Biomaterials in Implants

Contents

Historical background

- Tooth loss from disease has always been a feature of mankind’s existence.
- For centuries people have attempted to replace missing teeth using implantation.
- Greek, Egyptian civilization used materials like jade, bone , carved ivory , metal and even animal teeth

- Since then many types of implant materials were introduced but consistent failures occured with them
- In 1952 Branemark developed a threaded implant design made of pure titanium that showed direct contact with bone.
- Henceforth popularity of implants reached new heights

Introduction

- Currently the implant materials available are diverse
- Success and longevity of implant depends on fours B’s
  - Biomaterial
  - Biomechanics
  - Biological tissues
  - Body serviceability
- Definitive need to have a knowledge of these biomaterials for their judicious selection and application in implantology.

Definition

Biomaterials

- According to GPT-8
- Any substance other than a drug that can be used for any period of time as part of a system that treats ,augments or replaces, any tissue ,organ or function of the body

Classification

According to composition

1. Metal and Metal alloys

- Titanium
- Titanium alloys (Ti6Al4V)
- Cobalt, Chromium, Molybdenum alloy (Vitallium)
- Austenitic steel or Surgical steel (Iron , Chromium,Nickel alloy)
- Precious metals (Gold ,Platinum,Palladium)

According to composition

2. Ceramics and carbon

- Aluminium oxide
  - Alumina
  - Sapphire
- Zirconium oxide (zirconia)
- Titanium oxide (titania)
- Calcium phosphate ceramics (CPC)
  - **Hydroxyapatite (HA)**
  - **Tricalcium phosphate(TCP)**
- Glass ceramics
- Vitreous carbon (C), Carbon-silicon(C-Si)

According to composition

3. **Polymers**
   - Poly methyl metha acrylate (PMMA)
   - Poly tetra fluoro ethylene (PTFE)
   - Poly ethylene terapthylate (Dacron)
   - Dimethyl polysiloxane(Silicone rubber)
   - Ultrahigh molecular weight polyethylene(UHMW PE)
   - Poly sulphone
4. **Composites** (combination of polymer and other synthetic biomaterials)
   - Carbon – PTFE
   - Carbon- PMMA
   - Alumina- PTFE

Biological classification – according to tissue response

1. **Biotolerant** – Polymers

   Fibrous tissue encapsulation at implant interface

2. **Bioinert** – Titanium , Ti alloy , Alumina , zirconia

   Direct bone apposition at the implant interface

3. **Bioactive**- CPC ,Glass ceramics

   Direct chemical bonding of implant with the surrounding bone

Requirements for an ideal implant material

- Any material intended for use as dental implant must meet 2 basic criteria
  - Biocompatibility with living tissue
  - Biofunctionality with regard to force transfer
- Implant material should have certain ideal physical, mechanical, chemical and biological properties to fulfill these basic criteria
- Implant properties can be studied under
  - Bulk properties
  - Surface properties

Bulk properties

Modulus of elasticity (E)

- Measure of change in dimension (strain) with respect to stress
- Ideally a biomaterial with elastic modulus comparable to bone (18GPa)should be selected
- This will ensure more uniform distribution of stress at implant bone interface as under stress both of them will deform similarly.
- Hence the relative movement at implant bone interface is minimized.

Tensile, Compressive, Shear, Strength

- Forces exerted on implant material consists of tensile , compressive , shear components
- An implant material should have high tensile, compressive, shear strength to prevent fractures and improve functional stability.

Yield strength and Fatigue strength

- Yield strength is magnitude of stress at which a material shows initial permanent deformation
- Fatigue strength is stress at which material fractures under repeated loading
- An implant material should have high yield strength and fatigue strength to prevent brittle fracture under cyclic loading

Ductility

- Refers to relative ability of a material to deform plastically under a tensile stress before it fractures
- ADA demands a minimum ductility of 8% for dental implant
- Required for fabrication of optimal implant configurations
- Safeguards against brittle fractures of implant

Hardness and Toughness

- Hardness – resistance to permanent surface indentation or penetration
- Increase hardness decreases the incidence of wear of implant material
- Toughness – amount of energy required to cause fracture.
- Increased toughness prevents fracture of the implants.

Electrical and Thermal conductivity

- Should be minimum to prevent thermal expansion, contraction, and oral galvanism.

