Finite element analysis into eigenfrequencies of a total hip stem with different levels of loosening

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Background

Diagnosis of hip stem loosening: radiographs, scintigrams, arthrograms

Suboptimal sensitivities and specificities

- Average sensitivity: 82% - 91%  (Temmerman et al. 2006, Zilkens et al. 1988)

Periprosthetic black gap as a sign for loosening

Loosened hip stem

Loosened hip stem detail

Femoral bone defects

(Paprosky 1994)
Background

Vibration Analysis\textsuperscript{1,2}

- Shaker excites distal femur
- Accelerometer signal at proximal femur

Detection of harmonics

- Well fixed hip stem: Single frequency
- Loosened hip stem: Presence of harmonics
  - Limited patient compliance
  - Only advanced loosening can be detected. Diagnosing early loosening still remains challenging

\textsuperscript{1}Puers et al. 1999 and \textsuperscript{2}Georgiou & Cunningham 2001
Our approach

Internal excitation / sound analysis

1. Excitation unit
2. Extracorporeal coil
3. Hip replacement
4. Detection Unit
5. Evaluation Unit

Numerical investigation of the resonant frequency by FEA with COMSOL Multiphysics
Excitation Unit

Production in the laser sintering process
Varying the length of the spring
• 3.75mm - 7.75mm

Variation of the spring diameter
• Diameter 0.3mm current
• Reducible up to 0.25mm

Oscillator Unit Prototype
Oscillator Unit

Oscillator Unit Resonance Computation

<table>
<thead>
<tr>
<th></th>
<th>3.75mm spring</th>
<th>7.75mm spring</th>
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</thead>
<tbody>
<tr>
<td>Spring leaf design</td>
<td>112Hz</td>
<td>-</td>
</tr>
<tr>
<td>Diameter 0.3mm</td>
<td>262Hz</td>
<td>97Hz</td>
</tr>
<tr>
<td>Diameter 0.25mm</td>
<td>151Hz</td>
<td>56Hz</td>
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Methods

Total hip stem, artificial bone assembly
- Z-Stem (Merete Medical GmbH, Berlin, Germany)
- Artificial bone cylinder
- Interface between Z-stem and artificial bone
  - Defect area with 1 to 2 mm thickness
  - Variation with different level of loosening

1. Pressfit
2. Small defect
3. Larger defects
Materials

- COMSOL Multiphysics 5.0
- Material properties (Ti-6Al-4V / Sawbones 20 pcf)
- Meshing: element type: Free Tetrahedrons
  Number of elements: up to 700,000
- Study: Eigenfrequency
- Simulation of the first 15 natural frequencies (eigenmodes)
- The first 15 eigenmodes are in the range of about 45 Hz to 3.5 kHz
Influence of body weight

Modal analysis with the influence of a patient weight

- Frequencies of eigenmodes decrease with increasing weight load
Summary and Outlook

- Radiographic analysis today not precise enough
- New concept based on sound analysis revealed promising results
- Modal analysis showed:
  » Frequency decreases due to advanced loosening
  » Variable weight load on top even reduces the frequency
- Attenuation Analysis: Damping coefficient change due to advanced loosening
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Thank you for your attention!

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Attenuation analysis Total hip stem, artificial bone assembly

- Initial impulse, Gaussian pulse over 0.1 sec
- Fixed damping coefficient of artificial bone cylinder and titanium z-stem
- Vibration behavior
  - Variation with different level of loosening
  - Variation of vibration
  - Determine the damping coefficient

![Graph showing damping analysis and attenuation curves for different scenarios including:
  - Attenuation curve without loosening
  - Envelope without loosening
  - Envelope with small defect area
  - Envelope with larger defect area]