Review

Anchor Polymers in Arthroscopic Shoulder Surgery: From Bioabsorbable Materials to Advanced Biocomposites—A Comprehensive Review

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Review

Anchor Polymers in Arthroscopic Shoulder Surgery: From Bioabsorbable Materials to Advanced Biocomposites—A Comprehensive Review

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Abstract

Arthroscopic shoulder surgery has undergone significant evolution over the past decades, particularly in the materials used for suture anchors. The transition from metallic to bioabsorbable polymer anchors has revolutionized soft tissue-to-bone repair procedures, offering distinct advantages in terms of biocompatibility, imaging compatibility, and reduced complications. This comprehensive review examines the current state-of-the-art in anchor polymers used in arthroscopic shoulder surgery, including bioabsorbable polymers such as polyglycolic acid (PGA), poly-L-lactic acid (PLLA), poly-lactic-co-glycolic acid (PLGA), and their biocomposite formulations with beta-tricalcium phosphate (β-TCP) and calcium sulfate (CS). Additionally, we explore the role of biostable polymers like polyetheretherketone (PEEK) and emerging technologies in anchor design. The review synthesizes clinical outcomes, degradation kinetics, biocompatibility profiles, and mechanical properties of various anchor polymer systems. We also discuss the challenges associated with each material type, including osteolysis, cyst formation, premature degradation, and poor osseointegration. Recent advances in biocomposite anchors demonstrate promising solutions to address these limitations, offering controlled degradation rates and enhanced osteoconductivity. This review provides clinicians and researchers with a comprehensive understanding of anchor polymer technologies, their clinical applications, and future directions in arthroscopic shoulder surgery.

Keywords: shoulder; suture anchors; bioabsorbable; polymers; PGA; PLGA; PLLA; biocomposites; PEEK

1. Introduction

Arthroscopic shoulder surgery represents one of the most significant advances in orthopedic surgery, enabling minimally invasive repair of complex soft tissue injuries. [1,2] The use of suture anchors has revolutionized orthopedic surgery because it allows for simple and efficient fixation of soft tissue (e.g., tendons and ligaments) to the bone in both open and arthroscopic surgery around the shoulder, elbow, wrist, and lower limb joints. [3–5] Shoulder surgery particularly has experienced a significant change in the type of techniques used from open repair of the rotator cuff and labrum using screws, washers, transosseous sutures, and staples to arthroscopic repair using suture anchors. [4,6,7]

The evolution of suture anchor materials has been driven by the need to optimize several key factors: mechanical stability, biocompatibility, imaging compatibility, and the ability to facilitate native tissue healing. Bioabsorbable suture anchors have largely replaced metallic anchors because of concerns of implant loosening, migration, and chondral injury. [8,9] This shift has created new opportunities and challenges in the development of polymer-based anchor systems. [10]

The primary function of a suture anchor is to maintain secure fixation of soft tissue to bone during the critical healing period, typically 12-24 weeks for most shoulder repairs. [11] The primary

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function of the suture anchor is to attach tissue at the proper site and maintain its position without loosening or excessive tension until physiologic healing is accomplished. An ideal anchor should provide adequate initial fixation strength, maintain this strength throughout the healing period, and either integrate permanently with bone or degrade safely without adverse tissue reactions. [12]

This review provides a comprehensive analysis of anchor polymers currently used in arthroscopic shoulder surgery, examining their chemical composition, mechanical properties, degradation kinetics, clinical performance, and associated complications. We also explore emerging biocomposite technologies and future directions in anchor polymer development

2. Historical Evolution of Anchor Materials

2.1. From Metallic to Bioabsorbable Anchors

With major advances in arthroscopy, suture anchors became the primary devices used to assist in fixing soft tissues to bone. Metallic anchors were first produced and used in soft tissue fixation around the shoulder. [13,14] While metallic anchors, primarily constructed from titanium alloys and stainless steel, provided excellent mechanical properties and proved highly successful in many clinical applications, they were associated with several significant drawbacks. [14]

