Current Concepts

# Material Properties and Composition of Soft-Tissue Fixation

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**Abstract:** Surgical interference screws and suture anchors for attaching soft tissue, such as ligaments and tendons, to bone are routinely used in arthroscopic surgery and sports medicine. Interference screw fixation provides a press fit between bone, graft/tendon, and screw and is frequently used to attach replacement ligaments in tunnels drilled for anterior and posterior cruciate ligament reconstruction. Suture anchors are used in surgical procedures wherein it is necessary for a surgeon to attach (tie) tissue to the surface of the bone, for example, during joint reconstruction and ligament repair or replacement. The composition of these implants ranges from metals to polymers and composites. Typically, because of the relatively large amount of torque that must be applied during insertion, these screws are constructed from metal. However, interference screws and suture anchors have also been constructed from bioabsorbable polymers and composites. The ideal material would (1) provide adequate mechanical fixation, (2) completely degrade once no longer needed, and (3) be completely replaced by bone. Because no material has been shown to be superior for all applications, the surgeon must weigh the advantages and disadvantages of each to evaluate the optimum material for a given application and patient. The purpose of this article is to present a comprehensive review of the commercially available interference screws and suture anchors, with an emphasis on implant composition, interaction, and design. This article provides the orthopaedic surgeon with a background on biomaterials, specifically those used in interference screws and suture anchors. Because there is no material that is perfect for all surgical situations, this review can be used to make educated decisions on a case-by-case basis.

Interference screws and suture anchors are commonly used in arthroscopic surgery and sports medicine for fixation of soft tissue to bone. Interference screws provide a press fit between bone, graft/tendon, and screw, whereas suture anchors tie soft tissue to an implant embedded in bone. These implants are made from metals, polymers, and composites. Osseointegration, or the ability of a material to form direct bone-implant contact, allows for effective transmission of loading forces and enhances stability essential for long-term stabilization. The literature on biomaterials is vast but has confusing language because it is mostly written for the materials scientist. The purpose of this article is to present a comprehensive review of the commercially available interference screws and suture anchors, with an emphasis on implant composition, interaction, and design. A review of the bone-implant interaction for each material type is also conducted, with emphasis on biocomposites.

Bioabsorbable materials have received considerable attention because of the advantages of less complicated revision surgeries, better postsurgical imaging, good biocompatibility, and lack of need for removal

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operations. The ideal material provides adequate mechanical fixation, completely degrades once no longer needed, and is replaced by bone. The hope is that biocomposites will be able to meet these criteria.

## METALS

Most bone anchors currently approved for clinical use are made of metal.[1] The 2 most commonly used metals are stainless steel and titanium. Potential problems associated with metallic implants include migration and magnetic resonance imaging artifact. Metal anchors also remain permanently embedded in the bone, thereby limiting options for anchor placement during subsequent surgery. Metals are shiny or lustrous solid materials that are malleable and ductile yet very durable. The shiny and lustrous property is a result of the tightly packed atomic structure found in metals that prevents the transmission of visible wavelengths of light through the material. Metals have low electronegativities and therefore easily lose electrons. Metals undergo metallic bonding, which means that atoms are held together by a sea of electrons not confined to 1 nucleus. This allows metals to be malleable and ductile, because atoms can be moved without breaking the metallic bond.

A metal can be used alone or can be combined with other metals to form an alloy. Titanium is a strong, lightweight material by itself, but it can also be combined with other metals, such as iron or aluminum. Stainless steel is an alloy of iron, carbon, and chromium. It is stronger than pure iron and more resistant to corrosion than regular steel.

Titanium is widely used for orthopaedic applications. Unlike most metals, which do not integrate well into surrounding bone, titanium behaves more like a ceramic at the bone-implant interface. Stainless steel screws become encapsulated by a fibrous membrane rich in inflammatory cells,[2] whereas titanium forms a surface layer of calcium and phosphate, which bonds directly to bone[3] without evidence of this fibrous layer[4] and with minimal inflammatory response.[5] An oxide layer spontaneously forms, and calcium and phosphate precipitate on this layer. Osteoblasts then bind to the surface and actively secrete osteoid matrix.[5] Although this affords titanium some potential for osseointegration, it is less than that of other materials. To increase this potential, various methods of surface modification have been used with marked success,[6] including calcium phosphate substances[7] and the induction of a titanium dioxide ceramic-metal transition layer.[8] Despite these coatings, osseointegration is not always complete. In an animal study, although titanium-coated and uncoated screws had direct bone-implant contact in areas, soft tissue–implant contact was present in both.[7]

