Review Article

Biodegradable Implants in Orthopaedics

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ABSTRACT

Bioabsorbable materials are more commonly used now days in orthopaedic surgeries. Bioabsorbable implants for fracture fixation, and meniscal repair. These implants provide the advantages of gradual load transfer to the healing tissue, reduced need for implant removal, and radiolucency, which facilitates postoperative radiographic evaluation and no hinderance in second surgery. These also carries disadvantages like, more expensive, having less strength than metals, tissue reactions including mild fluid accumulation, painful erythematous fluctuating papule, sterile sinus tract formation, osteolysis, synovitis, and hypertrophic fibrous encapsulation. We advocate more researches to be carried out for the best suitability of these materials in orthopaedic surgeries.

Key Words: *Biodegradable implants, Implants, Orthopaedic implants*

INTRODUCTION

Basic Bioabsorbable Implants

A basic bio absorbable implant degrades in a biologic environment. Their breakdown products are incorporated into normal cellular physiologic and biochemical processes. These implants and degraded material are well tolerated by the host with no immunogenic or mutagenic tendency. For fracture fixation, these materials must have adequate strength and should not degrade too rapidly, so that fixation is not lost before adequate healing can occur. Ideally these implants should have mechanical characteristics equal to those of standard stainless steel implants. It would degrade with the healing process so that load is gradually transferred to the healing tissue. But currently available polymers do not have mechanical characteristics equal to those of metal implants [Table 1].[1-3]

Table 1: Mechanical properties of various bioabsorbable implant materials.

Implant Material	Diameter (mm)	Bending Modulus (GPa)	Bending Strength (MPa)	Shear Strength (MPa)
Stainless steel (for comparison)	-	200	280	-
Self-reinforced polyglycolic acid	2	13	320	240
Injection-molded polyglycolic acid	2	7	218	95
Self-reinforced poly-L-lactic acid	1.3	10	300	220
Injection-molded poly-L-lactic acid	2	3	119	68
Polydiaxanone (suture)	-	-	-	48

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Type Of Implants

Variety of implants made from different materials is commercially available. Their composition and the mode of reinforcement vary according to the operation for which they are intended. Polyglycolic acid (PGA) and Poly-L-lactic acid (PLLA) implants have been widely used, including pins, rods, screws and plates are available.[4-6] Many other implants such as membranes, arthroscopic and spine surgery implants are currently in use.[6]

PATHOPHYSIOLOGY

Implants modify the risk of infection by bacterial adhesion, tissue integration, and immunomodulation. Bacterial adhesion to implant leads to interaction between bacteria and implant.[7] There are numerous implant-dependent factors affecting the bacterial adherence to the surface [Table 2].[3-5] These include chemical composition, surface roughness and configuration, and possible surface coating. Bacterial colony accumulates over implant which secretes biofilm slim layer (extracelluar mucopolysaccharide), interfere with phagocytoses and antibody function of host and promotes bacterial aggregation.[8] This also provides a physiochemical barrier against both systemic and implant-released antibiotic therapy, making infections difficult to treat without implant removal.[8,9]

In addition to bacterial and implant properties, the modified immune response of the host plays a key role in the aetiological process of foreign-body infection. All implanted devices cause a foreign-body reaction, the severity of which is dependent on numerous factors: tissue damage caused by trauma and surgery, material of the implant, and size and chemical composition of the debris particles present.[10] The most common bacteria is coagulase negative staphylococcus (*Staphylococcus epidermidis).*[10-12]

Table 2: Factor affecting implant degradation

Implant factors	Environmental factors
Chemical composition	Implantation site
Molecular weight	Tissue type
Fiber orientation (SR)	Stress on the plant
Monomer concentration (for copolymers)	Vascularity
Stereoisomerism	
Material phase	
Conformation	
Volume/Surface rate	
Pores	
Presence of additives or impurities	
Sterilisation method	
Degradation mechanism (enzymatic vs. hydrolysis)	

BIODEGRADATION

To avoid second surgical intervention, the degradation of these implant materials is important. Degradation should be achieved at a rate such that partially degraded implant should maintain their mechanical integrity until the newly formed tissues have sufficient strength to replace them. Material degradation occurs by several mechanisms, including hydrolysis and enzymatic degradation [Table 3].[13,14] Most synthetic polymers are degraded by hydrolysis of their ester linkages.[14] On the other hand, many natural materials and some polymers, including degradable peptide sequences, are degraded by enzymatic mechanisms to oligomers and monomers. The final products (CO2 and H2O products of the TCA cycle) are excreted or used by the body.[15-17] PGA and Poly dioxanone (PDS) degradation products can also be excreted by the kidneys.[17,18] It is also known that PGA degradation is partially performed by enzymes such as esterase. Enzymes also seem to take part in Polylactic acid (PLA) degradation.

