A Comparison of Modular Tapered Versus Modular Cylindrical Stems for Complex Femoral Revisions

Revision Total Hip Arthroplasty Study Group *

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Despite the success of total hip arthroplasty, a small percentage of patients require repeat procedures, oftentimes related to failure of the femoral component. While revision of the femoral component has been described with the use of cemented implants [1], the use of cementless prostheses has gained widespread popularity, particularly in North America, as most studies have shown superior results with cementless fixation [2–4]. The basic tenet of revision surgery for femoral-sided failure is to implant the cementless prosthesis with intimate cortical bone contact to allow for initial implant stability and eventual osseointegration of the prosthesis.

In the absence of a supportive metaphysis, the revision implant must engage the diaphyseal bone of the proximal femur [5]. The use of extensively porous coated cylindrical stems in revision total hip arthroplasty has for many years been the standard by which to address these defects [6]. However, when the amount of isthmus available for distal fixation is short (<4 cm) or the canal diameter is large (>18 mm), higher rates of failed ingrowth have been reported [5,7].

Stems with a tapered distal geometry have been suggested as an alternative to extensively porous coated cylindrical stems in such complex situations, as the taper may better engage a short isthmic segment. Subsidence, however, has been a problem when monoblock stems with this distal geometry [8]. Modular, or “bibody”, revision femoral stems were developed to allow for impaction of the distal tapered segment until axial stability is obtained and then independent sizing and orientation of the proximal segment. The benefits of the modular design include the ability to better adjust both leg length and anteverision to optimize stability and potentially decrease the risk of dislocation. Some modular bibody revision femoral stems allow the surgeon to choose either a more traditional cylindrical distal geometry or one that is tapered.

In modular, bibody revision stems, it is not known whether a tapered distal geometry is superior or inferior to cylindrical geometry stems in complex femoral revisions where the metaphysis is non-supportive (Paprosky Type 3 and 4 femoral defects) [9]. We are unaware of any prior studies that have directly compared the results of these two methods of reconstruction in comparable femoral defects. The purpose of this study is to compare the outcomes of complex femoral revision using a modular revision stem for Paprosky Type 3 and 4 defects using bibody modular revision femoral components with either tapered or cylindrical distal geometry.

**Materials/Methods**

A review of all revision total hip arthroplasties performed at two institutions from January 2001 to January 2010 where the femoral component was revised with a modular revision femoral component (Restoration, Stryker, Mahwah, NJ or ZMR, Zimmer, Warsaw, IN) was performed. At one institution, the predominant philosophy favored the use of modular stems with a cylindrical distal geometry while at the second, modular stems with a tapered distal geometry were predominantly used.

Pre-operative radiographs were independently scored by three fellowship trained adult reconstructive surgeons to categorize each femur according to the Paprosky classification [9]. Only revision procedures where the consensus preoperative Paprosky grade of the


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femur was IIla, IIlb, or IV were included. Minimum follow-up for inclusion was two years.

Patient demographic data were collected and compared, including age at the time of revision, gender, body mass index (BMI), side, and etiology of failure necessitating revision surgery. Clinical outcomes were measured using the Harris Hip Score [10]. The initial post-operative radiograph was compared to most recent radiographs to determine femoral component stability; cylindrical stems were classified as osseointegrated, fibrous stable, or loose using the criteria set forth by Engh et al. by the same three observers (14). As the authors are unaware of any currently accepted radiographic criteria to define osseointegration or loosening in conical stems, conical stems in this study were considered osseointegrated if there did not exist a bony pedestal around the distal tip of the stem and there did not exist progressive stem subsidence on radiographs. Otherwise, these conical stems were considered loose. Any subsidence of the femoral components was measured from the initial post-operative radiograph to the most recent radiographs through the use of anatomic landmarks. All intra-operative or post-operative complications were identified, including intra-operative and post-operative periprosthetic femur fractures, dislocations, breakage of the femoral component and need for subsequent revision procedures.

