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Short-Stem Hip Arthroplasty

Kálmán Tóth and Gellért Sohár

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1. Introduction

Total hip arthroplasty has become a remarkably successful operation for treating osteoarthritis in the last half century. The increased need for better quality of life has led the operation to be extended to younger patients. However, long term results showed a rise in the number of revision surgeries. The longer life expectancy of the patient population led to the demand for multiple revision surgeries for the same patient. In revision surgery numerous technical difficulties are encountered because of bone loss due to the loosening. In addition, these solutions are exceptionally expensive. The search for alternatives led to the modification of the primary components. Improvements have introduced changes to achieve more proximal load transfer to the femur in order to reduce proximal stress shielding and thus preserve bone stock for potential revision surgery. As hip resurfacing declines in popularity, it is likely that there will be a corresponding increase in the number of short stem femoral components in use. Metaphyseal stems combine the advantages of straight stem implant design and hip resurfacing.

The aim of this chapter is to outline the recent developments in short (metaphyseal) stem arthroplasty.

2. Concise review of the pertinent literature

2.1. Rationale

Short metaphyseal femoral stems have been developed in order to improve the results of the standard non-cemented stems. Different designs of short stems are available, with differences in operative technique and published outcomes [Mai et al., 2010; McElroy et al., 2011]. The new generation short-stem hip implants are designed to encourage physiological-like loading to minimize stress-strain shielding and therefore implant loosening in the long term.

Traditionally, femoral stems are tapered, anatomical, or cylindrical. The classic tapered stem has rectangular cross-section, 4 corners and 4 flat surfaces that are compressed into the proximal femur. The second, equally popular design consists of anatomically shaped stems designed to match the shape of the proximal femur. The third design, with its different philosophy of fixation, consists of cylindrical, straight, nontapered, and extensively coated stems achieving distal fixation at the isthmus by means of a "scratch fit" between the fully roughened porous surface of the implant and the slightly smaller, underreamed femoral canal [Mai et al., 2010].

Proximal loading short stems have been designed to improve the results of the traditional non-cemented stems. [d'Imporzano & Pierannunzii, 2006; Renkawitz et al., 2008]. In a study by Westphal et al. the migration and cyclic motion were compared between a new short-stemmed hip prosthesis (Proxima™) and two clinically successful shaft prostheses in order to estimate the primary stability of the new stem [Westphal et al., 2006b]. Initially the short stem migrated more than the shaft prostheses. When cortical contact was achieved or the cancellous bone was compacted sufficient stability was acquired. Therefore, correct positioning and good bone quality are important factors for the short stem. Bony ingrowth is more favorable with the short stem because of the lowered cyclic motion after implantation. The effects of stress shielding are reduced by more physiological loading of the femur because of the new stem's lower bending stiffness [Westphal et al., 2006b].

The following advantages have been reported:

1.   bone stock and soft tissue (m. gluteus medius et minimus insertion) preservation, in the greater trochanteric and sub-trochanteric regions, at the time of implantation for future revisions [Khanuja et al., 2011; Morrey, 1989] Fig. 1,

2.   decreased stress shielding, caused by metaphyseal bone resorption and diaphyseal cortical hypertrophy [Pipino, 2000],

3.   stress concentration at the tip of a distal fixation traditional component causes thigh pain, with the short stem this is eliminated [Khanuja et al., 2011; Mai et al., 2010],

4.   the iliotibial band's tension band effect provides compression forces both medially and laterally in the proximal femur. [Leali et al., 2002] Fig. 2, lateral cortex provides a strong support as a second compression column [d'Imporzano & Pierannunzii, 2006]

5.   transfers load to the metaphysis from a superior to an inferior direction in a physiological manner [Leali et al., 2002; Walker et al., 1999],

6.   the method of implantation eases minimally invasive approaches [McElroy et al., 2011] Fig. 1,

7.   wide range of indication (over surface arthroplasty risk index grade 3), all types of bone stock with normal femoral morphology are acceptable [Kim et al., 2011],