Metallic screws provide rigid, reliable fixation and have been used successfully for decades. However, disadvantages are associated with their use. The presence of metal screws makes revision surgery more difficult, because the screws must either be removed or be avoided. When one is evaluating a patient postoperatively, it is sometimes necessary to obtain imaging, and both magnetic resonance imaging[9] and computed tomography scan are distorted by the presence of a metal screw. In addition, metal screws can cause graft laceration, particularly with soft-tissue grafts.[10]

## POLYMERS

Polymer-based absorbable implants were first used in the early 1960s when American Cyanamid (Wayne, NJ) developed Dexon, a polyglycol material that was used as a resorbable suturing material.[11] In the 1970s polymers for use as biomaterials in orthopaedics became popular because of the demand for biocompatibility and nontoxicity. Furthermore, because of the difficulties in imaging and revision surgery that metal implants posed, polymers were investigated. Polymers do not interfere with postoperative imaging, and they facilitate revision surgery because the implant either resorbs or can be drilled through. Plastics are found all around us with a variety of material properties ranging from soft to hard, pliable to robust, and transparent to opaque. This array of material properties allows for the fabrication of plastics for various types of applications. Polymers are solid, nonmetallic plastics composed of a small repeating unit, or monomer, covalently bonded together to form a macromolecule chain. Although rigid covalent bonds hold together monomers, chains are held together by physical interaction, similar to entangled Christmas tree lights. Polymer chains can move relative to one another without breaking covalent bonds, allowing polymers to deform without fracturing. However, this also diminishes strength compared with ceramics and metals. Inhibiting the ability of polymer chains to slide past each other results in more entanglement of chains and increased polymer strength. This can be accomplished by use of larger monomers, longer chains, or closer packing (e.g., crystalline regions, as discussed later).

Polymers are named for the monomer from which they are synthesized (e.g., polyethylene from ethylene) and can be either copolymers or homopolymers. A homopolymer is derived from a single monomer (polyethylene), and a copolymer is derived from 1 or more monomers (poly-D,L-lactide from L-lactide and D-lactide). These terms are important for determining the degree of crystallinity, which influences mechanical and degradation characteristics. Crystalline regions occur where an ordered, repeating structure allows for tight packing of chains. Amorphous regions occur where there is disorder or malalignment of chains. Polymers are either semicrystalline (both crystalline and amorphous regions) or amorphous because the large chains do not allow for completely crystalline structures. Homopolymers are typically semicrystalline, whereas copolymers typically have a single amorphous phase because the presence of multiple monomers interferes with ordered arrangement.[12] The degree of crystallinity also depends on the rate of cooling—slower cooling allows polymer chains to settle into an ordered configuration before solidifying.

Because order allows for closer packing and a higher density, semicrystalline polymers are typically stronger and more resistant to degradation. The decreased density of amorphous regions allows for faster diffusion into the polymer, leading to more rapid degradation. In semicrystalline polymers this results in a 2-phase degradation process: the amorphous region degrades first, followed by slower degradation of the crystalline region.

To illustrate the importance of these concepts, compare PLLA and PLDLA. PLLA is a homopolymer of poly-L-lactide, and PLDLA is a copolymer of poly-D,L-lactide. Whereas D-lactide and L-lactide contain the same functional groups, they are non-superimposable mirror images and are therefore different molecules (like right and left hands). The combination of these monomers interferes with ordered arrangement of the polymer chains, because each bonds with a different 3-dimensional geometry. This small difference has large implications for the degradation of PLDLA: the loss of mass time for PLLA occurs over years, compared with 12 to 16 months for PLDLA.[13]

## Bioabsorbable Polymers

The total number of shoulder reconstructions, small joint fixations, meniscal repairs, and cruciate ligament fixations in the United States is estimated to be more than 250,000 each year. Therefore there is an increasing demand for biodegradable or bioabsorbable fixation implants. These polymers do not interfere with imaging and do not need to be removed during revision operations. Bioabsorbable polymer screws have shown similar or superior fixation strength compared with metal,[10,14-17] and anterior cruciate ligament (ACL) reconstructions have shown acceptable clinical results.[16-19] Commercially available implants are outlined in Table 1. PLLA is used both as a homopolymer and part of a copolymer with polyglycolide (PLGA) or poly-D-lactide (PLDLA). Polyglyconate, a copolymer of glycolic acid and trimethylene carbonate, is also available.