Polymer breakage produces products that lower the regional pH and thus accelerate the procedure. The final degradation of polymer debris is done by macrophages and giant cells followed by mild local tissue reaction around absorbable implants.[19-21] This leads to production of a thin macrophage layer with incidentally multinucleated giant cells surrounded by a mild connective tissue capsule.[20,21] That is responsible for many adverse effects.

Table 3: Time of full absorption and mechanic properties loss

Material	Complete Absorption Time	Mechanical properties loss time
PGA	4-7 weeks	36 weeks
SR-PGA	3 months	1 month
	6-12 months	
PLLA	>5 years	
SR-PLLA	5-6 years	Reduction to cortical bone levels in
	>5 years	36 weeks
P(D/L) LA 70/30	2-3 years	18-36 weeks
PLA/PGA (PLGA) 80/20	1-2 years	6-8 weeks
	1-1.5 years	
P(D/L) LA 96/4	2 years	
PDS	2 months	

PGA (Polyglycolic acid); SR-PGA (Self-reinforced polyglycolic acid); PLLA (Poly-L-Lactic acid); SR-PLLA (Self-reinforced Poly-L-Lactic acid); P(D/L) LA (mixture of D- and L- isomers of Polylactic acid); PDS (Poly-p-dioxanone).

BIOCOMPATIBILITY

Biodegradable materials should be biocompatible. Not only it avoids eliciting inflammatory and immunogenic responses, but also degraded materials and related chemicals should be biocompatible in terms of both the local and the systemic response.[7-9]

The biocompatibility of a polymer depends on both its chemical structure and the processing method that produces it.[22-24] During a polymerization process, an initiator, a monomer, and sometimes a catalyst are needed, and these materials often remain in preformed implants even after purification are also a particular concern for in situ forming implants. Toxicity and concentration of residual monomers or initiators should be considered when assessing biocompatibility. Removal of these potentially toxic components is usually effected by prolonged rinsing in aqueous solution. Biocompatibility of the remaining material is confirmed in vitro by cytotoxicity assays. In vivo observation of the inflammatory response after implantation in animal models is also an important step before clinical application can be considered.[15,25]

Under in vitro conditions, PGA is an immunologically inert substance, provoking only slight lymphocyte activation.[26] Clinically significant foreign-body reactions are far more rarely seen with PLA than with PGA. In short-term studies, the biocompatibility has been acceptable with no clinical manifestations of foreign-body reactions.[26-29] There are no in vitro studies investigating the cytological immune response of PLA.

Processability, Sterility, Reproducibility And Ease Of Handling

As with other biomedical implants it would be possible to sterilize biodegradable implants without affecting their chemical or physical properties and to produce and pack them on a large scale for practical and economic uses. Factors such as viscosity, curing time, and implant shape should also be optimized for injectable scaffolds to facilitate their use during complex surgical procedures [24,30].

CLINICAL APPLICATION

These implants can also be used in fractures fixation of the glenoid fossa , radial styloid, patella and acetabulum; osteochondral fractures in the knee, tibial plateau, phalanx, calcaneus and talus; hallux valgus surgery, ankle surgery, radial head fixation , distal radial fractures , hand fractures , olecranon fractures, distal femoral epiphyseal fractures, meniscal injury, anterior cruciate ligament and shoulder lesions repair [Figure 1].[3,31,32] In addition to providing physical support, they have been employed to introduce bioactive molecules at the defect site.[33,34] In one strategy, scaffolds can be used to control the release of bioactive molecules, thus accelerating the healing process.[35] In other cases, the effectiveness of less stable drugs may be extended by encapsulating them inside a matrix.[35]

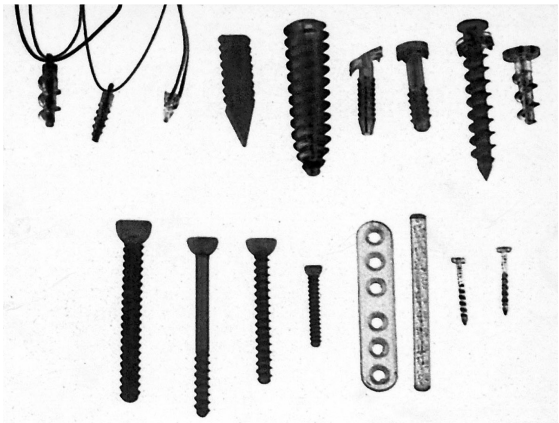

Figure 1: Currently available bioabsorbable implants for fracture/interference fixation, and meniscal repair.