Surface properties

Surface tension and surface energy

- Determines
  - Wettability of implant by wetting fluid (blood)
  - Cleanliness of implant surface
- Surface energy of > 40 dyne / cm
- Surface tension of 40 dyne/cm or more
- Characterstics of very clean surface
- Results in good tissue integration with load carrying capacity

Biocompatibility

- Not total inertness
- Ability of a material to perform with an appropriate biological response in a specific application
- Mainly a surface phenomenon
- Most important requirement for a biomaterial
- Depends on
  - Corrosion resistance
  - Cytotoxicity of corrosion products

Corrosion resistance

- Corrosion is deterioration of a metal caused by reaction with its environment
- Following types of corrosion are seen

Stress corrosion

- Failure of a metal by cracking due to increased stress

Fretting corrosion

- Due to micromotion or rubbing contact within a corrosive environment

Crevice corrosion

- Occurs in narrow region eg implant screw – bone interface

Pitting corrosion

- Occurs in surface pit
- Metal ions dissolve and combine with Cl ions

Galvanic corrosion

- Occurs between two dissimilar metal in contact within an electrolyte resulting in current flow between the two.

Electrochemical corrosion

- In this anodic oxidation and cathodic reduction takes place resulting in metal deterioration as well as charge transfer via electrons.
- All these types of corrosion and charge transfer can be prevented by presence of passive oxide layer on metal surface.
- The inertness of this oxide layers imparts biocompatibility to biomaterials

Cytotoxicity of corrosion products

- Toxicity of implant materials depends on toxicity of corrosion products which depends on
  - Amount of material dissolved by corrosion per unit time
  - Amount of corroded material removed by metabolic activity in same unit time
  - Amount of corrosion particles deposited in the tissue
- Both increased corrosion resistance and decreased toxicity of corrosion products contribute to biocompatibility

Bone and implant surface interaction

- The implant material should have an ability to form direct contact or interaction with bone (osseointergration)
- This is largely dependent on biocompatibility and surface composition of biomaterial (presence of passivating oxide layer).

Biomaterials

Titanium

- Gold standard in implant materials
- Composition of Commercially pure titanium
  - Titanium 99.75%
  - Iron 0.05%
  - Oxygen 0.1%
  - Nitrogen 0.03%
  - Hydrogen 0.012%
  - Carbon 0.05%
- Commercially pure titanium occurs in 4 grades , grade I II III IV ,according to oxygen content (0.18% to 0.40 %) & iron content (0.20 to 0.50 wt %)

- Consists of 2 phases α and β phase
- Ti implants are mainly manufactured through controlled machining (lathing , threading , milling)
- Configuration like cylinders ,screws and blade forms etc are used
- Casting of titanium alloy is difficult due to high melting points (1700°C)
- Also titanium readily absorbs nitrogen hydrogen and oxygen from air during casting which makes it brittle

Properties

Biocompatibility

- Titanium is one of the most biocompatible material due to its excellent corrosion resistance
- The corrosion resistance is due to formation of biologically inert oxide layer

Oxide layer

- Titanium spontaneously forms tenacious surface oxide on exposure to the air or physiologic saline
- Three different oxides are
  - TiO Anastase
  - TiO_2 Rutile
  - Ti_2O_3 Brookite

- TiO_2 is the most stable and mostly formed on titanium surface
- This oxide layers is self healing i.e. if surface is scratched or abraded during implant placement it repassivates instantaneously
- Also Ti oxide layer inhibits low level of charge transfer, lowest among all metals . This is the main reason for its excellent biocompatibility

- Good yield strength , tensile strength , fatigue strength .
- Modulus of elasticity (110 GPa) is half of other alloys and 5 times greater than bone .This helps in uniform stress distribution
- Good strength ,but less than Ti alloys.
- Ductile enough to be shaped into implant by machining
- Low density 4.5g/cm^3 , light weight

- Titanium allows bone growth directly adjacent to oxide surface
- Inspite of excellent corrosion resistance peri-implant accumulation and also accumulation in lung, liver, spleen of Ti ions is seen, however in trace amount it is not harmful
- Increased level of titanium ions can result in titanium metallosis.