Statistical analysis was conducted using t-tests for continuous variables, with Satterthwaite correction of unequal variances as needed and chi-square testing for categorical variables. Statistical significance was set at $P < .05$.

### Results

There were 105 femoral revisions in 104 patients with Paprosky IIla, IIlb, or IV femoral defects performed, with an average follow up of 60 months (range 24–139 months). Forty-four stems (one institution) had a cylindrical distal geometry (all ZMR), and 61 stems (second institution) with a tapered distal geometry were used (42 ZMR and 19 Restoration).

Mean age, sex, BMI, and causes of revision surgery were similar between the two groups (Table). The distribution of femoral defects, however, differed; the group treated with tapered distal geometry stems consisted of significantly more type IIIB or IV femoral defects compared to the group treated with cylindrical distal geometry stems (51% vs. 20%; $P < .01$), suggesting increased case complexity in patients where a tapered stem was used.

Patients in both groups had significant improvements in their Harris Hip Scores, with mean scores at last follow-up being statistically equivalent between the two groups (tapered 68.2 vs. cylindrical 75.3; $P = .210$).

In the cylindrical distal geometry group, there were 37 (84.1%) osseointegrated stems (84.1%), 3 (6.8%) with fibrous stable fixation and 4 (9.1%) that were loose, compared to 60 (98.4%) osseointegrated stems and one (1.6%) loose stem in the tapered group (Figs. 1 and 2). The lone loose stem in the tapered group occurred in a patient who developed severe intra-operative hypotension that required termination of the surgery prior to final distal canal preparation. There was a significantly higher rate of failed osseointegration (fibrous or loose) in the cylindrical group compared to the tapered group ($P < .01$).

### Table

<table>
<thead>
<tr>
<th>Patient Demographics</th>
<th>Tapered</th>
<th>Cylindrical</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Patients</td>
<td>61</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Age</td>
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<td>67.1</td>
<td>.52</td>
</tr>
<tr>
<td>Sex (% Females)</td>
<td>52%</td>
<td>53%</td>
<td>.99</td>
</tr>
<tr>
<td>BMI</td>
<td>30.0</td>
<td>(17.2–51.7)</td>
<td>.098</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(18.4–38.3)</td>
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</tbody>
</table>

Subsidence of the femoral component in the tapered and cylindrical groups averaged 3 mm (range 0–34 mm) and 1.5 mm (range, 0–17 mm), respectively. Five patients in the tapered group (8.2%) and 4 patients in the cylindrical group (9.1%) experienced subsidence greater than or equal to 10 mm ($P = 1.0$). Of the 5 patients in the tapered group, 4 had type IV femoral defects and 1 had a type IIIB femoral defect. This compares to 3 patients in the cylindrical group with type IIb femurs and 1 with a type IIIB femur. For those patients with subsidence >10 mm, re-revision was recommended in 3 patients in the cylindrical group for loosening, compared to 1 patient in the tapered group.

Intraoperative fractures occurred in 8/61 (13.1%) patients in the tapered group and 5/44 (11.4%) in the cylindrical group ($P = 1.0$). Postoperatively, there were 2 periprosthetic femur fractures that required ORIF in the tapered group compared to 3 in the cylindrical group ($P = .64$). There were 3 cases (6.8%) of femoral component managed with a tapered modular stem with osseointegration.

![Fig. 1. Preoperative and postoperative radiographs of high grade femoral defect managed with a tapered modular stem with osseointegration.](image1)

![Fig. 2. Preoperative and postoperative radiographs of high grade femoral defect managed with a cylindrical modular stem with failed osseointegration.](image2)
breakage in the cylindrical group and none in the tapered group. Additional complications included 5 dislocations (8.2%) in the tapered group and one dislocation in the cylindrical group (2.3%); one patient in each group underwent revision surgery for recurrent instability with an exchange of the proximal body segment. Subsidence did not appear to be correlated with dislocation in the tapered group; of the 5 patients with tapered stems that were revised for recurrent dislocations, the measured subsidence was 0 mm, 0 mm, 0 mm, 2 mm, and 4 mm. The patient with 4 mm subsidence underwent change of the proximal body. The other four had revision of the acetabular component. None of the nine patients (5 tapered; 4 cylindrical) with subsidence greater than 1 cm experienced dislocations.

