Various short hip stems have been introduced with differing implant concepts of femoral fixation and implant length. There is a lack of proper classification for short hip stems, with a clear and accepted definition for implant length and extent of bone preservation in the metaphyseal and diaphyseal femur. This study analyzed the length of short hip stems. Stems were divided into collum, partial collum, and trochanter-sparing implants. An additional category was added, trochanter harming, which was defined as interruption of the circumferential integrity of the femoral neck. For all of the femoral components described, the designs were compared, excluding stems with insufficient clinical data. The 15 finally selected stems were classified as collum (1 stem), partial collum (7 stems), trochanter sparing (4 stems), and trochanter harming (3 stems). Mid-term results (>5 years of follow-up) were available for only 3 designs in the partial collum group. Taking into account the results of short-term studies (<5 years of follow-up), the femoral revision rate per 100 observed component years was <1 for most total hip arthroplasties. However, the studies varied greatly regarding level of significance, and short hip stems without published results are available commercially. Short hip stems cannot be circumscribed by a simple length limit. For some designs, clinical data collected from large patient cohorts showed a survivorship comparable to traditional stems. In cases that must be revised, this often can be performed with a conventional primary stem, fulfilling the promise to preserve bone for potential future revisions in younger patients.
few concepts in total hip arthroplasty have led the academic debate or influenced surgical practice more than tissue-sparing surgery. Most of this debate has regarded minimally invasive approaches during the past decade, although conservative femoral hip stems with conventional approaches have shown excellent results, and in the early discussion, limited clinical data on short stem designs were available.

However, new research and design evolution have spread the concept of bone preservation, and clinical studies have provided more data as a starting point for building a better scientific basis for new stem designs and tissue-sparing surgical procedures. The purpose of this study was to further develop and apply an existing comprehensive classification system for short hip stem implants currently available.

**Classification of Short Hip Concepts**

There is still a lack of a proper classification system for short hip stem implants, with a clear and accepted definition for implant characteristics and the extent of bone preservation in the metaphyseal and diaphyseal femur. Therefore, it is not always clear whether a femoral hip stem can be classified as conventional or short, or even as something in between.

Recently, Feyen and Shimmin proposed a comprehensive classification system for femoral components, based on the level of femoral resection and implant fixation. However, in their categorization, implant type I (resurfacing), type II (mid-head resection), and type V stems with diaphyseal fixation are intuitively distinguishable, whereas the distinction between type III (short stems) and type IV (traditional stems) was based on length measurement that has not been validated. This length measurement was calculated by the authors as “total length less than twice the tip of greater trochanter (GT) to base of lesser trochanter (LT) vertical distance.” Moreover, the proposed type III subclassifications for short hip stems in a solely subcapital III-A and standard III-B osteotomy may not reflect all of the differences of femoral osteotomy for currently available short hip stems. In any case, it must be considered that the primary fixation principles and osteotomy level are intimately related and subsequently influence the geometry of the proximal short stem portion and the presence and eventually extension of its diaphyseal design toward the overall length of the femoral component.

Whether considering a brief distinction between subcapital and standard osteotomy as described by Feyen and Shimmin or a classification of collum, partial collum, and trochanteric osteotomy as described by Van Oldenrijk et al. in their comprehensive review, a definition of neck resection is an undeniable characterization for short stems to understand their functional and biomechanical behavior to support a proper clinical comparison. In addition, some recent designs, clearly or less clearly derived from conventional straight stems, are basically a short-stemmed component with a limited but still existing trochanteric violation, at least at the entry point of the fossa trochanterica. Therefore, the current authors introduced a fourth category of trochanter-harming short stems, described as interruption of the circumferential integrity of the femoral neck section. With this type of implant, impaction of cancellous bone inside an intact cortical ring is no longer needed because of a “filling” fit in the metaphysis, with a larger proximal geometry (compared to trochanteric osteotomy aspects) requiring the use of a box osteotomy as the initial step of femoral preparation (violating the fossa trochanterica) (Figure 1).

