Journal of Metals, Materials and Minerals. Vol. 11, No.1 pp.15-21, 2001.

Biomaterials : an Overview

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Abstract

Biomaterials have been used in the clinical practices to augment and replace bone loss for many years. Various biomaterials are being classified into metals, polymers, ceramics and composites. Their general properties including mechanical and physiological have been described. As their properties are still mismatched to the host bony tissue, failure of a biomaterial occurs. Close and long follow-up observation of biomaterials in clinical use is advised for any adverse effects that may occur.

Introduction

Many accidents result in bone loss either in the limb bones, hands, skulls or even teeth. The incident is increasing according to the growth and development of the country and her inhabitants. Though higher standards of new vehicles and factory machines are being implemented to prevent or avoid such risks, the increased numbers of patients suffering from bone loss still occur and seems unavoidable. Bone loss needs to be repaired and replaced by surgery in order to regain its nearest normal functional condition and in the shortest time, it possible. Bone graft is widely used for this purpose. There are also numerous bone diseases and deformities that require variable amount of bone grafts. Bone tumor is a good example of bone disease that needs a larged sized bone graft to fill the remaining defect in the limb after excising the tumor. Small bone grafts are used in the diseased bone, such as pscudarthrosis, bone cyst and others.

Many types of bone grafts, such as autografts, allografts, xenografts have been tried in the treatment of bone loss condition from diseases and accidents with variable results. However, these bone grafts are not always available and are not without problems. Xenografts are non-vitalized bone, taken from other species, not human being. Many complications arise when applying these grafts in clinical cases, such as, immunological problems resulting in host rejection, high rate of infection, inappropriate shape and size creating unstable fixation and etc. (Anderson, *et al.* 1964; and Karges, *et al.* 1963.) Allografts are dead bone, taken from deceased human donors. While they are becoming more popularly applied in bone tumor diseases, they are not without immunological problems. (Bos, *et al.* 1983; and Burcharat, *et al.* 1978.) These grafts have advantages over other types (Heiple, *et al.* 1963; and William, 1964.) because they can be selectively taken from cadavers with the shape and size tailoring to the implantation sites. But allografts also have disadvantages owing to their inadequate strength and high rate of infection when implanted into the living bony tissues. Besides, with the spreading of acquired immunological deficiencies and hepatitis diseases, the allograft donors are significantly limited. Autografts have been used generally, (Burcharat, *et al.* 1978; Enneking, *et al.* 1975; and Leung, 1983.) but frequently are in short supply. Autografts are usually small bone chips, taken from the donor site of the same person. In procuring autografts, it is necessary to make additional surgery on the same patient. This leads to heightening the risk of infection and complications of pain and deformities postoperatively. These practical problems are serious especially for children or aged persons whose bone volumes are already not sufficient.

With the significant limitations of these bone grafts, many investigators long searched for another source of bone substitute. Bone substitutes or so-called biomaterials should have to mimic the tissue they replaced, in size, shape, consistency and function. They should not be predisposed to infection and should not evoke a healing response the would alter their characteristics. As they disappear that should acquire qualities of the tissues they replaced or augmented. Or if they do not disappear they have to be tolerated permanently.

Biomaterials : Definition and biocompatibility

In 1982, Hence and Ethridge (1982) proposed the definition of biomaterials which is still universally acceptable nowsaday. He stated that the purpose of a biomaterial is to replace a part or a function of the body in a safe, reliable, economic, and physiologically acceptable manner.

There are several types of biomaterials (Hence and Ethridge, 1982) being used in orthopaedics, dentisty, neurosurgical, maxillofacial practices and etc. Many materials are not compatible when used clinically. Incompatible materials are those that release substances in toxic concentrations or antigens that cause immune reactions, eg, allergies, inflammation and rejection. Biocompatible materials, when implanted in body, must release substance in non-toxic concentrations. The host reaction should be mild, eg, fibrous connective tissue capsule formation, weak immune reactions. Of these biocompatible materials, some are inert and some are active. Bioinert materials release no toxic substance and have no positive interaction with living tissue. The host reaction demonstrates non-adherent connective tissue capsule around these biomaterials with shape-mediated distance or contact osteogeneses (bony on-growth). The compressive forces will be transmitted by the interface. Bioactive materials have positive interaction with host tissue including differentiation. There is reactive bonding to bone along the interface of the implant-bone or materials mediated bonding osteogenesis (bony in-growth). Tensile and shear forces can be transmitted through the interface.