8.   revision surgery becomes easier because of minimally invasive approach, less soft tissue damage, and the intact bone stock below the lesser trochanter [d'Imporzano & Pierannunzii, 2006].
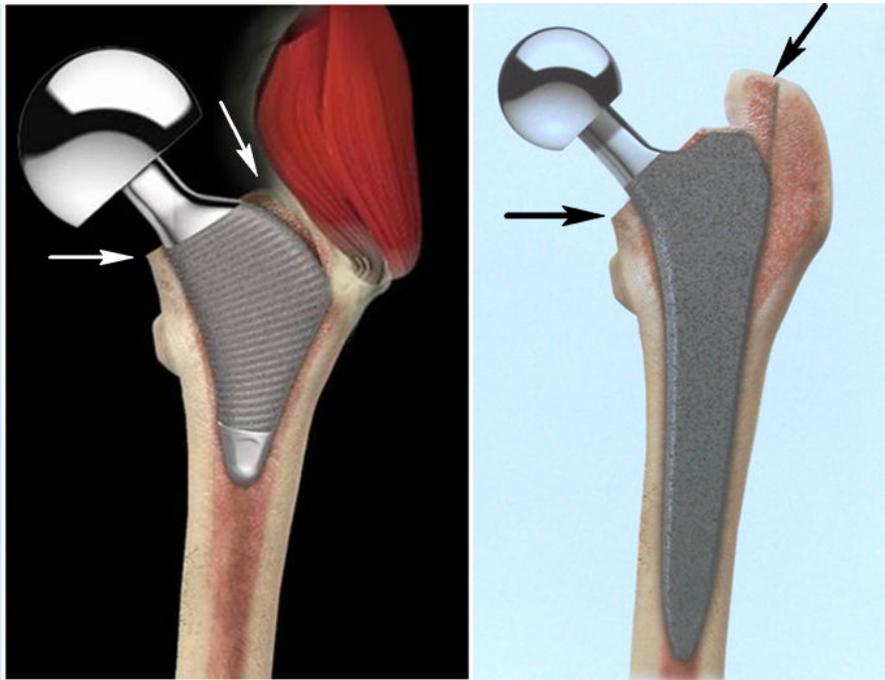
Figure 1. More bone stock and soft tissue preservation (arrows) in the greater trochanteric and sub-trochanteric regions at the time of implantation. Revision surgery becomes easier because of minimally invasive approach and less tissue damage.

Figure 2. The lateral flare geometry of short stem femoral components loads the proximal wider metaphyseal lateral and medial cortices of the femur. This additional contact area creates a wider base for support and provides a more physiologic load distribution in the proximal femur.

The design and geometry of the implant impacts its ability to transfer loads to the femur [Westphal et al., 2006a]. The lateral flare geometry of short stem femoral components loads the proximal femur more evenly [Walker et al., 1999]. The lateral flare component is stabilized by resting upon the lateral column of cortical bone. This additional contact area creates a wider base for support and provides a more physiologic load distribution in the proximal femur [Leali et al., 2002; Dabirrahmani et al., 2010]. Therefore, femoral components that engage the metaphysis and load the femur both medially and laterally are more stable [Leali et al., 2002]. The stem does not need to be 'press-fitted' into the femur or driven distally. The stem rests upon the proximal wider metaphyseal lateral and medial cortices of the femur [Leali et al., 2002; Walker et al., 1999].

2.2. Outcomes of different short stems

There are no long-term clinical studies available to prove the benefits of these short-stem implants so far. Owing to this lack of clinical data, numerical simulation may be used as a predictor of longer term behaviour. This finite element study predicted both the primary and long-term stability of a short-stem implant. The primary implant stability was evaluated in terms of interface micromotion. This study found primary stability to fall within the critical threshold for osseointegration to occur. Longer term stability was evaluated using a strain-adaptive bone remodelling algorithm to predict the long-term behaviour of the bone in terms of bone mineral density (BMD) changes. No BMD loss was observed in the classical Gruen zones 1 and 7 and bone remodelling patterns were comparable with hip resurfacing results in the literature [Dabirrahmani et al., 2010]

In previous reports on short stems, the HHS values showed an increase of 56 points for the Mayo® stem [Hube et al., 2004] and 33 points for the CUT® stem [Thomas et al., 2004] after a minimum follow-up period of three-months after operation. Our results showed an increase of 39 points with the Proxima™ stem [Tóth et al., 2010]. At a minimum follow-up time of 12 months, an increase in the HHS of 51 [Ender et al., 2007] and 34 points [Thomas et al., 2004] with the CUT® stem, 51 with both the Proxima™ [Ghera & Pavan, 2009] and the Mayo® stem [Morrey, 1989] have been reported. In a similar study [Tóth et al., 2010], we noted a 50 points increase in the HHS with the Proxima™ stem one year post operatively, which is comparable with previous reports.