Extra medullary anchorage (ie, thrustplate hip system) has been considered by Van Oldenrijk et al. This is a completely different concept and will not be discussed in this article.

For all of these considerations, a clear definition of short hip stems is far from being accomplished and is not easy to define. Even in cases in which hip stems have been shortened as an explicit evolution or range extension of a previous conventional component (eg, Taperloc Microplasty [Biomet, Warsaw, Indiana] or CLS Brevius [Zimmer, Warsaw, Indiana]), with the stem length varying in a way that the stems are borderline between short stems and conventional stems—if a given length will be validated—the definition is somewhat floating.

Restricting this overview to short stem implants (Table 1 and Figure 2), to components with a literature-based clinical outcome (phase 2 to 4 studies), and Level I to III longitudinal studies (ie, randomized controlled, controlled, and uncontrolled) or cross-sectional studies and case studies, van Oldenrijk et al. defined at least 16 different femoral short hip stem designs.

However, some of these designs have been taken off the market, mainly for commercial reasons or for further evolution of the stems; these include the Biodynamic hip implant (Howmedica,
Mahwah, New Jersey) that was essentially a precursor of the later CFP stem (Waldemar Link, Hamburg, Germany), Mayo stem (Zimmer), Delphi-M stem (ESKA Implants AG, Lubeck, Germany), and Proxima and Silent hip stems (DePuy Orthopaedics, Warsaw, Indiana). The Profile stem (DePuy Orthopaedics) and Citation stem (Stryker, Mahwah, New Jersey) seem quite far from being defined as short stem and have been excluded from the current study. The SMF short stem (Smith & Nephew, London, United Kingdom), LPI Prime (Exactech, Gainesville, Florida), GTS (Biomat, Warsaw, Indiana), and CLS Brevius stem (Zimmer) are included. The Trilock BPS bone preservation stem (DePuy Orthopaedics), with a somewhat different conservative concept that focuses more on the narrow cross-section than on the short stem character as stated by the manufacturer, was not included.

Therefore, for this study, a total of 15 contemporary short femoral designs were eligible for inclusion; for 10 of these designs, published clinical results or experience reports are available. For the remaining 5 designs, data in international clinical studies are expected in the near future. These implants can be divided into the categories described above, related to neck preservation and bone sparing (Table 1).

### SHORT STEM RESULTS

As mentioned, clinical reports are available for most of the short stems with reference to the system overview (Table 1); however, these studies show an extreme variability concerning their level of significance. Data for the Mayo stem and the CFP stem first appeared in clinical reports in the 1980s and 1990s3-6 introducing the concepts of short-stemmed femoral components. Because of the marked differences in sample dimensions and duration of follow-up among all of the available clinical results, a corrective factor was used, based on cases revised per 100 observed component years, pointing out a benchmark of 90% of survivorship at 10-years of follow-up (or revision rate <1 per 100 component years),² consistent with the National Institute of Clinical Excellence (NICE)⁷ and proposed by the Quality of Literature in Arthroplasty project (QoLA) supported by the European Federation of National Associations of Orthopaedics and Traumatology (Efort) and European Arthroplasty Registry (EAR).⁸,⁹

Such unification of results reported for collum prostheses² has shown a high revision rate of 2 per 100 observed