The limitations of metallic anchors included:

- Risk of migration into the joint space, potentially causing articular cartilage damage
- Interference with postoperative magnetic resonance imaging (MRI) due to metallic artifacts
- Permanent presence requiring removal during revision procedures
- Stress shielding effects leading to bone remodeling

However, their use resulted in some reported complications, including articular surface damage from migrating implants and distortion and artifact production in postoperative magnetic resonance imaging. These complications drove the development of bioabsorbable alternatives that could provide equivalent mechanical fixation while addressing the shortcomings of metallic systems. [15]

2.2. Introduction of Bioabsorbable Polymers

Bioabsorbable anchors were developed to avoid these problems. [16] Their newer versions were proven to have pulling-out strength equal to that of metallic anchors, with a reported lower complication rate. [14] The transition to bioabsorbable materials represented a paradigm shift in anchor design philosophy, prioritizing biological integration over permanent mechanical fixation. [17]

The evolution of bioabsorbable anchors has progressed through several generations:

1. First Generation: Pure polyglycolic acid (PGA) anchors
2. Second Generation: Poly-L-lactic acid (PLLA) anchors
3. Third Generation: Copolymer systems (PLGA, PLDLA)
4. Fourth Generation: Biocomposite anchors with ceramic fillers
5. Fifth Generation: Advanced biocomposites with controlled degradation profiles

3. Bioabsorbable Polymer Systems

3.1. Polyglycolic Acid (PGA)

Polyglycolic acid (PGA) is one of the first degradable polymers researched in biomedical fields. [18] Since the 1970s, surgeons used PGA as a degradable suture. PGA was among the earliest bioabsorbable materials investigated for suture anchor applications, offering the theoretical advantage of complete resorption and replacement by native bone tissue. [19]

3.1.1. Chemical Properties and Degradation

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PGA is a linear aliphatic polyester with the chemical formula $(C_2H_2O_2)_n$. Its degradation occurs through hydrolytic cleavage of ester bonds, producing glycolic acid as the primary degradation product. [20] The degradation process is characterized by:

- Initial degradation: Begins within the first week after implantation
- Complete resorption: Typically occurs within 6-12 weeks
- Degradation products: Glycolic acid, which is metabolized to carbon dioxide and water

3.1.2. Clinical Limitations

While it was initially also used as a biodegradable anchor, the rapid degradation of PGA and loss of strength shortly after surgery resulted in its discontinuation. Degradation of PGA starts during the first week after anchor implantation; as the glycolic acid products are released, they can cause an inflammatory reaction with synovitis, bursitis, or lytic bone changes. [19]

The rapid degradation of PGA anchors proved problematic for shoulder repair applications, where tissue healing typically requires 12-24 weeks. The loss of mechanical integrity before adequate soft tissue healing led to poor clinical outcomes and discontinuation of pure PGA anchors. [21]

3.2. Poly-L-Lactic Acid (PLLA)

To address the limitations of PGA, poly-L-lactic acid (PLLA) was developed as an alternative bioabsorbable material with significantly slower degradation kinetics. [17] Later, anchors started to be manufactured using poly-L-lactic acid (PLLA).

3.2.1. Chemical Properties and Degradation

PLLA is a semi-crystalline polymer with higher molecular weight and greater hydrophobicity compared to PGA. Its degradation characteristics include:

- Degradation timeline: 2-5 years for complete resorption
- Degradation mechanism: Hydrolytic cleavage producing lactic acid
- Crystallinity: Higher crystalline content provides greater mechanical strength

It has been shown to dissolve very slowly and may maintain up to five years. [22] Based on this attribute, poly-lactic acid (PLA), particularly its PLLA form, is not as problematic as PGA; however, very long degradation rates would not allow for complete bony replacement and may create intraosseous foreign body reactions. [23]