Each polymer has a different degradation profile, and the optimum time frame is yet to be determined. If degraded too quickly, the rapid release of the monomer overwhelms the body’s ability to clear it, and the accumulation of the degradation products can cause adverse reactions. Foreign-body reactions,[20-22] osteolysis,[22] synovitis,[22,23] intraosseous cyst formation,[19,24-26] intra-articular inflammatory reactions,[27] systemic allergic response,[28] and loose intra-articular foreign bodies[29-32] are sometimes seen. These reactions are thought to be due to the acidic nature of the byproducts.[33,34] This may also interfere with bone formation, because hydroxyapatite (HA) is the preferential form of calcium phosphate only at higher pH values.[35] Another disadvantage is failure during insertion[36,37]; however, alterations in screw design and drive mechanisms have led to less breakage on insertion.[36]

Degradation times determined in vitro have not been consistent with in vivo degradation. Both PLLA and PLGA have been shown to persist in vivo for up to 5 years[19,26,35,38] and completely resorb at 7 and 10 years, respectively.[26,39] When complete reabsorption is seen, screws were not replaced with bone but instead consisted of a partially calcified fibrous tissue.[39] In addition, the bone-implant interface consists of a fibrous layer that may interfere with bony ingrowth. At 12 weeks in PLLA implants, no host tissue penetration was seen at the implant-bone interface.[40]

## Biostable Polymers

Because some bioabsorbable polymers can degrade too rapidly, causing adverse reactions, biostable polymers were investigated. These materials offer the same advantages of bioabsorbable polymers without these complications. Polyetheretherketone (PEEK) is a stable, highly unreactive structure that is resistant to chemical, thermal, and radiation-induced degradation. Polyethylene and polyacetal are also biostable thermoplastic polymers used in orthopaedic implants. PEEK is a rigid, semicrystalline thermoplastic poly-

**Table 1.** *Commercially Available Bioabsorbable and Biostable Polymer Implants and Their Compositions*

| | Suture Anchors | | | Interference Screws | | |
|---|---|---|---|---|---|---|
| Manufacturer | Name | BA/BS | Composition | Name | BA/BS | Composition |
| Arthrex (Naples, FL) | Bio-PushLock | BA | PLLA | Bio-Cortical | BA | PLLA |
| | Bio-PushLock SP | BA | PLLA/titanium tip | Bio-Interference | BA | PLLA |
| | Bio-SutureTak | BA | PLDLA | Fully threaded Bio-Interference | BA | PLLA |
| | Bio-Corkscrew | BA | PLDLA | Sheathed Bio-Interference | BA | PLLA |
| | Bio-Corkscrew FT | BA | PLLA | RetroScrew | BA | PLLA |
| | Bio-FASTak | BA | PLDLA | Bio-Tenodesis screw | BA | PLLA |
| | Bio-SwiveLock | BA | PLLA/PEEK eyelet | Delta-Tapered | BA | PLLA |
| | Bio-SwiveLock SP | BA | PLLA/titanium tip | PEEK Tenodesis Screw | BS | PEEK |
| | PEEK PushLock | BS | PEEK | | | |
| | PEEK PushLock SP | BS | PEEK/titanium tip | | | |
| | PEEK Corkscrew FT | BS | PEEK | | | |
| | PEEK SwiveLock | BS | PEEK | | | |
| | PEEK SutureTak | BS | PEEK | | | |
| ArthroCare (Austin, TX) | ParaSorb | BA | PLLA | Graftlok Tapered | BA | PLLA |
| | LabraLock P | BS | PEEK | | | |
| | Magnum PI | BS | PEEK | | | |
| | SpeedScrew | BS | PEEK | | | |
| Biomet (Warsaw, IN) | LactoScrew | BA | 85% PLLA/15% PGA | Gentle Threads | BA | 82% PLLA/ 18% PGA |
| | LactoScrew | BA | 82% PLLA/18% PGA | Rattler | BA | 82% PLLA/ 18% PGA |
| | ALLThread LactoSorb L15 | BA | 85% PLLA/15% PGA | Bio-Core | BA | 82% PLLA/ 18% PGA |
| | MicroMAX | BA | 85% PLLA/15% PGA | | | |
| | ArthroRivet RC Tack | BA | 82% PLLA/18% PGA | | | |
| | ArthroRivet Cannulated Tack | BA | 82% PLLA/18% PGA | | | |
| | Hitch LactoSorb L15 | BA | 85% PLLA/15% PGA | | | |
| | ALLthread PEEK | BS | PEEK | | | |
| | Hitch PEEK | BS | PEEK | | | |
| Cayenne Medical (Scottsdale, AZ) | | | | iFix | BS | PEEK |
| Covidien (Mansfield, MA) | Polysorb | BA | PLLA/PGA | | | |
| ConMed Linvatec (Largo, FL) | Duet suture anchor | BA | SR PLDLA (96% L/4% D) | The Wedge | BA | SR PLDLA (96% L/4% D) |
| | IMPACT suture anchor | BA | SR PLDLA (96% L/4% D) | SmartScrew ACL | BA | SR PLDLA (96% L/4% D) |
| | BioCuff and BioCuff C | BA | SR PLDLA (96% L/4% D) | BioScrew | BA | PLLA |
| | Paladin | BA | SR PLDLA (96% L/4% D) | | | |
| | Bio Mini-Revo | BA | SR PLDLA (96% L/4% D) | | | |
| | Bio-Anchor | BA | PLLA | | | |
| | BioTwist RC | BA | PLLA | | | |
| | UltraSorb RC | BA | PLLA | | | |
| Mitek (Raynham, MA) | QuickAnchor Minilok | BA | PLLA | Absolute | BA | PLLA |
| | QuickAnchor Microfix | BA | PLLA | Intrafix | BS | Polyethylene |
| | Bioknotless SA | BA | PLLA | | | |
| | BioROC EZ anchor | BA | PLLA | | | |
| | Lupine | BA | PLLA | | | |
| | SpiraLok | BS | PLLA | | | |
| | PanaLok | BS | PLLA | | | |
| | Healix PEEK SA | BS | PEEK | | | |

