Osseointegration and Direct Skeletal Attachment of Prosthetic Limbs

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Osseointegration

About 100 trans-femoral amputees fitted osseointegrated implant

Branemark Osseointegration Center
Socket-type Prostheses

- The most commonly used attachment technique among >3 million amputees globally;

- Residual limb pain and soft tissue breakdown sometimes occur;

- Very short residual limb can be contraindicative.
Osseointegration—Application in Lower-Limb Prosthetics

A surgical approach which allows connections of a prosthesis directly to a living bone using a titanium implant.
Surgery stage 1

6 months

Surgery stage 2

P-I Branemark. The Osseointegration Book, p.39
The stage-2 surgery
The components

Skin

Femur

Implant

Abutment

Retaining bolt
Osseointegration—Benefits

- Skin problems and residual limb pain can be alleviated [Sullivan et al., 2003];

- Amputees can enjoy
  - A greater hip range of motion [Hagberg et al., 2005];
  - Better sitting comfort [Hagberg et al., 2005];
  - Improved sensory feedback [Branemark et al., 2001]
Osseointegration—Potential drawbacks

• Extensive rehabilitation program

• Risk of bone fracture;

• Mechanical failures of osseointegrated fixation [Sullivan et al., 2003];

• Requirement of additional 2 surgeries;
Weight bearing exercise

- After the 2\textsuperscript{nd} surgery;
- 20kg of load initially;
- Increment of a maximum of 10kg per week;
- If pain is perceived, the load is decreased to a non-painful level

Load applied directly to the bone;
- Encourage osseointegration of the bone-implant interface, and strengthen residual femur
- Prepare the bone to tolerate forces during walking

Mechanical loading to the residual bone

Load bearing exercise
~6 weeks

Gait training with assistive devices
~12 weeks
Osseointegration—Potential drawbacks

• Extensive rehabilitation program

• Risk of bone fracture

• Mechanical failures of osseointegrated fixation [Sullivan et al., 2003];

• Requirement of additional surgeries;
Load measurements

Age: $54\pm12$ years
Mass: $84.3\pm16.3$ kg
Height: $1.78\pm0.10$ m
Walking around circle

Descending stairs

Ascending slope

Weight bearing exercise

Ascending stairs

Descending slope
Straight-line level walking

**A**

FAP (%BW)

-20 to 30

FAP1

FAP2

Anterior

Posterior

**B**

FML (%BW)

-10 to 30

FML

Lateral

Medial

**C**

FL (%BW)

-40 to 120

FL1

FL2

Compression

Traction

**C**

ML (Nm)

-8 to 8

ML

External rotation

Internal rotation

**A**

MAP (Nm)

-20 to 40

MAP

Lateral rotation

Medial rotation

**B**

MML1

MML2

Anterior rotation

Posterior rotation

**C**

ML (Nm)

-20 to 40

ML

External rotation

Internal rotation

Time (%CG)
Computational models help refine clinical procedures. Loading leads to computational modelling, which results in stress distribution. This better understanding aids in bone remodelling, pain, and risk of fracture. Therefore, computational models help refine clinical procedures.
Geometries

- Implant-abutment geometry created in Solidworks.
  - Implant and abutment being one piece.
  - Implant length of 100mm, diameter of 20mm, and thread pitch of 1.75mm.

- Bone geometry obtained from the BEL Repository.
  - Third-generation standardized femur size #3306 with an intramedullary canal.
  - The residual bone length of 230mm (greater trochanter to the distal cut end).
  - Threads generated by geometrically subtracting from the threaded implant.
Material properties

- The femur and implant were assumed to be linearly elastic and homogeneous;

- The femur was assumed to be transversely isotropic:
  - Longitudinal elastic modulus of 17GPa,
  - Shear modulus of 11.5GPa.
  - Radial and circumferential moduli of 3.28GPa (Reilly and Burstein, 1975; Zhang et al., 2005);

- The implant was assumed to be isotropic:
  - Elastic modulus of 115GPa (Xu et al., 2000; Xu et al., 2006);

- A Poisson’s ratio of 0.3 was used for the two structures.
Bone implant tied together
- Fixed femoral head
- Applying loading at distal end
- Fine mesh at the threaded regions at the bone and implant

211,117 tetrahedral elements
Loading B - actual 3D load (loading exercise)

- Less uniform distribution;
- Peak stress about 4 times higher than in loading A;

Peak stress: 9.34MPa
Loading C - Load experienced during walking
At about 50% of the gait

- Peak stress: 8.54

> Peak stress magnitude comparable to loading B
Insights

- The rehabilitation program controlled by visual feedback from the weigh scale may apply significantly higher stresses than intended.
- The 3D load should be monitored and carefully prescribed.
- Refinement in loading protocols of weight bearing exercises
Insights

- Bone fracture is possible in osteoporotic bone under high loading (~3 times of walking load) condition.

- This suggests the importance of assessing the bone quality for amputees receiving implanted prostheses.

<table>
<thead>
<tr>
<th>I: Change of E while normal walking load was applied</th>
<th>II: Change of axial loads, while keeping E=15,000MPa</th>
<th>III: Change of axial loads, while keeping E=3,000MPa</th>
<th>IV: Change of bone length while normal walking load was applied and E=3,000MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>E (MPa)</td>
<td>MPS</td>
<td>Load multiple</td>
<td>MPS</td>
</tr>
<tr>
<td>15000</td>
<td>0.09%</td>
<td>1</td>
<td>0.09%</td>
</tr>
<tr>
<td>9000</td>
<td>0.13%</td>
<td>2</td>
<td>0.18%</td>
</tr>
<tr>
<td>3000</td>
<td>0.38%</td>
<td>4</td>
<td>0.36%</td>
</tr>
</tbody>
</table>

Possible bone fracture!!!
Conclusions

- A prosthesis can be bone-anchored by the technique of osseointegration.

- This offers some benefits because of the lack of a prosthetic socket. But some problems exist which are related to loading.

- By using appropriate engineering approaches, we might be able to identify solutions to problems encountered in clinical practice.