Some studies reported a vertical or horizontal (varus) migration of short stems requiring a subsequent revision [Ender et al., 2007; Morrey, 1989; Thomas et al., 2004], others described significant radiolucent lines or progressive proximal femoral osteolysis around the short stems without a need for revision [Gilbert et al., 2009; Goebel & Schulz, 2009]. In our reported study [Tóth et al., 2010], no horizontal or vertical migration was found at follow-up at that time, not even with the under-sized and varus positioned stem (Fig. 3). The patient cohort is continuously followed both by radiological and clinical examination. After average follow-up of 4.5 years still no horizontal nor vertical migration was seen.

Thigh pain is a common complaint following traditional non-cemented hip arthroplasty. Among the Proxima™ hip cases evaluated by Tóth et al [Tóth et al., 2010], none of the patients reported any thigh pain even after 4.5 years. Ghera and Pavan reported similar find-

ings with Proxima™ stems [Ghera & Pavan, 2009]. Hube et al also did not find any thigh pain following THA with the Mayo® stem [Hube et al., 2004]. Other studies reported severe thigh pain following short stem implantation (Mayo®, CUT®), requiring revision [Ender et al., 2007; Gilbert et al., 2009; Thomas et al., 2004].
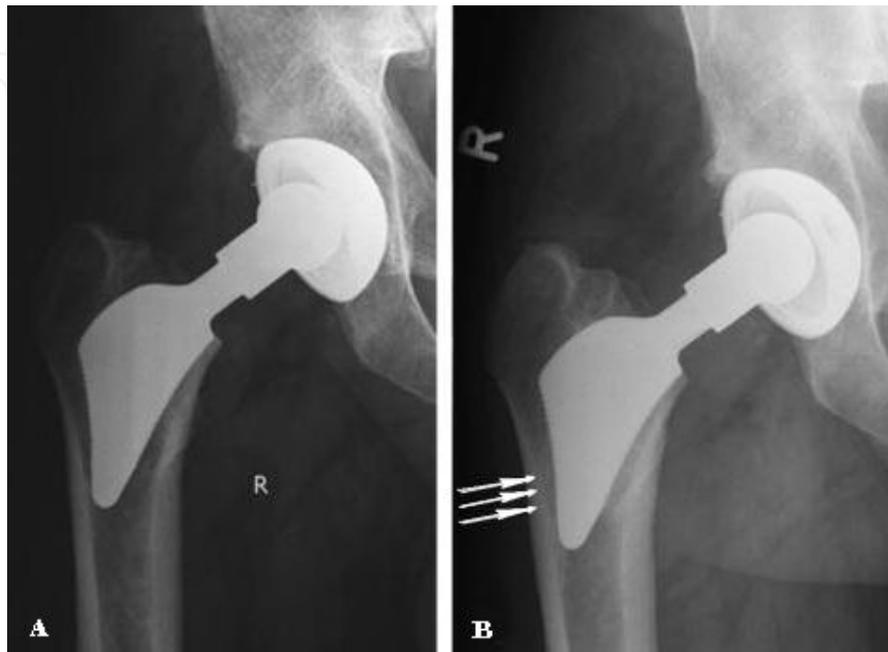

Figure 3. Undersized Proxima™ short-stem in severe varus position (a) immediate postoperative radiograph (b) radiograph 4 year post-op. Even though the long neck is biomechanically disadvantageous, after 4 years the position of the stem is the same. Strengthening of the trabecular structure against the lateral aspect of the stem (arrows) is stimulated by proximal loading (Wolf's law).

Survival of the implanted short stems are summarized in Table 1.

Type	Author	Follow-up	Survival
May® Conservative Stem (Zimmer)	Morrey et al, 2000	5 and 10 years	98.2%
CFP™	Gill et al, 2010	3 years	97%
CFP™	Pons, 2010	3,1 years	100%
Cut® (ESKA)	Steens et al, 2010	6.6 years	98%
Metha™	Synder et al, 2009	1 year	100%
Metha™	Floerkemeier et al, 2012	2.75 years	96%
Proxima™ (DePuy)	Santori et al, 2010	8 years	100%
Proxima™ (DePuy)	Tóth et al, 2010	2.1 years	100%
Proxima™ (DePuy)	Kim et al, 2012	4.1 years	100%
Proxima™ (DePuy)	Ghera et al, 2009	1.7 years	100%
SPS™	Sariali et al 2012	10 years	100%
TaperLoc® Microplasty™	Molli et al 2012	1.8 years	99.7%