**Table 1.** *Continued*

| Manufacturer | Suture Anchors | | | Interference Screws | | |
|---|---|---|---|---|---|---|
| | Name | BA/BS | Composition | Name | BA/BS | Composition |
| | ROC EZ anchor | BS | Polyethylene | | | |
| | Versalok | BS | PEEK and Titanium eyelet | | | |
| Smith & Nephew (Memphis, TN) | TwinFix AB | BA | PLLA | BioRCI | BA | PLLA |
| | Suretac | BA | Polyglyconate | Endo-FIX L | BA | PLLA |
| | BioRaptor 2.9 | BA | PLLA | | | |
| | Raptormite | BA | PLLA | | | |
| | TAG | BA | Polyglyconate | | | |
| | KINSA | BS | PEEK | | | |
| | BioRaptor PK | BS | PEEK | | | |
| | TwinFix PK | BS | PEEK | | | |
| | Footprint PK | BS | PEEK | | | |
| | Spyromite | BS | PEEK | | | |
| | Dynomite | BS | PEEK | | | |
| | Raptormite PK | BS | PEEK | | | |
| | Nonabsorbable TAG | BS | Polyacetal | | | |
| Stryker (Hopkinton, MA) | BioZip | BA | PLLA | Bioabsorbable wedge | BA | PLLA |
| | XCEL anchor | BA | PLLA | | | |
| | PEEK IntraLine | BS | PEEK | | | |
| | PEEK BioZip | BS | PEEK | | | |
| | PEEK TwinLoop | BS | PEEK | | | |
| Zimmer (Warsaw, IN) | Bio-Statak | BA | PLLA | | | |

NOTE. Pure PLLA was the most common bioabsorbable component in both interference screws (14 [74%]) and suture anchors (22 [55%]) followed by PLGA for interference screws (3 [16%]). PLDLA and PLGA for suture anchors (8 [20%]) were equal. The most commonly used biostable polymer in interference screws (2 [67%]) and suture anchors (22 [92%]) is PEEK.