Titanium alloys Ti6Al4V

- Consists of
  - Titanium
  - 6% Aluminium – alpha stabilizer
  - 4% Vanadium – beta stabilizer

Properties

- Excellent corrosion resistance
- Oxide layer formed is resistant to charge transfer thus contributing to biocompatibility
- Modulus of elasticity is 5.6 times that of the bone ,more uniform distribution of stress
- Strength of titanium alloy is greater than pure titanium – 6 times that of bone hence thinner sections can be made

- Ductility is sufficient
- Exhibits osseointergration

Uses

- Extensively used as implant material due to excellent biocompatibility ,strength ,osseointegration

Cobalt , Chromium , Molybdenum alloy

- Composed of same elements as vitallium
- Vitallium introduced in 1937 by Venable Strock and Beach
- Composition
  - 63% Cobalt
  - 30% Chromium (CrO provides corrosion resistance)
  - 5% Molybdenum(strength)

Properties

- High mechanical strength
- Good corrosion resistance
- Low ductility
- Direct apposition of bone to implant though seen ,it is interspersed with fibrous tissue

Uses

- Limited for fabrication of custom designs for subperiosteal frames due to ease of castability and low cost.

Iron , Chromium, Nickel based alloy

- These are Surgical steel alloys or Austenitic steel
- Have a long history of use as orthopedic and dental implant devices

Composition

- Iron
- Chromium – 18% - corrosion resistance
- Nickel – 8% - stabilize austenitic steel

Properties

- High mechanical strength
- High ductility
- Pitting and crevice corrosion.
- Hypersensitivity to nickel has been seen
- Bone implant interface shows fibrous encapsulation and ongoing foreign body reactions
- Use is limited

Precious metals

- Gold , Platinum , Palladium
- They are noble metals unaffected by air , moisture , heat and most solvents
- Do not depend on surface oxides for their inertness
- Low mechanical strength
- Very high ductility
- More cost per unit weight
- Do not demonstrate osseointegration
- Not used

Ceramics

- Ceramics are inorganic , non metallic materials manufactured by compacting and sintering at elevated temperature
- Consist of
- Bioinert ceramics –
  - Aluminium oxide
  - Titanium oxide
  - Zirconium oxide
- Bioactive ceramics –
  - Calcium phosphate ceramics – (CPC)
    - **hydroxyapatite (HA)**
    - **tricalcium phosphate (TCP)**
  - Glass ceramics

Bioinert Ceramics

- These ceramics show direct bone apposition at implant surface but do not show chemical bonding to bone

Properties

- Bioinert ceramics are full oxides i.e. bulk and surface thus excellent bio compatibility
- Good mechanical strength
- Low ductility which results in brittleneSS
- Color similar to hard tissue

Uses

- Though initially thought to be suitable for load bearing dental implants but to due inferior mechanical properties
- Used as surface coatings over metals
  - to enhance their biocompatibility
  - to increase the surface area for stronger bone to implant interface

Bioactive ceramics

Calcium phosphate ceramics

- These ceramics have evoked greatest interest in present times
- Mainly consists of
  - Hydroxyapatite(HA)
  - Tricalcium phosphate(TCP)

Properties

Biocompatibility

- CPC have biochemical composition similar to natural bone
- CPC form direct chemical bonding with surrounding bone due to presence of free calcium and phosphate compounds as implant surface
- Excellent biocompatibility
- No local or systemic toxicity
- No alteration to natural mineralization process of bone

- Lower mechanical tensile and shear strength
- Lower fatigue strength
- Brittle, low ductility
- Exists in amorphous or crystalline form
- Exists in dense or porous form
  - Macro porous - > 50 μm
  - Micro porous - < 50 μm

- The pores though decrease the strength they increase the surface area providing additional region for tissue ingrowth
- Ideal pore size is around 150μm, same diameter as shown by inter trabecular spaces in bone

Solubility of CPC

- CPC show varied degree of resorption or solubility in physiologic fluids
- The resoption depends on

Crystallinity

- High crystallinity is more resistant to resorption

Particle size

- Large particles size requires longer time to resorb

Porosity

- Greater the porosity, more rapid is the resorption.