The overall rate of failure for femoral component osseointegration was 1.6% (1/61) in the tapered group compared to 15.9% (7/44) in the cylindrical group \( (P < .01) \). The overall rate of repeat revision surgery of the femoral component for any reason was 4.9% (3/61) in the tapered group compared to 22.7% (10/44) in the cylindrical group \( (P = .013) \).

**Discussion**

High-grade femoral defects present challenging reconstructive problems during revision total hip arthroplasty. The compromised femur usually has minimal support in the proximal metaphysis and only limited support in the diaphyseal bone. Paprosky and Sporer noted an increase in failure of fully porous coated cylindrical stems when the femoral canal exceeded 18mm, which is often seen in type IIIB and IV femoral defects \[7\]. As noted by Aribindi et al, cylindrical stems that bypass deficient bone in the proximal femur rely on a minimum of 4cm of “scratch fit” to enhance stability and eliminate micromotion \[5\]. Tapered stems may gain axial and rotational stability over a smaller distance. This stability prevents micromotion and may favor osseointegration in more compromised diaphyseal bone. In addition, biomechanical comparison of a tapered versus cylindrical distal geometry in a cadaveric model favors the tapered design \[11\].

When subjected to synchronous axial and torsional loads, there was a statistically significant difference between the stems, with less axial and rotational displacement noted with the tapered design.

In this study, we noted that despite a greater case complexity, patients who were treated with a modular tapered stem had a lower rate of recurrent femoral component loosening, re-revision surgery and stem related failures. We believe this improved outcome can be attributed to the distal geometry of the tapered stem. Although we observed the tapered stems to be more susceptible to subsidence, we did not observe a corresponding increase in failure of ingrowth or loosening as was seen in the cylindrical group. Moreover, the majority of tapered stems that subsided occurred in femurs with type IV defects.

The potential advantages of mid-stem modularity in revision THA include the ability to adjust leg length despite the final resting length of the diaphyseal component, as well as femoral neck version and offset control independent of the distal stem, which can be difficult to control when achieving distal fixation with monoblock stems. Despite the use of modularity in all cases in this series, the rate of instability was still nearly 6%, which is comparable to other studies with nonmodular tapered stems and nonmodular cylindrical stems \[3,8\]. Thus it is unclear if a modular stem decreases the risk of dislocation. Five of the six dislocations in this study were seen in the tapered group, which could potentially be related to the increase case complexity seen in this cohort.

Potential downsides of modularity include stem breakage and wear debris generated from the additional modular junction. We observed 3 stem fractures in the modular cylindrical group, all occurring at the modular junction. All stem fractures occurred in an older stem design that has since been changed to a larger taper (Zimmer Modular Revision Hip Systems (ZMR, Zimmer)). Moreover taper junction corrosion and increased metal debris is a concern with modularity, however there have not been any reported data on this theoretical clinical problem in these systems.

We acknowledge several limitations of this study. This is a non-randomized retrospective review of patients treated at different institutions by different surgeons. Next, implants from two different manufacturers were used in this study. Finally, subsidence measured via internal radiographic landmarks may not be as accurate as other techniques, for example radiostereometric analysis.

In conclusion, we found that modular femoral stems with a tapered distal geometry were associated with a higher rate of osseointegration and a lower risk of repeat revision for loosening despite being used in femurs with more severe femoral defects. While modular stems are useful for these complex cases, breakage can occur at the modular junction and it is unclear if they lead to a decreased risk of dislocation.

**Appendix**

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**References**