BONE LOSS FOLLOWING HIP REPLACEMENT SURGERY: ROLE OF THE ABDUCTOR MUSCLES

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Introduction

The reduction in strength of the abductor muscles after total hip arthroplasty may provoke functional impairment, such as limping and reduced walking speed [6, 8], and also may contribute to bone loss of the femur [1]. While most successful hip arthroplasties maintain at least 90% of the abductor strength postoperatively, it is possible to lose as much as 50% of the abductor function following the insertion of the implant [8]. The recovery period for the abductors varies greatly and may last up to two years after surgery [4, 5, 7]. We used a bone remodeling simulation to investigate the effects of the reduction and recovery in the abductor muscle force on femoral bone loss following hip replacement surgery.

Methods

An adaptation simulation based on bone remodeling stimuli of damage and disuse was used for this study [3]. The mechanical stimulus for remodeling was assumed to be proportional to the product of the strain range (s) raised to a power and the loading rate (R) for remodeling was assumed to be proportional to the product of the

\[ \Phi = \sum_{i=1}^{n} s_i^p R_i \]

Damage in the bone matrix was assumed to accumulate at a rate proportional to \( \Phi \). The principal strain (compressive or tensile) with the largest magnitude was used as the strain quantity, s, for this simulation. Disuse was assumed for values of \( \Phi \) below an equilibrium mechanical stimulus.

The damage removal rate was calculated from existing damage, basic multicellular unit (BMU) activation frequency, and the area of bone removed by each BMU. A removal specificity factor was included to spatially associate removal with damage. Daily activation frequency values were calculated from the amount of disuse, existing damage, and the surface area available for remodeling. The number of resorbing and refilling BMUs active each day were calculated from the activation frequency history over the remodeling period: 25 days for resorption, 5 days for reversal, and 64 days for refilling. Daily density changes were then calculated from the net amount of bone removed or added by each resorbing or refilling BMU, respectively. A mechanism was included to allow for less than complete refilling on trabecular surfaces in disuse. Elastic modulus–density relationships were determined from empirical data for both cortical and trabecular bone.

A two-dimensional finite element model (linearly elastic, isotropic), consisting of 4216 4-node quadrilateral elements, was created from a radiograph of a representative femur. A bony side plate was added to the model to account for the out-of-plane cortical bone [9]. Three load cases, each consisting of joint reaction and abductor muscle forces, were used to simulate the daily loading history for normal activity [2]: single-leg stance was applied for 3000cpd while the abduction and adduction load conditions were each applied for 500cpd. The bone adaptation algorithm was integrated into the analysis through a user subroutine and the simulation was run using ABAQUS 5.8 (HKS, Pawtucket, RI) until the density distribution achieved steady state.

The steady state results of the femur model were used as the pre-surgical condition. Hip replacement surgery was simulated by inserting a conventional press-fit prostheses and reducing the abductor muscle force to 50% or 70% of normal. The abductor muscle strength was allowed to linearly recover to 100% after either 400 days or 800 days for each simulation, and bone loss was analyzed after simulating remodeling of the femur for 2000 days.

Table 1. Simulated Femoral Bone Loss (%) in the 7 Gruen Zones after 2000 Days for 50%, 70%, and 100% Abductor Function

<table>
<thead>
<tr>
<th>zone</th>
<th>100%</th>
<th>50%</th>
<th>70%</th>
<th>50%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>P/L (1)</td>
<td>33.1</td>
<td>38.2</td>
<td>35.1</td>
<td>45.3</td>
<td>38.4</td>
</tr>
<tr>
<td>M/L (2)</td>
<td>31.3</td>
<td>36.6</td>
<td>33.2</td>
<td>42.6</td>
<td>36.8</td>
</tr>
<tr>
<td>D/L (3)</td>
<td>27.5</td>
<td>31.7</td>
<td>30.4</td>
<td>35.9</td>
<td>34.3</td>
</tr>
<tr>
<td>D/M (4)</td>
<td>3.7</td>
<td>6.1</td>
<td>6.5</td>
<td>7.1</td>
<td>7.6</td>
</tr>
<tr>
<td>M/M (5)</td>
<td>33.7</td>
<td>39.1</td>
<td>37.3</td>
<td>43.2</td>
<td>41.1</td>
</tr>
<tr>
<td>M/L (6)</td>
<td>38.4</td>
<td>43.2</td>
<td>39.2</td>
<td>48.8</td>
<td>43.3</td>
</tr>
<tr>
<td>P/M (7)</td>
<td>61.7</td>
<td>64.4</td>
<td>63.1</td>
<td>67.6</td>
<td>64.8</td>
</tr>
</tbody>
</table>

P/L=proximal/lateral, M/L=mid/lateral, D/L=distal/lateral, D/M=distal/medial, M/M=mid/medial, P/M=proximal/medial

Essential Results

A reduction in the initial abductor muscle function to 50% of normal after hip replacement surgery produced increases in femoral bone loss in the seven Gruen zones surrounding the implant stem (Table 1). Increasing the recovery period of the abductor muscles also produced increases in predicted bone loss in the regions examined, especially in the proximal/lateral region (P/L, zone 1). In this region, bone loss for an 800 day recovery period increased by 19% compared to a recovery period of 400 days for a 50% reduction in initial muscle force. Femoral bone loss was generally greater in the proximal and medial regions than the distal and lateral ones, and was found to be largest in the proximal/medial zone (P/M, zone 7). In this region, only slight affects in femoral bone loss were observed following changes in the reduction and recovery of the abductor muscle function.

Discussion

Many factors contribute to the bone loss of the femur following hip replacement surgery: bone quality, implant material and design, patient weight and activity level, duration of implantation, etc. In this study, it was found that the reduction and recovery in the strength of the abductor muscle forces following hip replacement surgery also affect bone loss around implant stems. With several options available to surgeons for exposing the hip during surgery, these results imply that a surgical approach which maintains most of the abductor muscle function would not only improve patient functionality, but also would reduce the amount of femoral bone lost in the period following implantation. In addition, patients who undergo hip surgery usually participate in a rehabilitation program that emphasizes strengthening of the abductor muscles. Our results suggest that if such a program were designed to allow for the quickest feasible recovery of the muscle function, then subsequent bone loss following surgery may be significantly reduced.

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References


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