FORMATION OF SOFT TISSUE AND BONE AROUND IMPLANTS: The Chronic Response to Implants

M. Spector, Ph.D.
Mast cells were first described by Paul Ehrlich in his 1878 doctoral thesis on the basis of their unique staining characteristics and large granules. These granules also led him to the mistaken belief that they existed to nourish the surrounding tissue, and he named them "mastzellen," a German term, meaning "feeding-cells."
RESPONSE TO IMPLANTS: WOUND HEALING

Surgical Implantation

Vascular Response
  Clotting
  Phagocytosis
  Neovascularization
  New Collagen Synthesis

Inc. time

Tissue of Labile and Stable Cells
  Tissue of Permanent Cells

Framework
  Intact
  Destroyed

Regen.
  (incorp. of implant)

Scarring
  (fibrous encapsulation; synovium)

Chronic Inflammation

Acute Inflammation

Granulation Tissue

Implant Movement

Chronic Inflammation
I. Metchnikoff
In 1923 a piece of glass was removed from a patient’s back; it had been there for a year. It was surrounded by a minimal amount of fibrous tissue, lined by a glistening synovial sac, containing a few drops of clear yellow fluid.

See J. Bone Jt. Surg., 30-B:59 (1948)
Slides of histology photos removed due to copyright restrictions.

- Synovium: Macrophage-like (Type A) and Fibroblast-like (Type B) Cells
- Tissue response to a cylindrical implant of polysulfone in lapine skeletal muscle, 2 yrs. post-op
- Polyethylene implant, 6 mos. post-op
- Porous Coated Co-Cr Tibial Component (retrieved 1 yr. post-op)
MACROPHAGES ON SURFACES

- Macrophages are attracted to surfaces (dead space)
- Fuse to form MFBGC
- More MFBGCs on irregular surface
CHRONIC RESPONSE TO IMPLANTS

• Persistence of macrophages* at the implant surface
• Presence of fibroblasts*
• Proliferation and increased matrix synthesis of fibroblasts can result from mechanical perturbation by the implant or by agents released by the implant, leading to an increase in the thickness and density of the scar tissue.
• Fibroblast contraction can result in scar contracture.

* Constituents of synovium
MACROPHAGE AND FIBROBLAST INTERACTIONS IN SYNOVIIUM

- Ions
- Mechanical force
- Endocytosis
- Mitosis
- Migration
- Synthesis
- Contraction

Fibroblast + ECM → + Reg.
Fibroblast + ECM → + Reg.
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- Framework Destroyed
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Chronic Inflammation

Granulation Tissue

Intact        Destroyed
(fibrous encapsulation; synovium)
Soft Tissue (that does not regenerate)

- Fibrous capsule (scar)

  Synovium: fibrous tissue interspersed with macrophages

  Wound healing response of repair (scar formation) coupled with macrophage accretion at the “dead space” - chronic inflammation

Bone

- Tissue integration and tissue bonding
- Why don’t macrophages remain at the biomaterial surface?
Tissue Integration (Osseointegration)

Apposition of tissue (bone) to the implant (contact of bone with the surface but not necessarily bonding); no macrophage layer?

Regeneration of tissue up to the surface of the implant

Tissue Bonding (Bone Bonding)

Chemical bonding of tissue (viz., bone) to the surface

Protein adsorption and cell adhesion

Biomaterials: calcium phosphates and titanium (?)
Dental Implant Designs and Materials

- Titanium
- Carbon
- Alumina

Photos of various dental implants removed due to copyright restrictions.
Blade Implant

Photos of three installed dental implants removed due to copyright restrictions.