Abbreviations: BA, bioabsorbable; BS, biostable; SR, self-reinforced.

mer with excellent mechanical properties.[41] Thermoplastic polymers harden on cooling and tend to be relatively soft.[42] PEEK offers the advantages of good postoperative imaging[43-46] and stable fixation while not having the complications associated with polymer degradation. PEEK implants in animals have shown no acute inflammatory response and only mild chronic inflammation.[47] Similar to metals, the major problem has been poor osseointegration. In animals PEEK implants showed direct bone contact in some areas but cartilage and fibrous interfaces as well.[47] This decreased bone-implant interaction is because the inertness and hydrophobicity of PEEK's surface hinder protein and cell adhesion.[46,48,49] PEEK fails to form HA on its surface when exposed to simulated body fluid.[50] As with metals, methods of surface modification have been used with PEEK.[46,48,51]

## BIOCOMPOSITES

Biocomposites have the same advantages of polymers, such as ease of postoperative imaging[16,52] and revision surgery, with the added benefit of bone formation within the screw. A composite consists of 2 different materials, and those used in interference screws and suture anchors (Table 2) consist of a ceramic and polymer. All available implants consist of a bioabsorbable polymer and bioactive ceramic, but PEEK-ceramic composites are currently being investigated.[50] Studies have shown good clinical results with biocomposite interference screws,[53,54] as well as satisfactory biomechanical testing.[10,55]

A ceramic is a compound composed of metallic and nonmetallic elements with predominantly ionic bonding. The metallic cation (positively charged ion) and the nonmetallic anion (negatively charged ion) are then held together by an electrostatic force because opposite charges attract. Although this force is strong, giving ceramics an inherit strength and toughness, it is not rigid and can be disrupted by movement of the atoms relative to one another, particularly with tensile or sheer forces. This gives ceramics their characteristic brittleness. Bioactive ceramics (those that enhance bone formation) include HA [$Ca_{10}(PO_4)_6(OH)_2$], $\beta$-tricalcium phosphate ($\beta$-TCP [$Ca_3(PO_4)_2$]), biphasic calcium phosphate (HA and $\beta$-TCP), calcium car-

**TABLE 2.** *Commercially Available Composite Implants and Their Compositions*

| Manufacturer | Polymer | Ceramic |
|---|---|---|
| Arthrex | | |
| Suture anchors | | |
| Biocomposite Corkscrew FT | 85% PLA | 15% β-TCP |
| Biocomposite SutureTak | 85% PLA | 15% β-TCP |
| Biocomposite PushLock | 85% PLA | 15% β-TCP |
| Interference screws | | |
| Biocomposite Interference | 70% PLDLA | 30% Biphasic Ca-P |
| ArthroCare | | |
| Suture anchors | | |
| Doubleplay | 30% PLLA | TCP |
| Interference screws | | |
| Bilok Parallel Sided | 70% PLLA | 30% β-TCP |
| Bilok Tapered | PLLA | TCP |
| Biomet | | |
| Interference screws | | |
| ComposiTCP | 40% PLDLA | 60% β-TCP |
| ConMed Linvatec | | |
| Interference screws | | |
| Matryx | 75% SR PLDLA (96% L/4% D) | 25% β-TCP |
| Mitek | | |
| Suture anchors | | |
| Healix BR | 70% PLGA (85% PLLA/ 15% PGA) | 30% β-TCP |
| Lupine BR | 70% PLGA (85% PLLA/ 15% PGA) | 30% β-TCP |
| BioKnotless BR | 70% PLGA (85% PLLA/ 15% PGA) | 30% β-TCP |
| Gryphon BR | 70% PLGA (85% PLLA/ 15% PGA) | 30% β-TCP |
| Interference screws | | |
| Bio-Intrafix | 70% PLLA | 30% β-TCP |
| Milagro BR | 70% PLGA (85% PLLA/ 15% PGA) | 30% β-TCP |
| Smith & Nephew | | |
| Suture anchors | | |
| OsteoRaptor | 75% PLLA | 25% HA |
| Interference screws | | |
| BioRCI-HA | 75% PLLA | 25% HA |
| BioSure HA | 75% PLLA | 25% HA |
| Stryker | | |
| Interference screws | | |
| Biosteon Wedge | 75% PLLA | 25% HA |

NOTE. Pure PLLA comprised the majority of interference screws (7 [64%]) and suture anchors (5 [56%]) for polymers. β-TCP was used as the ceramic component most often in both interference screws (6 [55%]) and suture anchors (7 [89%]).

bonate, and calcium sulfate. Because HA and β-TCP are composed of calcium and phosphate, the primary inorganic component of bone, they closely mimic its mineral phase.[56,57] Essentially, bone mineral is HA with the addition of impurities.[56]