Local environment

- Resorption is more at low pH eg in case of infection or inflammation

Purity

- presence of impurities accelerate resorption

It has been seen that HA resorb less readily than TCP

Uses

- Due to lack of mechanical strength, not used as load bearing implants
- Used as Bone grafts material for augmentation of bone
- As bioactive surface coating for various implant material to increase
  - biocompatibility
  - strength of tissue integration

Glass ceramics

- They are bioactive ceramics
- Bioglass or Ceravital
- Silica based glass with additions of calcium and phosphate produced by controlled crystallization

Properties

- High mechanical strength
- Less resistant to tensile and bending stresses
- Extremely brittle

- They chemically bond to the bone due to formation of calcium phosphate surface layer

Uses

- Inferior mechanical properties – not used as load bearing implant
- Used more often as bone graft material
- When used as coating bond between coating and metal substrates is weak and subject to dissolution

Carbon and carbon silicon compounds

- Vitreous Carbon and Carbon compounds (SiC)were introduced in 1960 for use in implantology

Properties

- Inert
- Biocompatible
- Modulus of elasticity is close to that of bone
- Bone implant interface shows osseointegration
- Brittle
- Susceptible to fracture under tensile stress

Uses

- Used mainly as surface coatings for implants materials

Polymers

- Polymeric implants were first introduced in 1930s
- However they have not found extensive use in implant due to
- Low mechanical strength
- Lack of osseointegration

- Used currently to provide shock absorbing qualities in load bearing metallic implants. E.g. in IMZ system a polyoxymethylene intra mobile element (IME) is placed between prosthesis and implant body which
  - Ensures more uniform stress distribution
  - Acts as internal shock absorber

Composites

- Combination of polymer and other synthetic biomaterial.
- They have advantages that properties can be altered to suit clinical application
- Have a promising future .

Surface characterization and preparation of implants

- Interaction between host tissue and implant primarily occurs at implant surface
- Thus characterization of implant surface to suit clinical needs is of paramount importance
- Surface characterization can be accomplished by following techniques

Passivation –

- Refers to enhancement and stabilization of oxide layer to prevent corrosion
- Performed by immersion in 40% nitric acid
- Used for Co Cr implant

Acid etching

- In this the surface is treated with nitric or hydrofluoric acid
- Results in clean surface with roughened texture for increased tissue adhesion

Sand blasting

- Sand particles are used to get a roughened surface texture which
  - increases the surface area
  - increases the attachment strength at the bone implant interface

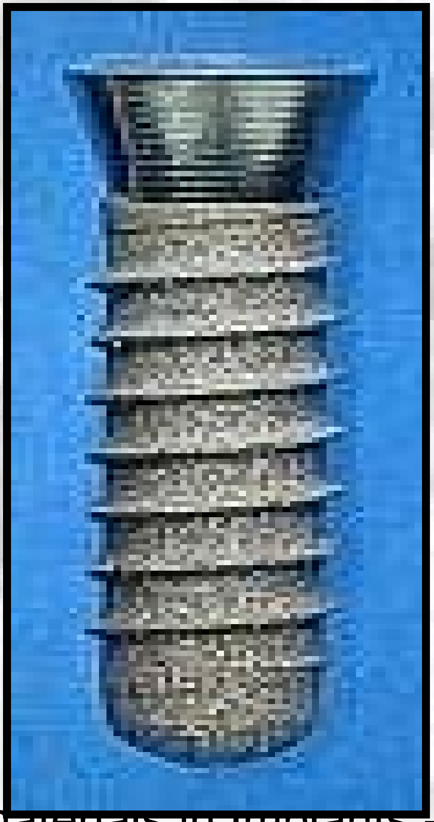
Surface coatings

- Implant surface may be covered with porous coatings which increases
- Surface area and roughness
- Attachment strength at bone implant interface
- Biocompatibility
- Several coating techniques exist .
- Plasma sprayed technique is used most commonly
- Two types
  - **Plasma sprayed titanium**
  - **Plasma sprayed hydroxyapatite**

Plasma sprayed Titanium

- Described by Schroeder et al (1976)
- Titanium particles with mean size of 0.05 to 0.1 are heated in plasma flame
- Plasma flame consists of electric arc through which argon gas stream passes
- A magnetic coil directs the stream of molten titanium particles, which is then sprayed on the titanium surface