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### Table 1

Overview and Classification* of Commercially Available Short Hip Stems

<table>
<thead>
<tr>
<th>Level of Conservation</th>
<th>Short Stem</th>
<th>Stem Lengthb, mm</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collum</td>
<td>Spirion</td>
<td>76-96</td>
<td>III A</td>
</tr>
<tr>
<td>Partial collum with neck preserving osteotomy</td>
<td>CFP</td>
<td>130-155</td>
<td>III A</td>
</tr>
<tr>
<td></td>
<td>Collo-Mis</td>
<td>99-123</td>
<td>III A</td>
</tr>
<tr>
<td></td>
<td>Nanos</td>
<td>97-128</td>
<td>III A</td>
</tr>
<tr>
<td></td>
<td>Mini-Hip</td>
<td>90-130</td>
<td>III A</td>
</tr>
<tr>
<td></td>
<td>Metha</td>
<td>98-123</td>
<td>III A</td>
</tr>
<tr>
<td></td>
<td>Optimys</td>
<td>95-139</td>
<td>III A</td>
</tr>
<tr>
<td></td>
<td>LPI Prime</td>
<td>102-107</td>
<td>III A</td>
</tr>
<tr>
<td>Trochanter sparing</td>
<td>Taperloc Microplasty</td>
<td>112-140</td>
<td>III B</td>
</tr>
<tr>
<td></td>
<td>GTS</td>
<td>108-159</td>
<td>III B</td>
</tr>
<tr>
<td></td>
<td>Fitmore B</td>
<td>113-143</td>
<td>III B</td>
</tr>
<tr>
<td></td>
<td>Aida</td>
<td>107-155</td>
<td>III B</td>
</tr>
<tr>
<td>Trochanter harming</td>
<td>CLS Brevius</td>
<td>123-172</td>
<td>III B</td>
</tr>
<tr>
<td></td>
<td>Profemur Preserve</td>
<td>97-125</td>
<td>III B</td>
</tr>
<tr>
<td></td>
<td>SMF</td>
<td>120-133</td>
<td>III B</td>
</tr>
</tbody>
</table>

*Classification system developed by Feyen and Shimmin.¹

bMeasurement from medium head center to stem tip.

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Figure 2: Short hip stems in the study (from left to right): Spirion, CFP, Collo-Mis, MiniHip, Nanos, Metha, Prime, Aida, Profemur Preserve, Optimys, Taperloc-Microplasty, GTS, Fitmore, SMF, and CLS Brevius.
component years and an estimated survivorship at 10 years of more than 90%, except for the Gothenburg Osseointegrated Titanium (GOT) hip (Sweden),\textsuperscript{10} but this was only on the basis of one study with 40 patients observed after 24 months of follow-up. The well-documented CUT stem (Eska, Luebeck, Germany)\textsuperscript{11-14} showed a revision rate close to 1% per 100 observed component years,\textsuperscript{11,14} but the overall rate reported in the literature for this particular stem missed the expected benchmark. In addition, most of the components included in this group are no longer available for implantation (CUT, GOT) or are close to be taken off the market (Silent). The Spiron collum-type hip (K-Implant, Garbsen, Germany) is available for implantation, and a recent clinical study\textsuperscript{15} with short-term follow-up (1-3 years) reported 1 revision in 28 implanted stems.

The available clinical results for partial collum stems represent a different situation, appearing with an overall rate of 0.64 cases revisied per 100 observed component years\textsuperscript{2} that definitely meet the NICE criteria. Excluding systems without clinical reports or only short-term, biomechanical, or descriptive studies, Table 2 summarizes study results of currently commercially available partial collum and trochanter-sparing short hip implants published through mid-2014.

The longest mean follow-up (approximately 10 years or longer) has been reported for the CFP implant.\textsuperscript{16,17} Mid-term clinical surveillance (>6 years) is available for the CFP,\textsuperscript{18-21} Mayo,\textsuperscript{22-25} Namos\textsuperscript{26} (Smith & Nephew), and Metha\textsuperscript{27,28} (Aesculap AG, Tuttingen, Germany) (implants). Short-term studies have been published for the Taperloc Micro,\textsuperscript{29} Fitmore\textsuperscript{30} (Zimmer), and GTS stems.\textsuperscript{31,32}

The revisions per 100 component years (ie, time incidence rate) has been calculated for each study; cup-related short hip stem revisions were excluded, as they should not influence the comparison of survival performance of the femoral hip stem. For the Mayo hip,\textsuperscript{22} 9 femoral stem revisions induced by polyethylene osteolysis were excluded. The described modular neck-related complications pertaining to the initial titanium-alloy neck series of the Metha\textsuperscript{27} short stem were considered separately as well.

