By: Ryan Pyrke and Anuja Goyal

MAXILLOFACIAL AND SKULL IMPLANTS
Phineas Gage (1823-1860)

- A 1 meter long tamping iron which weighed 6 kilograms impaled Phineas’ skull
- Miraculously survived.
- One of the most famous and earliest recorded survivors of a severe skull fracture
Overview

- Anatomy of the skull
- Types of skull and maxillofacial trauma
- Methods of treatment
- Future research
Anatomy of the Skull

Bones of the Skull - Side View

- Frontal bone
- Parietal bone
- Ethmoid bone
- Nasal bones
- Zygomatic bone
- Temporal bone
- Occipital bone
- Sphenoid bone
- Maxilla
- Mandible
Types of Trauma

- Basilar skull fracture
- Penetrating skull fracture
- Depressed and Compound skull fracture
- Linear and Diastasis fractures
Basilar skull fracture
Penetrating skull fracture
Depressed skull fracture
Linear & Diastasis fractures
Methods Of Treatment

- Autologous Reconstruction
- Allogenic Reconstruction
- Alloplastic Reconstruction
  - Titanium Plates and Screws
  - Titanium Mesh
  - Ceramics (Glass)
  - Calcium Orthophosphate
  - Polymethyl-methacrylate (PMMA)
Autologous Reconstruction

- Replacement bone from the patient is used to mend a fracture
- Bone chips or dust can be used to mend small holes
- High degree of biocompatibility and long term stability
Autologous Reconstruction (cont)

- Complications can arise at the donor sites of the patient
- Not a suitable method for large skull fractures
Allogenic Reconstruction

- Bones from donors (living or cadaveric) are used to mend a skull fracture
- Live donors share the same problems as autologous reconstruction
- Short supply of materials
- Xenografts may be possible in the near future that use bovine materials
Alloplastic Reconstruction

- Synthetic substitutes are used in place of live materials
- Materials used to create these implants include titanium, ceramics, calcium orthophosphate, PMMA, and others
- Each have their own individual benefits and drawbacks
Titanium Plates and Screws

- A very strong material.
- Biocompatibility has been proven over a long period of time.
- Most commonly used material for the skull.
- Easy to implant and inert within the body.
- Alloys of titanium come very close to matching mechanical properties of bone.
Titanium Plate Example

- Osteoplastic craniotomy performed to alleviate pressure on the brain
- Can be performed to provide access to brain (i.e. to remove tumors)
Titanium Mesh

- Allows for natural bone growth in the gaps of the titanium mesh.
- Over time becomes very strong and stable.
- Risk of infection with larger scale bone replacement.
Ceramics (Glass)

- Very bio-compatible
- Post-operative imaging is unhindered
- Easy to break when fixing it to the skull
- TiO$_2$/glass composites are used
- Fibrous tissue will not form around this material
- Small implants can be connected by chemical bonding
Calcium Orthophosphate

- Very poor mechanical properties
- Biocompatible and non-toxic
- Osteointegrates into living tissue
- Acts as an osteoconductive scaffold for new bone
- Used as a coating to promote bone growth into porous implants
Calcium Orthophosphate

- Used only as fillers, coating, or bone cement and not practical for large-scale skull reconstruction
- Protect against emission of toxins from a coated material
- Increases the lifetime of an implant it is integrated into

![Strength vs Implantation time chart](image)
Polymethyl-methacrylate (PMMA)

- PMMA is used most often for cranial reconstruction
- Powder Polymer and Liquid Monomer combine to form cement that then hardens.
- Heats up to 70°C when mixed raising a concern for surrounding tissue
- Performed free-hand
Future Applications

- Biodegradable Plates
- Ion Implantation
- Biodegradable Adhesives
Biodegradable Plates

- Plates and screws that will be reabsorbed over time
  - Biocompatible
  - Adaptable
  - Degrades at right amount of time
  - Stable enough to allow bone to unify

- 70/30 poly(L/DL-lactide) (PLDLA) is a biodegradable material
Biodegradable Plates (continued)

![Graph showing strength and resorption over time for 70:30 Poly (L/DL-Lactide)]
Biodegradable Plates (continued)

- Advantages:
  - Plate and screws would not need to be removed later on
  - Since the material is reabsorbed it will not affect long term development in children
Biodegradable Plates (continued)

- Future Steps:
  - Develop material for larger plate applications
  - Investigate long-term effects of resorption
  - Make material easier to work with
Ion Implantation

- Process used to make materials more bio-compatible
- Prevents production/leakage of toxic by-products
- Ions are embedded on outer layer
Ion Implantation
Biodegradable Adhesives

- An adhesive to hold bones together while degrading over time

- Development considerations
  - Must bond to bone in a wet, bloody environment
  - Cannot be cytotoxic
  - Strong enough to hold bone together
  - Disappear gradually
Biodegradable Adhesives

- Biomimicry: solving problems using examples from nature

<table>
<thead>
<tr>
<th>Proteinaceous Adhesive produced by Sandcastle Worm</th>
<th>Developed biodegradable adhesive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used to assemble bits of seashells underwater</td>
<td>Used to repair crainiofacial fractures</td>
</tr>
<tr>
<td>Composed of opposite charged proteins with Ca(^{2+}/Mg^{2+}) ions</td>
<td>Created with oppositely charged copolyelectrolytes</td>
</tr>
</tbody>
</table>
Biodegradable Adhesives

- It is a phase separated fluid
- Will not cause volume change
- Non-cytotoxic
- Tested both in vitro and in vivo in a rat
Progression Of Surgical Methods

- Implantation Of A Titanium Plate
- Current Surgical Procedure
- CAD Technology
Implantation Of A Titanium Plate

- during initial surgery:
  - first clean up wound
  - template is made from soft malleable metal
  - skull thickness is measured
- preparation of plate:
  - dental plaster cast made from impression
  - titanium plate is formed by using a high pressure hydraulic pump
  - Many holes on the plate allow fluid to flow and fibrous tissues to go through
- Insertion of Plate:
  - A second surgery is performed to insert the plate
Current Surgical Procedure

- Technology is used to create custom skull implants

Figure 1. The repair process for custom design of skull bone.
CAD Technology
Ongoing Development

- Various companies and institutes are actively researching maxillofacial and skull implants
  - Kelyniam is able to provide custom skull implants 24 hours after receiving CT scan data
  - Research centered around the use of PEEK, a growingly popular new biomaterial
References

References