“Commercially pure” Titanium
Branemark Dental Implant

Photo of “Original Branemark implant fixture” removed due to copyright restrictions. See http://www.oral-implants.com/home1.htm

Dr. Per-Ingvar Branemark

http://www.oral-implants.com/home1.htm
Photo sequence showing installation of dental implants removed due to copyright restrictions. See http://www.oral-implants.com/home1.htm
Osseointegration: Control of Surgical Trauma

Guidelines for drilling into bone
• Remove as little of the host periosteum as possible
• Drill speed less than 1500 rpm
• Cool (with water) during drilling and tapping
• Drill using smaller diameter than tap
• Drill tool rake angle 25°-35°
• Always tap for stabilizing screws
• Tap same diameter and same metal as screw
Osseointegration


Images removed due to copyright restrictions.
See Figure 5a (tissue-titanium interrelationship at the interface zone) and Fig. 6c in Albrektsson, T. et al.
http://dx.doi.org/10.1007/BF02363944
b. Gingiva: Epithelium regenerates

c. Sub-gingival CT

d. Bone

http://dx.doi.org/10.1007/BF02363944
Images removed due to copyright restrictions.
http://dx.doi.org/10.1007/BF02363944
Implants with Porous Coatings in Bone

Metal stem

Beaded porous coating

Images removed due to copyright restrictions.
Several photos of implants removed due to copyright restrictions.
Cylindrical implant in canine prox. femur

Plasma-sprayed HA coating, 40 μm thick

3 hr

100μm

Bone

Metal
Cylindrical implant in canine prox. femur

Plasma-sprayed HA coating, 40 μm thick

Gap between implant and bone

Metal

Bone

3 hr

100μm
Bone regeneration in the gap between the implant surface and surrounding bone: bone tissue engineering coupled with permanent implants; a hybrid approach; how to engineer the tissue response to implants?
Bone regeneration in the gap between the implant surface and surrounding bone: bone tissue engineering coupled with permanent implants; a hybrid approach; how to engineer the tissue response to implants?

New bone fills the gap and appears to be formed on the surface of the coating, but is the bone bonded to the biomaterial: inter-digitating physical bond or a chemical bond?
Bone regeneration in the gap between the implant surface and surrounding bone: bone tissue engineering coupled with permanent implants; a hybrid approach; how to engineer the tissue response to implants?
14 da

HA Coating

Bone
TISSUE INTEGRATION
TISSUE BONDING

- Osseointegration (i.e., bone apposition to the implant; not necessarily bonding) is demonstrated by light microscopy

- How to determine if bone bonding to the implant has occurred?
  - Mechanical testing
  - Transmission electron microscopy to demonstrate the continuity of mineral from the implant to bone, at the ultrastructural level (i.e., nanometer scale)
BONE BONDING

Shear Strength (MPa)

Time in vivo (weeks)

- Grit-Blasted Ti
  Ra 7.8
- Plasma-Sprayed HA
  Ra 4.4
BONE BONDING

- Biological Apatite Deposition
- Protein Adsorption
- Bone Cell Attachment
Plasma-Sprayed Hydroxyapatite Coating
14 days

Osteoblasts
Bone
Osteocyte
HA
BONE BONDING

- Biological Apatite Deposition
- Protein Adsorption
- Bone Cell Attachment
Images removed due to copyright restrictions. 
See Table 1; a photo of implants; and graph of % bone apposition. 
TEM of PSHA coating 3 hrs. post-implantation in a canine model showing plate-like apatite crystallites viewed *en face* and on edge.

TEM of PSHA coating 3 days post-implantation in a canine model

AE Porter, et al., Biomat. 2002;23:725

TEM of PSHA coating 10 days post-implantation in a canine model


AE Porter, et al., Biomat. 2002;23:725
TEM of an annealed PSHA coating 10 days post-implantation in a canine model

AE Porter, et al., Biomat. 2002;23:725

TEM of PSHA coating 10 days post-implantation in a canine model

Non-annealed

Image removed due to copyright restrictions.
See Figure 6a in Porter, AE et al.
http://dx.doi.org/10.1016/S0142-9612(01)00177-6

Annealed

Image removed due to copyright restrictions.
See Figure 6c in Porter, AE et al.
http://dx.doi.org/10.1016/S0142-9612(01)00177-6
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