Bioactive ceramics have been studied extensively for use as bone-graft substitutes.[58-60] Whereas bioabsorbable polymers are surrounded by a fibrous layer,[61] bioactive ceramics spontaneously form a bone-like apatite layer from amorphous calcium phosphate on their surface,[62] which bonds directly to and integrates with the bone matrix.[27,56,58,62] Both HA and β-TCP have excellent osteoconductivity because of the release of calcium and phosphate when degraded,[60] which encourages mineralization and provides a scaffold for bone growth.[63,64] This degradation is osteoclast mediated and similar to that of normal bone.[57,65] However, the degradation of HA is much slower, and it is sometimes classified as nonresorbable.[66] The increased calcium levels with degradation potentiate chemotaxis and differentiation of osteoblasts. Several proteins associated with connective tissue regeneration increase expression with increased calcium concentration.[67,68]

The similarity of this apatite-like layer to the mineral phase of bone allows osteoblasts to preferentially proliferate and differentiate, forming an extracellular matrix of biological apatite and collagen.[62] This allows new cells to migrate into the implant[69] and generate bone from within[58,60,70] at the same time as implant resorption.[60,71] Biocomposites show increased bone formation and contact area compared with polymers.[61] The mineral matrix may also mimic the interactions of osteoblasts with normal bone and regulate intracellular signal transduction and gene transcription, enhancing bone production. Serum protein adhesion to HA is almost 60 times greater than adhesion to titanium,[56] and many of these proteins are important for directing the differentiation of osteoblasts. For example, fibronectin and vitronectin, known to influence cellular response to growth factors, differentiation, and proliferation of osteoblasts, mediate spreading of human osteoblast-like cells on HA.[56] These molecules are absent on titanium,[56] which may help explain its inferior osseointegration.

The combination of ceramics with biodegradable polymers creates a macroporous structure on polymer degradation. Porosity is an important factor in the formation of bone,[60] because it allows for faster resorption of the calcium phosphate (Ca-P) components and better bony ingrowth.[60] A minimum pore size of 100 nm is required, but microstructure is also important because increased pore roughness correlates with better bone-forming ability. In animals PLGA/Ca-P composites formed a porous material on degradation of PLGA and showed bony ingrowth in the previously occupied spaces, whereas Ca-P alone only showed bone formation within small fractures of the cement and minimal implant reabsorption.[60] Increased porosity by changing the polymer percentage from 15 to 30 resulted in more bone formation.[60] Biphasic calcium phosphate shows good integration between newly formed bone within the degrading material and existing bone.[59] $\beta$-TCP bonds directly to bone, but its mechanism appears to be different from that of HA and other bioactive ceramics.[66] $\beta$-TCP fails to form an apatite layer in simulated body fluid unless modified, because the formation appears to be more pH dependent and forms only at higher pH values.

Compared with the well-documented inflammatory response seen with bioabsorbable polymers, several studies have failed to observe adverse clinical reactions with biocomposites[54,60,72] or have shown only a mild reaction.[52,61] Histologically, less inflammatory response was seen in HA/PLLA composites than with PLLA alone.[61] The release of basic salts by the degradation of the bioceramic may buffer the acidic breakdown products of the polymers. $\beta$-TCP has been shown to buffer the pH near poly(lactic acid)-poly (glycolic acid) implants undergoing degradation,[33]