Table 1. Reported survival of different short stems

3. Authors' own experience

3.1. Materials and methods

At the Orthopedic Department of the University of Szeged, implantation of the short-stemmed Proxima™ (DePuy; Leeds, UK) began in September 2006. Proxima™ was chosen of all the short stemmed designs on the market because the 36 stem options provide broader variety for the anatomical shape of the femur than the rest. All the 50 procedures were examined clinically and radiologically. Mean age of the patients was 48 (rang from 35 to 61, SD 7) years at time of the surgery. Mean follow-up time was 54 (range from 45 to 61, SD 5) months. Thirty male and 14 female patients were operated on; one female and five male patients had bilateral surgery in two stages. Patients' distribution according to diagnosis was: primary osteoarthritis (OA) in 22, avascular femoral head necrosis in 18, OA with mild dysplasia in 6, post-traumatic OA in 3 and OA secondary to Perthes disease in 1. All procedures were performed by the same surgeon, in the routinely used supine position, from anterolateral approach, with minimally invasive technique. Any intra- or postoperative complications were recorded.

The Proxima™ stem is made of forged titanium alloy, with a Duofix™ HA (porous coating and hydroxyapatite) surface coating. Nine sizes of standard as well as high-offset stems for each side are available. Cementless Duraloc™ porous coated cups (Depuy) with 10° lipped polyethylene liners and 28 mm metal heads were used in all cases.

The indication was hip osteoarthritis or avascular necrosis in young and active patients who were not appropriate candidates for a resurfacing procedure. The following elements were considered contraindications to implantation of a Proixima stem: stem size 1 or 2 for patients with body weight over 100 kg, severe hip dysplasia, previous hip osteotomy or other acquired femoral distortion, cortical index less than 3, severe osteoporosis.

The clinical status of the patients was documented with the Harris Hip Score (HHS) [Harris, 1969]. Low molecular weight heparin was administered for 42 days postoperatively for thromboembolism prophylaxis. Partial weight bearing using crutches was recommended for four weeks post operatively, thereafter full weight bearing with canes was allowed for two additional weeks.

Pre- and post-operative radiographs were taken with identical settings for each patient. Implant migration was assessed according to Martell et al [Martell et al., 1993]. Implant stability was evaluated according to Engh et al [Engh et al., 1987], based on the radiological features of the bone-implant interface. Criteria for radiological loosening of the implant were defined as a radiolucent zone greater than 3 mm, or a horizontal and/or vertical migration greater than 2 mm with an adjacent radiolucent zone [Kim et al., 2003]. Stem alignment was rated as normal if its deviation from the axis of the femoral shaft was 5° or less. A deviation of 6 to 10° was rated as "varus" or "valgus"; a deviation exceeding 10° was rated as "severe varus" or "severe valgus".

3.2. Results

Mean preoperative HHS value was 39 (range: 11 to 71; SD 13). Mean postoperative HHS was 78 at six months (range: 44 to 94; SD 14), 90 at twelve months (range: 52 to 99; SD 13) and 87 at fifty four months (range: 51 to 95; SD 13). We had two complications: an intraoperative fracture was treated by open reduction and fixation with a plate. One patient had dislocation as a result of socket malposition, therefore only the socket's position was adjusted in a revision surgery as the stem had been properly implanted. We did not observe any infection, deep vein thrombosis or pulmonary embolism.

The alignment of the Proxima™ stem on the immediate post-operative radiograph was found to be in severe varus position on two occasions (Fig. 3); nine stems were implanted in varus, and 39 in neutral position. During the follow-up period, no signs of either clinical or radiological loosening were detected.

At the latest follow-up examinations, all respondents stated that they would undergo the operative procedure again. Ninety five percent of the patients were completely satisfied with the outcome of the surgery; the patient who had an intraoperative periprosthetic fracture and the other patient who had a dislocation were satisfied as well.

3.3. Discussion

The number of cases and the length of follow-up are not extensive enough to draw a final conclusion in comparison to traditional arthroplasty procedures. However, it is sufficient to conclude that this procedure greatly differs from standard femoral implantation; therefore a number of factors may be usefully discussed.

3.3.1. Head-neck resection

Attention should be paid to the level of the head-neck resection. A crucial bony surface for fixation of the stem is lost if the cutting plane is more oblique than optimal, i.e. if it is close to the traditional cutting plane. On the medial side the resection should always start at the head-neck junction and run more distally while proceeding laterally, thus creating a wider entrance for the stem (see paragraph 3. below). Ender et al have reported in conclusion of a five-year follow-up of 120 CUT® short-stem implantations, that out of the 11 revision cases, seven femoral necks had ben resected either too diagonally (traditionally) or too widely [Ender et al., 2007].