Published short-term results were only available in German in an overview monograph about short hip stems by Jerosch\textsuperscript{33} and for the MiniHip\textsuperscript{34} (Corin, Cirencester, United Kingdom), Optimys (Mathys, Bettlach, Switzerland),\textsuperscript{35} Collo-Mis\textsuperscript{36} (Lima, Udine, Italy), and Aida (Implantcast, Buxtehude, Germany).\textsuperscript{37} Because no additional international literature was found, the review by Oldenrijk et al\textsuperscript{3} also was considered. The only trochanter-sparing stem with a revision rate per 100 component years >1 was the Aida short stem, with a rate of 2.3. The reason is exactly the same that can be described for Optimys (among partial collum stems), where a single revision in a small series with short follow-up may influence the calculation of the expected mean revision rate per 100 component years. This seems reasonable, considering that the Aida short stem appears to be an evolution of the Mayo stem with improved surface finishing and that the Aida stem may reach the Mayo revision benchmark.

**DISCUSSION OF CLAIMS VERSUS EVIDENCE**

**Collum Stems**

From the literature review, it is immediately evident that the most conservative group of short stems (collum type) have yielded the worst clinical results, with higher actual or estimated revision rates. More than one consideration subsequently arises about this group of conservative femoral components. The first consideration is whether mechanical behavior is a factor. Despite the fact that preliminary studies for one of these designs reported a satisfying reproduction of joint biomechanical parameters,\textsuperscript{11} a mid-term follow-up study\textsuperscript{31} described a tendency to valgization with femoral lateral offset decrease, periprosthetic radiolucency as well as calcar atrophy expression of loosening, and stress shielding, with an unacceptable failure rate of nearly 50% at 8 years.

Other reasons for variation in clinical outcome may be that the implantation technique is technically demanding or prone to a higher risk of intraoperative fracture or suboptimal positioning (with potential detriment to future stability and integration of the component, more than expected with short stems provided with larger metaphyseal anchorage). For the same reason, a potential limit in the appropriate indications (beyond the simple age considerations) may be an explanation for failure, for example, if suboptimal bone quality or abnormal anatomy of the femoral neck is ignored. Even if the use of these types of implants has decreased, further follow-up data may reveal valuable data on the biomechanics of the femoral neck. Further design developments may improve initial stability, as a key factor in future stability. The authors are currently working on this by participating in the first clinical evaluations of the X-FIT component (Samo, Bologna, Italy).

**Partial Collum and Trochanter-Sparing Stems**

When looking at partial collum and trochanter-sparing short hip stems, it became evident that there was no difference in these 2 types of stems regarding survival rate. Both types of stems have a revision rate per 100 component years <1. As stated previously, the clinical survival of the Metha stem would remain consistently below that
benchmark if neck breakages were ignored (9 cases at a mean follow-up of 4.9 years as reported by Wittenberg et al27). This particular failure mechanism has been related to a fatigue fracture of titanium alloy modular neck adapters, originating in surface cracks caused by fretting or fretting corrosion (apparently initiated by micromotion at the tapered connection).38 The titanium neck components were then replaced by the manufacturer with cobalt-chromium adapters, reducing micromotion dramatically in mechanical tests39 with a subsequent decrease in fretting corrosion and surface cracks.

Commercial reasons have entailed retirement of the Proxima femoral component that showed a definitely favorable clinical behavior: the best revision per 100 component years rate, limited to the trochanter-sparing stem, as reported by Van Oldenrijk et al2 in their review, at a short follow-up but a considerable sample size of 125 cases in 3 different studies.40-42 Future clinical surveillance of components implanted to date may reveal further information about biomechanics and implant-to-bone stimulation. Regarding the latter aspect, a supposed superiority of partial collum stems to load the proximal femur and thus avoid stress-shielding,
particularly in Gruen zone R1 compared to trochanter-sparing designs, seems to be contradicted by dual-energy x-ray absorptiometry (DEXA) findings reported in the literature.\textsuperscript{43,44} Besides a favorable stimulation of the calcar region (R7) in many conservative stems belonging to these 2 groups, except for the Nanos stem, which showed a decrease in bone density in R7 in 2 reports,\textsuperscript{45,46} a slight-to-mild reduction in bone density was seen in the trochanteric region (R1) for most of the stems after follow-up of 1 year or longer, except for the Proxima conservative hip, in relationship to the lateral flare provided by this particular component as reported by Learmonth.\textsuperscript{47} Moreover, for most of the designs, a stimulation in the distal portion of the stems (R3-R5) can be detected as a result of a partial distal loading potentially not researched by the stem designers.