3.2.2. Clinical Performance

PLLA anchors demonstrated improved clinical performance compared to PGA, offering several advantages. [17,23] They maintained mechanical strength throughout the critical healing period, reduced inflammatory reactions relative to PGA, and exhibited a favorable biocompatibility profile. However, the extremely slow degradation rate of PLLA introduced new challenges, including prolonged visibility on imaging studies for up to seven years, an increased risk of foreign body reactions, and the potential for cyst formation around the anchor sites.PLLA anchors demonstrated improved clinical performance compared to PGA, offering several advantages. They maintained mechanical strength throughout the critical healing period, reduced inflammatory reactions relative to PGA, and exhibited a favorable biocompatibility profile. However, the extremely slow degradation rate of PLLA introduced new challenges, including prolonged visibility on imaging studies for up to seven years, an increased risk of foreign body reactions, and the potential for cyst formation around the anchor sites.

3.3. Poly-Lactic-co-Glycolic Acid (PLGA)

To regulate the degradation period of bioabsorbable anchors and reinforce their mechanical properties, copolymers such as poly (D, L-lactide) from L-lactide and D-lactide and PLLA with PGA

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have been developed. PLGA copolymers represent a significant advancement in bioabsorbable anchor technology, offering tunable degradation rates through manipulation of the lactide-to-glycolide ratio. [24,25]

3.3.1. Chemical Composition and Tunable Properties

PLGA copolymers consist of randomly distributed lactic and glycolic acid units, with the ratio determining degradation kinetics:

- PLGA 85:15 (85% lactide, 15% glycolide): Slower degradation (~24 months)
- PLGA 75:25: Intermediate degradation (~18 months)
- PLGA 50:50: Fastest degradation among PLGA formulations (~12 months)

3.3.2. Degradation Kinetics and Clinical Benefits

PLGA showed a resorption time of 24 months. The controlled degradation profile of PLGA offers several clinical advantages:

- Adequate mechanical support during critical healing periods
- Predictable resorption timeline
- Reduced risk of long-term foreign body reactions
- Compatibility with advanced imaging techniques

4. Biocomposite Anchor Systems

4.1. PLGA/β-Tricalcium Phosphate (β-TCP) Composites

Biocomposite suture anchors are composed of both a biodegradable polymer material and a bone formation-promoting bioceramic material. The most commonly used bioceramic is beta-tricalcium phosphate (β-TCP); others include hydroxyapatite, calcium sulfate, and calcium carbonate. [25,26]

4.1.1. Composition and Rationale

Biocomposite anchors typically consist of:

- 70-85% PLGA: Provides mechanical integrity and controlled degradation
- 15-30% β-TCP: Enhances osteoconductivity and bone ingrowth

Poly-lactic co-glycolide (PLGA)/β-TCP is a biocomposite material explicitly developed to promote absorption at a controlled rate. PLGA/β-TCP minimizes inflammatory reaction while promoting osteoconductivity at the implant site via the homogeneously disseminated β-TCP within the absorbable copolymer. [27,28]

4.1.2. Clinical Performance

This material has the highest reported osteoconductivity rate in the literature. A systematic review revealed that almost 90% of suture anchors composed of PLGA/β-TCP were absorbed within 3 years and promoted osteoconductivity with few reported adverse events. [29] (Table 1.)

Table 1. Perianchor Cyst Formation Rates by Anchor Type.