**TABLE 3.** *Commercially Available Metal Implants and Their Compositions*

| | Suture Anchors | | Interference Screws | |
|---|---|---|---|---|
| Manufacturer | Name | Composition | Name | Composition |
| Arthrex | FASTak | Titanium alloy | Fully threaded | Titanium alloy |
| | FASTak II | Titanium alloy | RetroScrew | Titanium alloy |
| | Corkscrew | Titanium alloy | Softscrew | Titanium alloy |
| | Corkscrew FT | Titanium alloy | Sheathed cannulated | Titanium alloy |
| | Corkscrew FT II | Titanium alloy | Tenodesis screw | Titanium alloy |
| ArthroCare | Magnum X | Stainless steel | Graft fixation screw | Titanium |
| | Magnum2 | Stainless steel | | |
| | Mini-Magnum | Stainless steel | | |
| | Parafix | Titanium | | |
| Biomet | ALLThread Titanium | Titanium | TunneLoc | Titanium |
| | Titanium | Titanium alloy | | |
| | Harpoon | Stainless steel | | |
| | Mini-harpoon | Stainless steel | | |
| Covidien | Ogden | Titanium alloy | | |
| | Herculon | Titanium alloy | | |
| ConMed Linvatec | Ultrafix RC | Stainless steel | Guardsman | Titanium alloy |
| | Ultrafix Knotless Minimite | Stainless steel | Propel | Titanium alloy |
| | Ultrafix Minimite | Stainless steel | | |
| | Ultrafix Micromite | Stainless steel | | |
| | Revo | Titanium alloy | | |
| | Mini-Revo | Titanium alloy | | |
| | Super Revo | Titanium alloy | | |
| Mitek | Knotless | Titanium alloy/nitinol arcs | Profile | Titanium alloy |
| | Mini anchor/micro anchor | Titanium alloy/nitinol arcs | Advantage | Titanium alloy |
| | GII anchor | Titanium alloy/nitinol arcs | Big Advantage | Titanium alloy |
| | Easy anchor/Quick anchor | Titanium alloy/nitinol arcs | | |
| | Fastin | Titanium | | |
| Smith & Nephew | TwinFix Titanium | Titanium | Cannuflex silk | Titanium |
| | MiniTac | Titanium | RCI | Titanium |
| | | | Softsilk | Titanium |
| Stryker | Titanium wedge anchor | Titanium | Wedge | Titanium |
| | IntraLine | Titanium alloy | | |
| Wright Medical Technology (Arlington, TN) | Anchorlok | Titanium alloy | | |
| Zimmer | Statak | Titanium alloy | | |

NOTE. The current commercially available implants comprise 33 metal suture anchors and 16 metal interference screws. Titanium alloy comprised all of the available metal interference screws and 73% of suture anchors (24).

**Table 4.** *Summary of Interference Screw and Suture Anchor Compositions*

| Type of Soft-Tissue Fixation | Suture Anchors | Interference Screws |
|---|---|---|
| Metal | 24 Titanium (73%) | 16 Titanium (100%) |
| | 9 Stainless steel (27%) | |
| Bioabsorbable polymer | 22 PLLA (55%) | 14 PLLA (74%) |
| | 8 PLDLA (20%) | 3 PLGA (16%) |
| | 8 PLGA (20%) | 2 PLDLA (11%) |
| | 2 Polyglyconate (5%) | |
| Biostable polymer | 22 PEEK (92%) | 2 PEEK (67%) |
| | 1 Polyethylene (4%) | 1 Polyacetal (33%) |
| | 1 Polyacetal (4%) | |
| Biocomposite | | |
| Ceramic | 8 β-TCP (89%) | 6 β-TCP (55%) |
| | 1 HA (11%) | 4 HA (36%) |
| | | 1 Biphasic Ca-P (9%) |
| Polymer | 5 PLLA (56%) | 7 PLLA (64%) |
| | 4 PLGA (44%) | 3 PLDLA (27%) |
| | | 1 PLGA (9%) |

and pH buffering causes less toxicity.[34] HA has also been shown to buffer the acidic breakdown products of PLLA (pH >7.3 for HA/PLLA *v* 3.0 for PLLA).[73] Similar to polymers, screw breakage during insertion is an issue for biocomposites.[36]

The bioabsorbable polymer in biocomposites can be used as a vehicle for the release of molecules to enhance bone formation. BMP is well known to enhance bone formation.[6,70] Biodegradable polymers release BMP slowly,[70] which studies have shown to be most effective.[6] Several studies have proven the efficacy of biocomposites as vehicles for growth factor delivery.[59,74,75]

## SCREW GEOMETRY

Although attention must be given to material composition and biomechanical suitability, it is important to consider the screw geometry. This is especially important when comparing different studies, because some