Biomaterials : classifications and general properties

(Hench, *et al.* 1982; ASM International, 1992; and Friedman, *et al.* 1994.)

a) Metals have metallic bonds, free electrons distributed throughout lattice, high thermal and elective conductivity, high fracture toughness and ductility, and reflection of light.

b) Polymers have covalent bonds within molecules and van der Waals bonds between molecules with low melting point.

c) Ceramics have predominantly ionic bonds but also covalent bonds. They are heat resistant with various electric and magnetic properties. They have low fracture toughness and are brittle.

d) Composite may compose of either metal and ceramics, metals and polymers or polymers and ceramics according to the purpose of practical application.

Mechanical properties of Metals

Materials	Elastic modulus GPa (psi x 10^6)	Tensile strength Mpa (Ksi)
Compact bone	~ 21	~ 138
Cobalt alloys		
- cast	235	~ 655
- wrought	235	~ 1172
Stainless steel (316L)	193	480-1000
Titanium alloy	117	860-896

Mechanical properties of bone cement

Compressive strength	15,680 psi (50% cortical bone)
Tensile strength	10,000 psi (25% cortical bone)
Elastic modulus	0.3 x 10^6 psi (15% cortical bone)

Mechanical properties of ceramics

Materials	Compressive strength (psi x 10^6)	Bending strength (psi x 10^6)	Elastic modulus (Kg/mm^2)
Cortical bone	16-18	16	1,800
Alumina	500	50-130	40,000
Ceravital	50	10	6,500
Dense HA	60-90	12	7,400
AWGC	108	23	11,700

Physiological properties

	Autograft	Allograft	Ceramics	Polymers	Metals
Osteoconduction	+	+	+	-	-
Osteoinduction	+	+/-	-	-	-
Imm. torque strength	++	++	+/++	++	++
Imm. Stability	-	-	-	+	-
Chemical bonding	++	+	++	-	-

Examples of biomaterials used in orthopaedic practice

Material	Application	Behaviour
Stainless steel	Osteosynthesis (bone screws)	Biotolerant
Bone cement (PMMA)	Fixation of implants	Biotolerant
Cp-titanium	Acetabular cups	Bioinert
Ti6Al4V	Shafts for hip implants, tibia	Bioinert
CoCrMo	Femoral balls and shafts, femur parts (knee implants)	Bioinert
Alumina	Femoral balls and shafts, femur parts (knee implants)	Bioinert
Zirconia (Y-TZP)	Femoral balls	Bioinert
HD-polyethylene	Articulation components	Bioinert
Hydroxyapatite	Bone replacement, coatings	Bioactive
Tricalciumphosphate	Bone replacement	Bioactive
Tetracalciumphosphate	Dental cements	Bioactive
Bioglass	Bone replacement	Bioactive

Ideally implant materials should have similar stiffness but higher strength compared to bone. That is why biomaterials fail clinically in many circumstances.

Failure of a material

The service performance of a material depends upon :

a) Its inherent mechanical, physical and chemical properties
b) The stress system acting up on it
c) The operating environment

Reasons for failure

1) Incorrect design
2) Incorrect material selection
3) Faults in processing or fabrication leading to defects and/or incorrect microstructures
4) Faults in assembly and/or commissioning
5) Inadequate quality control, testing and inspection
6) Incorrect use
7) Incorrect maintenance
8) Mechanical and/or chemical and/or thermal or other damages in service

Mechanisms of failure

1) Ductile and brittle fracture
2) Fatigue and corrosion fatigue
3) Plastic deformation
4) Corrosion and erosion
5) Wear behavior and damage
6) Stress corrosion
7) Hydrogen damage and etc

Clinical consideration of failure

a) Early failure :

This arises due to faulty material or manufacturing and/or assembly errors that have not been detected by quality systems.

b) Randon failure :

This caused by chance eg. accidental overload or blocking of lubricant flow

c) Overload failure :

Overloading of a part beyond its safe capacity may cause failure or damage leading to eventually failure under subsequent normal loading

d) Wearout failure :

It occurs when the component reaches the end of its intended life. This is progressive as the part gradually loses its efficiency.

Conclusion

Biomaterials have been used in clinical practice widely with all equal importance, no matter will they be metals, polymers, ceramics and composites. Metals in the forms of various shaped-plate and screws have been implanted to fix fractured bones for a long time with good success. However, it is advised to have them removed especially in young patients with the reason that the bone supported beneath the metals might be weakened. A form of polymers, bone cement (polymethylmethacrylate) has been used in prosthetic replacement as a grouting material. It has no bonding to the host bone because it is not bioactive. It still can create loosening in the long follow-up cases. Total joint prosthesis, whether composes of metal, polyethylene and ceramics still have not reach life long period. Wear of polyethylene is considered a serious problem.

An ideal biomaterial is still being investigated and searched for to really match the bony tissue to be augmented or replaced. Until then, the use of biomaterials have to be watched out carefully, closely and consistently for any adverse effects that may occur.

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(Revised version accepted August 17, 2001)