Anchor Type	Cyst Formation Rate	Severe Cyst Rate	Timeline
PLLA	15-30%	5-10%	12-24 months
PLGA/β-TCP	60%	15-21%	6-18 months

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Anchor Type	Cyst Formation Rate	Severe Cyst Rate	Timeline
PLGA/β-TCP/CS	<5%	<2%	12-21 months

The superior performance of PLGA/β-TCP composites stems from the synergistic effects of the polymer matrix and ceramic filler:

- β-TCP provides osteoconductive scaffolding for bone ingrowth
- PLGA matrix maintains structural integrity during degradation
- Controlled release of calcium and phosphate ions promotes bone formation

4.2. Advanced Triple-Component Biocomposites

4.2.1. PLGA/β-TCP/Calcium Sulfate (CS) Systems

Recent biocomposite suture anchor materials consist of 65% PLGA, 15% β-TCP, and 20% calcium sulfate (CS). This triple-component system represents the latest advancement in biocomposite anchor technology, designed to optimize both mechanical properties and biological performance. [30,31]

4.2.2. Degradation Timeline and Benefits

PLGA showed a resorption time of 24 months. And the other two components have shorter resorption times as shown in animal models (β-TCP, 18 months and CS, 4–12 weeks).

The staggered degradation profile provides several advantages:

1. Early Phase (0-12 weeks): CS degradation creates porosity for cellular infiltration
2. Intermediate Phase (12-18 months): β-TCP provides osteoconductive framework
3. Late Phase (18-24 months): PLGA matrix maintains structural support

The use of this type of suture anchor is associated with: (1) strong primary stability, (2) good healing of the soft tissue, and (3) nearly complete absorption within 24 months. [32]

4.2.3. Clinical Evidence

Vonhoegen et al. analyzed 82 PLGA/β-TCP/CS anchors in 48 patients who had undergone arthroscopic rotator cuff repair. They reported that the degradation process seemed to be completed within 21 months, and there was no severe osteolysis or cyst formation observed around any of the 82 anchors. Only two retears occurred, and no anchor pull-out complications were detected. [32]

5. Biostable Polymer Systems: PEEK

5.1. Introduction to PEEK Anchors

Because some biodegradable anchors can be absorbed too quickly, the development of biostable anchors was pursued. Such a biostable anchor—a polyetheretherketone (PEEK) polymer—is obtained by dialkylation of bisphenol salts. [33]

5.1.1. Material Properties

PEEK (polyetheretherketone) is a high-performance thermoplastic polymer with exceptional properties for orthopedic applications:

- Chemical resistance: Excellent resistance to hydrolysis and chemical degradation
- Mechanical properties: High strength-to-weight ratio with optimal flexibility
- Biocompatibility: Excellent tissue tolerance with minimal inflammatory response
- Imaging compatibility: Radiolucent properties allowing clear postoperative imaging

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PEEK materials showed high strength, strong mechanical properties, good wear- and heat-resistance, and excellent chemical and biological resistance. Therefore, it has many other applications in engineering and medicine. [33,34]

5.1.2. Clinical Advantages

PEEK also offers advantages, such as good postoperative imaging and stable fixation, and no complications associated with polymer degradation. [5]

The primary advantages of PEEK anchors include:

- Permanent mechanical fixation without degradation
- Superior imaging compatibility for postoperative monitoring
- Excellent biocompatibility with minimal tissue reaction
- Reliable mechanical properties throughout implant lifetime

5.2. Limitations and Challenges

Importantly, the major problem with PEEK has been shown to be poor osseointegration. The biologically inert nature of PEEK, while preventing degradation-related complications, also limits its ability to integrate with surrounding bone tissue. [34,35]

5.2.1. Osseointegration Challenges

The poor osseointegration of PEEK anchors results from:

- Chemical inertness preventing cellular attachment
- Smooth surface characteristics limiting mechanical interlocking
- Lack of bioactive surface properties

5.2.2. Clinical Outcomes and Comparisons

Shoulder function was improved after complete rotator cuff repair and similar clinical outcomes were achieved regardless of suture anchor material and shape. However, the open-construct PEEK anchor provided better bone ingrowth into the anchor than the non-vented biocomposite anchor at 6 months after arthroscopic rotator cuff repair. [5,36]