ADVANTAGE

Biodegradable implants provide the advantages of gradual load transfer to the healing tissue, reduced need for implant removal, and radiolucency, which facilitates postoperative radiographic evaluation and no hinderance in second surgey.[36] They can be engineered to alter their degradation characteristics and material properties.

These biodegradable implants are safe as they are made of biocompatible material; hence there is no risk of metal allergic reactions as compared to metallic implants. These implants degrade, they lose strength and this increases pressure over the bone, strengthening it and therefore preventing bone resorption.[27,37] Resorption of these implants also makes revision surgery less complicated, as there are no permanent implants inside. So there is no need of another surgery for implant removal.[38] Hence there is reduced trauma to soft tissue thereby decreasing the cost of surgery and reducing the risk of cross infection.

As compared to metallic implants there is no long-term implant palpability hence patient compliance is much better.[39,40] There is no implant temperature sensitivity so short wave diathermy and micro wave diathermy can be used after a period of time thus complying increased patient satisfaction.[40]

Due to characteristic nature of these biodegradable implants there is no growth disturbances in children after surgery as biodegradable screws or rods can

also be used for treating epiphyseal fractures.[41,42] It facilitates fracture healing by allowing micro-movements at fracture site. It can be used to control the release of bioactive molecules to accelerate the healing process.[42] The fixation does not disturb the anatomy as depicted on radiographs as there is reduced radiographic scatter or obstruction and is compatible with magnetic resonance imaging if further evaluation of the affected joint post operatively is necessary. Bioabsorbable suture anchors are becoming alternative to metal staples and screws.[43] In this, sutures don't have to pass through bone tunnels. Pullout strengths for bioabsorbable suture anchors are comparable to those of their metallic counterparts.[43] Bioabsorbable suture anchor fixation has several advantages. The anchor undergoes reabsorption so no need for removal of implant as compared to metallic implants which need to removed because of osteopenia, corrosion and irritation of adjacent tissues.

Improperly placed anchors may simply be drilled out rather than unscrewed or pushed through due to which stress is gradually transferred to the healing soft tissue as the anchor degrades.

DISADVANTAGE

These are more expensive, have less strength than metals.[5,6] Complications with the use of these materials include tissue reactions including mild fluid accumulation, painful erythematous fluctuating papule over the implant track, the papule, if left untreated, bursts within a few days and revealed a sinus draining liquid remnants of the implant leading sterile sinus tract formation, osteolysis around the implants, synovitis when implanted intra articularly, and hypertrophic fibrous encapsulation.[23]

Adverse effects such as migration of implant, growth disturbance, rigidity, radio-opacity, infection, effects on cellular level and implant removal operations, often accompany the use of these materials.[5,6,16,44-52] Similarly improper insertion of the anchor too deep in the bone can cause suture failure. Superficial insertion of the anchor can lead to cartilage wear on the opposing articular surface[50,51]. There may be pullout from bone and become an intra-articular loose body. Due to its radiolucent nature, diagnosis can be difficult to make postoperatively in a persistently painful joint.

DISCUSSION

The use of PGA is now limited, since materials and copolymers with better degradation properties.[2,22] As per Bostman *et al*[22] and Tuompo *et al*[41], a total of 2037 and 1879 patients respectively were included in study, adverse reaction ranged from 2.8% to 60%in a series of paediatric fractures and wrist fractures respectively. Tissue reactions included fluid accumulation, sinus formation and osteolysis that was apparent 2 to 17 months postoperatively. PLLA has a low degradation rate because of this, adverse reaction tend to appear late, even 4-5 years postoperatively. This renders many studies weak regarding the presentation of true adverse reaction rate in procedures where PLLA implants have been used, since the follow-up of these studies is shorter than the complete absorption time of the material. A review of the first clinical trials where PLLA implants were used presents 14 series that were performed from 1990 to 1996.[22] A wide variety of reaction rates was reported, from no adverse reactions to swelling in 47% of the patients. Advances in material science, such as self-reinforcement technique and elimination of factors that were considered responsible for reaction (e.g. dyes and older sterilisation techniques), have changed PLLA implants' behaviour. Enantiomeric isomers of PLA were mixed to develop a material less crystallic and more hydrophilic than PLLA, in order to accelerate the degradation process and avoid late tissue reactions.[53] Latjai *et al*[54] used P(L/D)LA-PGA copolymer screws in ACL reconstruction procedures. No material-related tissue reactions were reported in the mean follow-up time of 5.2 years in the 28 patients that were included in the study.

CONCLUSION

Clearly, future work in the area of orthopaedic biomaterials should be focused on the reduction of the foreign-body response. Reducing the crystallinity of the polymer or controlling the pH in the degrading implants may help reduce the incidence of the foreign-body response

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