Metacarpophalangeal Joint Replacement

Abstract

Existing metacarpophalangeal (MCP) joint replacements require collateral ligament support. The proposed design, an osteointegrated constrained joint replacement, makes it possible to reconstruct MCP joints of patients who do not have functional collateral ligaments. The artificial joint is designed to fail at a replaceable interface, preserving osteointegration and simplifying secondary surgery. Osteointegration is further enhanced by damping effects of the flexible pin. Lack of effective existing designs and an aging population contribute to market potential for this device.

Background

Anatomy and Terminology

- MCP joints fall between the proximal phalange and the metacarpal
- Collateral ligaments connect the metacarpal to the proximal phalange
- The volar plate prevents hyperextension of the finger

Problem Statement

- Patients who have congenital defects or severe trauma lack collateral ligaments and a volar plate
- Patients with rheumatoid arthritis often lack functional collateral ligaments
- Desired joint replacement should not require collateral ligaments for joint stability

Design Criteria

<table>
<thead>
<tr>
<th>Client Requirements</th>
<th>Design Specifications</th>
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</thead>
<tbody>
<tr>
<td>Functional range of motion</td>
<td>20° extension to 90° flexion&lt;sup&gt;1&lt;/sup&gt; 40° abduction and adduction at 0° flexion&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td>Lifespan of at least 10 years</td>
<td>Withstands -310 million cycles at varying movement angles&lt;sup&gt;2&lt;/sup&gt;</td>
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<tr>
<td>Withstand physiological loading</td>
<td>70 N pinch grip&lt;sup&gt;3&lt;/sup&gt;</td>
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<tr>
<td>Appropriate mode of failure</td>
<td>Lowest factor of safety at the articulation</td>
</tr>
<tr>
<td>Biocompatible</td>
<td>Uses materials that are FDA-approved</td>
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<tr>
<td>Osteointegratable</td>
<td>Stems coated with surface treatment</td>
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</table>

Materials implemented:

- Metacarpal component
- Cobalt chromium (CoCr) plasma sprayed and coated in hydroxyapatite
- Phalange components
- Alumina head
- CoCr plasma sprayed and coated in hydroxyapatite
- CoCr pin connection
- Polyoxymethylene (POM) pin

Features of design:

- Fails at replaceable interface
- Damping at flexible pin

Finite Element Analysis

<table>
<thead>
<tr>
<th>Component</th>
<th>Applied Load</th>
<th>Yield Strength</th>
<th>Factor of Safety</th>
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</thead>
<tbody>
<tr>
<td>Metacarpal stem</td>
<td>616 N @ 0°</td>
<td>450 MPa</td>
<td>2.3</td>
</tr>
<tr>
<td>Metacarpal stem</td>
<td>616 N @ 90°</td>
<td>450 MPa</td>
<td>1.3</td>
</tr>
<tr>
<td>Phalange head</td>
<td>616 N</td>
<td>3,000 MPa</td>
<td>10.5</td>
</tr>
<tr>
<td>POM pin</td>
<td>50 N</td>
<td>66 MPa</td>
<td>2.4</td>
</tr>
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</table>

Future Development

- Disclose to WARF for patenting
- Propose to companies
- Premarket approval required for FDA acceptance

Material Selection: Deflection v. Load

- Silicone Rubber
- Delrin Impact
- Delrin 500 AF
- UHMWPE
- PEKK
- Delrin HS

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- Professor Heidi Ploeg-Orthopedics, FEA
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- Professor Tim Osswald-Materials

References