6. Clinical Performance and Complications

6.1. Bioabsorbable Anchor Complications

6.1.1. Early Complications

Biodegradable suture anchors are also associated with challenges, including problems in the intraoperative or early postoperative period such as (1) implant breakage during anchor insertion, (2) initial fixation loss, (3) incomplete burial of anchors within a bone, which could damage the articular cartilage, and (4) possible anchor migration. [8,24,25,28]

6.1.2. Osteolysis and Cyst Formation

Screw breakage has been reported in the literature. Glueck et al. reported the case of a 20 year old American football player with osteolysis around the site of insertion of PLLA bioabsorbable suture anchors after 8 months of postoperative followup. [37] The formation of perianchor cysts represents a significant complication associated with bioabsorbable anchors. [38] (Table 1)

6.1.3. Loose Body Formation

Biodegradable suture anchors have facilitated and revolutionized arthroscopic tissue-to-bone repair, especially in the shoulder. However, the anchor is but a part of the repair construct, which

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also includes a suture, tied in a knot, that attaches the tissue (tendon or labrum) to bone. Bioabsorbable anchors may result in loose bodies. The formation of loose bodies represents a unique complication of bioabsorbable anchors, particularly when rapid degradation occurs before adequate tissue healing. [39,40]

6.2. PEEK Anchor Complications

6.2.1. Perianchor Cyst Formation

While PEEK anchors avoid degradation-related complications, they are still associated with cyst formation: [41,42]

- Lower overall incidence compared to bioabsorbable anchors
- Different mechanism related to mechanical factors rather than degradation
- Generally smaller and less symptomatic cysts

6.2.2. Revision Surgery Challenges

Revision Bankart repair using PEEK anchors of the same diameter in a pre-existing bone socket is possible but bears high risk of premature anchor failure and can jeopardize the reconstruction. [43]

7. Degradation Kinetics and Tissue Response

The degradation of bioabsorbable anchors follows a predictable sequence of steps. Initially, water is absorbed into the polymer matrix, leading to the hydration of the material. This is followed by chain scission, in which hydrolytic cleavage of ester bonds occurs. [27] As the process continues, the polymer chains progressively break down, resulting in a reduction in molecular weight. [24] Subsequently, mass loss occurs as degradation products are released and the material begins to dissolve. Finally, the space previously occupied by the anchor is gradually replaced by the ingrowth of native tissue. [44] (Table 2)

Several factors influence the rate of degradation of bioabsorbable anchors. The polymer composition, particularly the lactide-to-glycolide ratio in copolymers, plays a significant role. [45] A higher crystalline content within the polymer slows degradation, while polymers with a higher molecular weight take longer to degrade. [46] Local pH also has an effect, as acidic degradation products can accelerate the breakdown process. [47,48] Additionally, mechanical stress, such as loading, can hasten the breakdown of polymer chains. [49]

The results of the present study demonstrated that biocomposite suture anchors are frequently still visible on MRI scans two years after rotator cuff reconstruction, indicating that complete degradation may take longer than initially expected. [29]

Table 2. Degradation Timeline of Common Anchor Materials.

Material	Initial Strength Loss	50% Mass Loss	Complete Resorption
PGA	2-4 weeks	6-8 weeks	12-16 weeks
PLLA	12-18 months	2-3 years	4-5 years
PLGA (85:15)	6-12 months	12-18 months	24-30 months
PLGA/β-TCP	8-12 months	18-24 months	30-36 months

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Material	Initial Strength Loss	50% Mass Loss	Complete Resorption
PLGA/β-TCP/CS	6-9 months	15-21 months	21-24 months