**Table 5.** *Advantages and Disadvantages of Various Materials Used for Soft-Tissue Fixation*

| Type of Soft-Tissue Fixation | Advantages | Disadvantages | Examples |
|---|---|---|---|
| Metals | • Malleable<br>• Ductile<br>• Durable<br>• Formation of alloys<br>• Reliable fixation | • Migration<br>• Magnetic resonance imaging artifact<br>• Artifact in subsequent surgeries<br>• Can result in graft laceration<br>• Incomplete osseointegration | • Titanium<br>• Aluminum<br>• Stainless steel<br>• Alloys |
| Bioabsorbable polymers | • Biocompatible<br>• Bioabsorbable<br>• Nonobstructive in imaging<br>• Nonobstructive in subsequent surgeries<br>• Wide range of material properties<br>• Metal-like mechanical properties are achievable<br>• Positive clinical results<br>• Various degradation profiles | • Byproducts of degradation are acidic<br>• May interfere with bone and soft-tissue healing<br>• Possibility of foreign-body reactions<br>• Failure during insertion | • PLLA<br>• PLGA<br>• PLDLA |
| Biostable polymers | • Same advantages of bioabsorbable polymers with fewer complications<br>• Polymer that does not degrade<br>• Little to no inflammatory response<br>• Very similar modulus to bone (PEEK) | • Poor osseointegration because of inertness and hydrophobicity | • PEEK<br>• PET |
| Biocomposites | • Advantages of polymers<br>• Consists of ceramic and polymer making the screw bioactive<br>• Positive clinical results<br>• Creates macroporous structure on polymer degradation to improve osseointegration<br>• Able to carry growth factors<br>• Little to no inflammatory response | • Failure during insertion | • HA/PLA<br>• PLA/β-TCP<br>• PEEK-ceramic<br>• PLGA/Ca-P<br>• PLA/PLGA/TMC<br>• PLC |

NOTE. Many of the new materials have shown an increase in absorption, osseointegration, and compatibility; however, failure during insertion still remains problematic.

Abbreviations: PET, polyethylene terephthalate; PLA, poly(lactic acid); TMC, trimethylenecarbonate.

have suggested that screw geometry is a more important determinant of pullout strength than the type of material. Several studies have stressed the importance of various aspects of screw geometry, such as thread diameter,[15,76] core diameter, screw length,[77] gap size,[77,78] buttress geometry,[79,80] and drive mechanism.[76] In general, increased thread-bone surface area results in increased fixation strength.[77,80]

## COMMERCIALLY AVAILABLE PRODUCTS

Companies producing interference screws and suture anchors were identified by contacting the operating room coordinators at local hospitals, checking articles for references to orthopaedic companies, and obtaining product pamphlets from exhibitors at the American Academy of Orthopaedic Surgeons annual meeting in February 2009. Each company was contacted, and information on available products was obtained from each company's Web site and sales representatives.

## IMPLANT REVIEW

The review of commercially available implants found 33 metal suture anchors and 16 metal interference screws (Table 3). All of the available metal interference screws and 73% of suture anchors (24) are made of titanium alloys.

Table 1 outlines the available bioabsorbable and biostable polymers. For bioabsorbable polymers, pure PLLA was the most common in both interference screws (14 [74%]) and suture anchors (22 [55%]). The second most common material was PLGA for interference screws (3 [16%]), with a tie between PLDLA and PLGA for suture anchors (8 [20%]). Seven of the PLDLA implants (5 suture anchors and 2 interference screws) are self-reinforced, containing PLDLA fibers within the implant. PEEK is the most commonly used biostable polymer in interference screws (2 [67%]) and suture anchors (22 [92%]). Only 3 biostable interference screws are available, compared with 24 suture anchors.

The compositions of available biocomposite implants are outlined in Table 2. For the polymer component, pure PLLA comprised the majority of interference screws (7 [64%]) and suture anchors (5 [56%]). For the ceramic component, $\beta$-TCP was used most often in both interference screws (6 [55%]) and suture anchors (7 [89%]).

Table 4 summarizes the available interference screws and suture anchors by material category.

## CONCLUSIONS

Interference screws and suture anchors are commonly used for fixation of soft tissue to bone in arthroscopic surgery and sports medicine. Interference screws tightly sandwich the graft/tendon between the screw and the bone, whereas suture anchors attach soft tissue to an implant embedded in bone. Many implants are made from metals; however, the advancement of new polymers and composites has made the use of these materials more common (Table 5). In biceps tenodesis and ACL reconstruction, bioabsorbable screws provide mechanical stabilization in the short term, allowing for early range of motion while bone-tendon healing occurs. Biological fixation, through osseointegration, provides the long-term stabilization of the tenodesis or ACL graft by allowing for effective transmission of loading forces and enhancing stability. When this stability is achieved, the screw becomes redundant. Attention has turned to options that allow for bone formation within the implant. Because no material has been shown to be superior for all applications, the surgeon must weigh the advantages and disadvantages of each to evaluate the optimum material for a given application and patient.

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