- Thickness of coating 0.04 to 0.05 mm
- Sprayed coating exhibits round pores that are interconnected ,pore diameter(150-400µm)



Advantages

- Increases the surface area by 600%
- Increases attachment of implant to bone
- Increase load bearing capacity

Disadvantages

- Cracking and exfoliation of the coating due to stresses ,sterilization and insertion.
- Metallic particles found in perimplant tissue

Plasma sprayed hydroxyapatite

- Herman 1988
- Crystalline HA powder is heated to a temperature of 12000 to 16000 °C in a plasma flame formed by a electric arc through which an argon gas stream passes .
- HA particle size is approximately 0.04mm
- The particles melt and are sprayed on to the substrate ,they fall as drops and solidify
- Round interconnected pores are formed

- Coating bonds to substrate by mechanical interlocking
- Coating of 0.05 mm is formed
- There is a lot of controversy regarding the ideal coating thickness
- Studies have shown that:
- Fracture occurred in coatings more than 0.1mm in thickness
- Whereas bioresorption was unacceptably rapid with coatings less than 0.03mm in diameter
- Ideal coating thickness of 0.05 mm is recommended

Advantages

- Permits direct chemical bonding of the bone to implant surface
- Increases surface area
- Stronger bone to implant interface
- Increases corrosion resistance and biocompatibility
- Decreases healing period of implants
- Bone adjacent to coated implant is better organized and mineralized ,thus increased load bearing capacity

Disadvantages

- Studies have shown that coatings exhibit several drawbacks:
- Coatings have shown to undergo gradual resorption over time and subsequent replacement with bone (creeping substitution)
- Studies have shown that this resorption results in decreased % of bone implant contact area over time
- Due to resorption of the coating ,biocompatibility of exposed and altered core substrate becomes questionable

- Bond strength between coating and the substrate seems to be inadequate to resist shear stresses
- Due to this weak bond ,coating is susceptible to removal or fracture during
  - sterilization
  - insertion in dense bone
- Due to roughened surface, coating often shows adherence of microorganisms on their surface

Indications

- HA coated implants can be used in
- D3 and D4 bone which show poor bone density and structure as they
  - Increase bone contact levels
  - Forms stronger bone implant interface
  - Increases survival rates
- Fresh extraction sites as they promote
  - Faster healing
  - Greater initial stability
- Newly grafted sites where implants are to be placed eg sinus lifts

Alternative surface coating techniques

Electrophoretic deposition

- Mineral ions that need to be coated on the implant surface are dissolved in the electrolytic bath
- Current flows through electrolyte leading to formation of surface coating

Sol gel deposition (Dip Coating)

- Coating is applied on substrate by dipping into a solution HA powder and ethanol in dip coating apparatus and finally sintering it

Hot isostatic pressing

- In this the HA powder is mixed with water and sprayed on the substrate
- It is then hot pressed at 850°C
- The coating produced is dense having increased shear strength

Pulsed laser deposition

- Alternative procedure to obtain HA coating
- Nd YAG laser beam is used to spray HA on the preheated substrate in a vacuum chamber
- HA coating of greater crystallinity is obtained that shows decreased resorption

Sterilization

- Today in most cases manufacturers guarantees precleaned and presterilized implants ,ready to be inserted
- In case the implants needs to be resterilized conventional sterilization techniques are not satisfactory
- Steam sterilization
  - should not be used as it results in contamination of surfaces with organic substances
- Dry heat sterilization
  - Also leaves organic and inorganic surface residues

Radio frequency glow discharge technique (RFGDT) or Plasma cleaning

- Most frequently used methods
- In this, material to be cleaned is bombarded by high energetic ions formed in gas plasma in a vacuum chamber
- Removes both organic and inorganic contaminants

UV light sterilization

- Recently UV light sterilization is also being used
- It cleans the surface and also increase the surface energy

Gamma radiation

- Method used to sterilize pre packaged dental implants.
- Radiation dose exceeding 2.5 megavolts is given
- Components remain protected, clean and sterile until packaging is opened, within sterile field of surgical procedure

Conclusion

- A wide range of biomaterials are currently in use
- Appropriate selection of biomaterials directly influences, clinical success and longevity of implants
- Thus the clinician needs to have adequate knowledge of the various biomaterials and their properties for their judicious selection and application in his clinical practice

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