8. Future Directions and Emerging Technologies

The: future of bioabsorbable and polymer-based suture anchors lies in advanced material innovations designed to enhance osseointegration, durability, and biological performance. [34] Polyetheretherketone (PEEK) has favorable mechanical properties but is biologically inert, limiting direct bone integration. [33] To overcome this, various surface modification strategies are being explored. Plasma treatment can create micro-textures on the PEEK surface, improving cell adhesion and early osteoblast attachment. [50] Bioactive coatings, such as hydroxyapatite (HA) or other osteoconductive ceramics, are also applied to PEEK to stimulate bone formation and enhance osseointegration. [51] Additionally, chemical etching techniques can increase surface roughness, promoting stronger mechanical interlocking between the implant and bone tissue. [52]

Beyond: PEEK, bioactive polymer surfaces are being developed to actively promote tissue integration. [53] This includes the incorporation of growth factors, such as bone morphogenetic proteins (BMPs), directly into polymer matrices for localized delivery. [54] Surface grafting of bioactive peptides, like RGD sequences, has also been shown to improve cell adhesion and osteogenic differentiation. [55] Furthermore, controlled release systems embedded within polymers allow for sustained release of osteogenic factors, facilitating long-term tissue regeneration. [56]

The: next generation of anchors may utilize stimuli-responsive polymers that adapt to local physiological conditions. [57] These advanced materials can be engineered to respond to pH changes, allowing controlled degradation based on the acidic or neutral environment around healing tissue. [58] Temperature-responsive polymers can undergo phase transitions to release therapeutic agents when exposed to specific temperature ranges. [57] Similarly, polymers that react to mechanical stress can dynamically alter their stiffness or other properties depending on the biomechanical loads applied. [57,58]

Another: emerging concept is self-healing polymers, which possess the ability to autonomously repair micro-damage caused by repetitive stress, thereby extending the life of the implant. [59] These materials can also adapt to continuous mechanical stress and maintain their structural integrity under cyclic loading, which is especially beneficial for high-demand joints like the shoulder. [60]

Nanotechnology: offers promising pathways for improving anchor performance. Nano-enhanced anchors integrate nanomaterials into polymer matrices to achieve superior functional properties. [61] Carbon nanotubes (CNTs) provide exceptional mechanical reinforcement, increasing the strength and fatigue resistance of the polymer. [62] Nanohydroxyapatite (nHA) particles enhance osteoconductivity by mimicking the natural bone mineral structure, encouraging osteoblast proliferation and bone integration. [63] Additionally, Anchors are also being designed with hierarchical structures that combine multiple length scales for optimal performance. At the macro-

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scale, these anchors maintain strong mechanical stability. The micro-scale porosity allows for cell infiltration and vascularization, while nano-scale surface features improve cellular interactions and signaling, promoting bone ingrowth and integration. [64] This multi-scale approach reflects a biomimetic strategy inspired by natural bone architecture.

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9. Clinical Decision-Making Guidelines

The selection of appropriate suture anchor material is a critical factor in optimizing outcomes for shoulder and other orthopedic soft tissue repair surgeries. [29] The decision should be based on a comprehensive assessment of patient factors, surgical considerations, and material properties, ensuring a balance between mechanical performance, biological response, and clinical objectives.

9.1. Patient Factors

Patient-specific variables significantly influence material selection. Age and activity level play a major role; for instance, younger and highly active patients require anchors with greater mechanical strength and slower degradation to withstand higher loads during rehabilitation. [29] Bone quality and density are also important, as osteoporotic bone may necessitate anchors with enhanced fixation strength, such as titanium or PEEK-based designs. [65] Patients with a history of prior surgeries may present with altered bone architecture or scar tissue, requiring careful consideration of anchor design and placement. [66] Finally, healing potential is affected by systemic factors such as diabetes, smoking, or autoimmune disease, which can influence the rate of tendon-to-bone integration and may favor the use of bioactive or slower-degrading anchor materials. [67]

9.2. Surgical Factors

The complexity and size of the repair dictate the mechanical demands on the anchor. Larger or multi-tendon tears, such as massive rotator cuff tears, require anchors with higher pullout strength and fatigue resistance. [67] Revision surgeries are particularly challenging because of compromised bone stock and previous hardware, often necessitating specialized anchor designs such as all-suture or biocomposite systems. [29,67] The expected postoperative mechanical loading is another determinant; for example, early active rehabilitation protocols demand materials with high initial stability. Additionally, surgeon preference and experience influence anchor choice, as familiarity with specific insertion techniques can affect both procedural efficiency and clinical outcomes .