Thus, the question remains whether stem choice is only justified by the need of bone stock preservation for future revisions. Theoretically, a partial collum device is replaceable with a trochanter-sparing stem, but preserving the trochanteric fossa during revision is difficult, and a trochanter-harming device then appears to be more reliable in a possible conservative revision as well as a conventional standard stem.

**Trochanter-Harming Stems**

Results of trochanter-harming femoral stems are still lacking in the peer-reviewed literature, but results in line with standard or trochanter-sparing may be expected. The shortness of the component and the pure proximal primary fixation should limit the proximal stress shielding observed with longer components, a statement to be proved with dedicated DEXA.

The key point in defining this fourth category of short stems, compared to trochanter-sparing components, is the interruption of the circumferential integrity of the femoral neck section (at any given osteotomy height, required by the surgical technique): impaction of cancellous bone inside an intact cortical ring is no longer needed because of a different fit in the metaphyseal region. This different fit is generally achieved with a larger proximal geometry (compared to trochanter-sparing designs) and requires the use of a box osteotome as the initial step in femoral preparation (violating the trochanteric fossa); it allows for removing and impacting a part of the trochanteric cancellous bone with rasps and impactors to achieve a proper settlement of the component.

It does not mean harm to the trochanteric structure, but rather the term trochanteric harming states that the integrity of the greater trochanter, starting from the opening of the trochanteric fossa and moving laterally, is not a requirement (or a consequence) of surgical technique, in opposition to trochanter-sparing components. A much-discussed topic is that many of the conservative stems have been designed with a neck modularity to improve joint biomechanical reconstruction. However, since the discovery of potential ion-related complications caused by neck-stem taper junctions, and the fact that a proper offset usually can be defined preoperatively, the trend is moving toward the use of monolithic versions of the prosthesis. A particular situation may be considered if computer-assisted surgery is routinely used: the use of this technology allows the surgeon to select not only the cervicodiaphyseal angle but also ante- and retroversion intraoperatively to optimize range of motion and stability on the basis of measurable and reliable data.\textsuperscript{48}

Short stems are attractive for minimally invasive approaches, allowing an easier femoral preparation with short broaches. In a study by Molli et al\textsuperscript{49} comparing Taperloc standard and micro stems, implanted via a minimally invasive approach, the intraoperative complication rate was significantly lower in 269 hips receiving the short version of the stem.

**CONCLUSION**

The complexity of this topic is not easily decoded with a simple definition of a length limit, to which a definitive value is attributed for traditional and short lengths of a femoral component. If a given length will become a reliable limit for short stem definition, it may happen that components previously not qualified as “short” will be included in this family (eg, Trilock BPS), especially in cases of a stem length comparable to one or more “shortened” hip stems.

Short stems, particularly when bone preservation has not been taken to the extreme of collum type implants, have proved to be reliable in terms of survivorship. Even if absorptiometry generally detects less proximal bone stimulation than expected, particularly in the trochanteric region, most of these components can be revised with at least a conventional primary stem fulfilling one of the main goals: to preserve bone for future revision in young patients, with only few exceptions, such as in the case of periprosthetic fracture with an unstable component.

A suggestive field of application of short stems may be, in the near future, the development of cemented short designs. A shortened version of the Exeter stem (Stryker) is already under in vitro investigation.\textsuperscript{50} After the encouraging results achieved with a special series of Exeter stems implanted in Asia, shorter than conventional, with reduced offset and different taper angles to match the smaller femora in that specific population.\textsuperscript{51,52} It may seem that short stems and cemented stems are clashing terms, but perhaps it is possible that the shortness of the component will reduce the complexity of cemented stem revision and that the long-term follow-up of cemented prostheses will increase potential survivorship of short stems.
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