscopy, Sports Medicine, and Rehabilitation, Vol 4, No 5, pp. 1601-1607.

11. Nick S. Rappa, Robert M. Radasch. *Post-operative complications associated with the Arthrex Canine Cranial Cruciate Ligament Repair Anchor System in small-to medium-sized dogs: A retrospective analysis (2009-2012).* s.l. : Canadian Veterinary Journal, 2016.

12. Arthrex. *Arthrex-Corkscre Suture Anchor.* [Online] 11 22, 2024. https://www.arthrex.com/shoulder/corkscrew.

13. Logothetou V, Pappa E, Pettitt R, Comerford E. *Use of bone anchors for the treatment of partial and complete traumatic elbow luxations: A retrospective case series of three dogs.* s.l. : Veterinary Record Case Reports, 2022.

14. Smith+Nephew. *Bioraptor 2 3 PK Suture Anchor PPL.* [Online] 11 22, 2024. https://www.smith-nephew.com/de-de/health-care-professionals/products/sports-medicine/bioraptor-2-3-pk-suture-anchor-ppl.

15. Smith+Nephew. *SUTUREFIX Suture Anchor.* [Online] 11 24, 2024. https://www.smith-nephew.com/en-us/health-care-professionals/products/sports-medicine/suturefix-suture-anchor-ppl#referencematerials.

16. Jan Vonhoegen, Dominik John, Constanze Hägermann. *Osteoconductive resorption characteristics of a novel biocomposite suture anchor material in rotator cuff repair.* s.l. : Journal of Orthopaedic Surgery and Research, 2019.

17. Arthrex. *Arthrex-Corkscrew FT.* [Online] 11 22, 2024. https://www.arthrex.com/de/schulter/corkscrew-ft.

18. Jason Hurst. *Biomechanical Evaluation of the JuggerKnot Long Soft Anchor in Cadaver Bone.* s.l. : Biomet Sports Medicine Research and Development, 2013.

19. Zimmer Biomet. *JuggerKnot All-Suture Anchor | Zimmer Biomet | Zimmer Biomet.* [Online] 11 22, 2024. https://www.zimmerbiomet.eu/en/products/juggerknot-all-suture-anchors.

20. *A prospective study comparing tendon-to-bone interface healing using an interposition bioresorbable scaffold with a vented anchor for primary rotator cuff repair in sheep.* Jeremiah Easley, Christian Puttlitz, Eileen Hackett, Cecily Broomfield, Lucas Nakamura, Michael Hawes, Charles Getz, Mark Frankle, Patrick St. Pierre, Robert Tashjian, P. Dean Cummings, Joseph Abboud, Derek Harper, Kirk McGilvray. 2020, Journal of Shoulder and Elbow Surgery.

21. *Comparison of mechanical properties in interference screw fixation technique and organic anterior cruciate ligament reconstruction method: a biomechanical study.* Amirhossein Borjali, Amir Nourani, Hadi Moeinnia, Mahdi Mohseni, Hossein Korani, Narges Ghias, Mahmoud Chizari. 2021, BMC Musculoskeletal Disorders.

22. Pei-I Tsai, Chih-Yu Chen, Shu-Wei Huang, Kuo-Yi Yang, Tzu-Hung Lin, San-Yuan Chen, Jui-Sheng Sun. *Improvement of Bone-Tendon Fixation by Porous Titanium Interference Screw: A Rabbit Animal Model.* s.l. : Wiley Online Library, 2018.

23. Narges Ghias, AMir Nourani, Mahdi Mohseni, Hossein Korani, Hadi Moeinnia, Amirhossein Borjali, Mahmoud Chizari. *The use of BASHTI as an organic ACL fixation technique.* Hartfield, UK : University of Hertfordshire, 2022.

24. Jeys L, Korrosis S, Stewart T, Harris NJ. *Bone anchors or interference screws? A biomechanical evaluation for autograft ankle stabilization.* s.l. : Am J Sports Med., 2004.

25. *In Vitro Evaluation of Screws and Suture Anchors in Metaphyseal Bone of the Canine Tibia.* Robb, J.L., Cook, J.L. and Carson, W. 2005, Veterinary Surgery, pp. 499-508.

26. *Biomechanical analysis of suture anchors and suture materials in the canine femur. .* Giles JT 3rd, Coker D, Rochat MC, Payton ME, Subramarian V, Bartels KE. 2008, Vet Surg, pp. 12-21.

27. *Interference Screw Versus Suture Anchor Fixation for Subpectoral Tenodesis of the Proximal Biceps Tendon: A Cadaveric Study.* S. Raymond Golish, M.D., Ph.D. Paul E. Caldwell, III, M.D. Mark D. Miller, M.D. Naveen Singanamala, M.B.B.S., M.S. Anil S. Ranawat, M.D. Gehron Treme, M.D. Sara E. Pearson, Ph.D. Ryan Costic, M.S. Jon K. Sekiya, M.D. 2008, Arthroscopy, pp. Volume 24, Pages 1103-1108.