9.3. Material Properties

The intrinsic properties of the anchor material must align with biological and mechanical requirements. [18,29,33] The degradation timeline should match the tissue healing process, ensuring that the anchor maintains stability until robust tendon-to-bone healing is achieved. [29,33] Mechanical strength and fatigue resistance are essential to withstand repetitive cyclic loading during early rehabilitation. Biocompatibility is critical to minimize inflammatory reactions, cyst formation, or osteolysis. Moreover, imaging compatibility must be considered, as metallic anchors can produce MRI artifacts, whereas polymer or biocomposite anchors allow for clearer postoperative evaluation of tendon integrity.

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Table 3. Anchor Material Recommendations by Clinical Scenario.

Clinical Scenario	First Choice	Second Choice	Rationale
Primary rotator cuff repair (young patient)	PLGA/β-TCP/CS	PLGA/β-TCP	Optimal degradation timeline
Primary rotator cuff repair (elderly patient)	PEEK	PLGA/β-TCP	Permanent fixation preferred
Revision surgery	PEEK	PLGA/β-TCP	Avoid degradation complications
Large/massive tears	PEEK	PLGA/β-TCP	Maximum mechanical strength
Bankart repair	PLGA/β-TCP	PEEK	Good balance of properties

10. Conclusions

The evolution of anchor polymers in arthroscopic shoulder surgery represents a remarkable advancement in orthopedic biomaterials. From the early challenges with rapid degradation of PGA anchors to the sophisticated biocomposite systems available today, each generation has addressed specific clinical limitations while introducing new considerations. Current evidence supports the use of biocomposite anchors, particularly PLGA/β-TCP/CS systems, for most primary shoulder repair procedures. These materials offer an optimal balance of mechanical properties, controlled degradation, and enhanced osteoconductivity. Compared to PLLA and PDLDA, PLGA/β-TCP/CS seems to have superior characteristics regarding degradation time and the occurrence of osteolysis and cyst formation.

PEEK anchors remain valuable for specific clinical scenarios, particularly revision surgeries and cases requiring permanent fixation. The development of open-construct PEEK anchors with enhanced venting has addressed some osseointegration concerns, making them increasingly attractive for certain applications.

The future of anchor polymer technology lies in smart materials that can adapt to local tissue conditions, provide controlled drug delivery, and actively promote tissue regeneration. As our understanding of polymer degradation kinetics and tissue healing biology continues to advance, we can expect further refinements in anchor design that will improve clinical outcomes while

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minimizing complications. Clinicians must remain informed about the properties and performance characteristics of different anchor materials to make optimal choices for individual patients. The continued development of evidence-based guidelines for material selection will be crucial for maximizing the benefits of these advanced polymer systems in arthroscopic shoulder surgery.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, Kim JH and Yoon EJ.; methodology, Kim JH; software, Kim JH; validation, Kim JH, Yoon EJ and Lee JW; formal analysis, Lee JW; investigation, Lee JW; resources, Kim JH; data curation, Baek JW; writing—original draft preparation, Kim JW; writing—review and editing, Kim JH and Yoon EJ; visualization, Lee JW; supervision, Kim JH; project administration, Yoon EJ. All authors have read and agreed to the published version of the manuscript.

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Abbreviations

The following abbreviations are used in this manuscript:

PGA	polyglycolic acid
PLLA	poly-L-lactic acid
PLGA	poly-lactic-co-glycolic acid
β-TCP	beta-tricalcium phosphate
CS	calcium sulfate
PEEK	polyetheretherketone

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