3.3.2. Positioning

Inadequate hit force during the "round the corner" broaching can result in a varus position of the stem. As no intramedullary guidance is available for the Proxima™ stem due to its metaphyseal location, a varus position is more likely to occur, especially when a minimally invasive approach is used, as visualization of the femoral axis is difficult. It is imperative to perform intraoperative axis measurements during sequential broaching. Until proper experience is acquired the use of fluoroscopy is advisable. Ghera and Pavan reported a study on

65 Proxima™ stem implantations, in which 44 stems were found to be in neutral position, 15 in varus and 6 in valgus [Ghera & Pavan, 2009]. Gilbert et al found that from 34 Mayo® short stems implanted, 14, 19, and 11 cases were neutrally aligned, in varus and in valgus position, respectively [Gilbert et al., 2009]. In our series 2 of 50 Proxima™ stems at the beginning of the learning curve were found to be in severe varus (Fig. 3), 9 in varus and 39 in a neutral position, which seems to be comparable with the previous reports.

3.3.3. Stem sizing

The "round the corner" broaching technique was developed to save bone stock in the lateral segment of the metaphysis. However, it can happen that the broach of the planned size would not fit into the resected part of the femoral neck (Fig. 4).
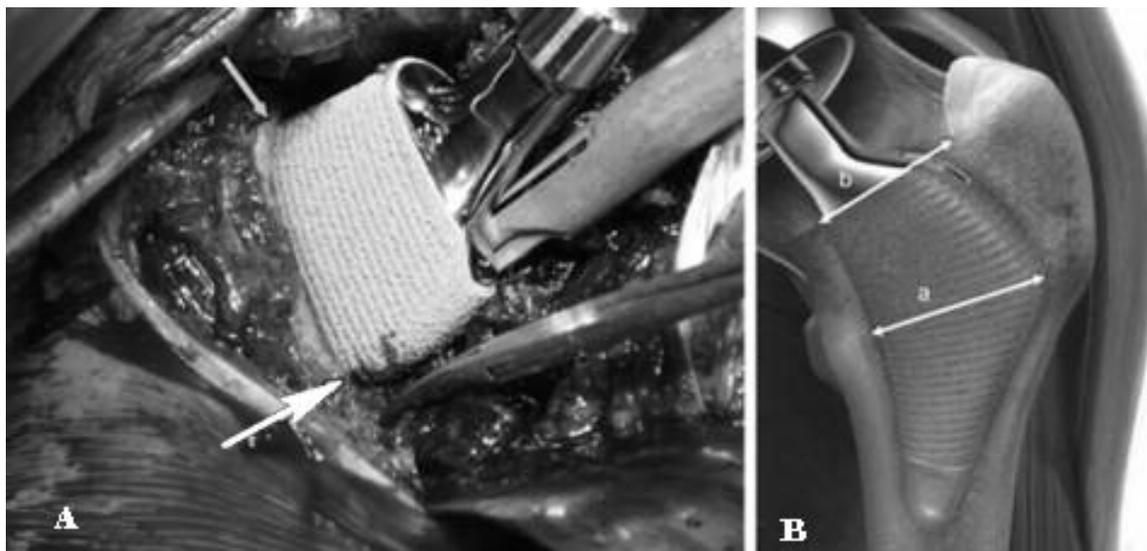
Figure 4. Fitting of the Proxima™ stem into the proximal femoral metaphysis. "Round the corner" technique is used to protect the soft tissues and bone stock, and take advantage of the lateral flare. (a) Intraoperative picture; the cortical bone of the neck is in contact all around with the largest diameter of the stem (arrows) (b) the measured width of the stem (a)is wider than the entrance (b).

In this situation, the following solutions are possible depending on the bone stock quality:

a. When the cancellous bone is weak, the neck in the lateral aspect of the resection plane should be gently enlarged until the stem of the desired size can be implanted. An undersized stem in a weak cancellous bone tends to tilt into varus, and may sink deeper than expected. The deep position of the stem then needs to be corrected by a longer neck, which raises the biomechanically disadvantageous torque force on the short stem (Fig 3).

b. When the cancellous bone is hard, implantation of a Proxima™ stem smaller than the calculated size of the metaphysis is acceptable. Even if the stem does not reach the lateral cortex, the strong and compact cancellous bone can hold the femoral component firmly (Fig. 5).

Figure 5. AP and lateral radiographs of a Proxima™ stem in a hard cancellous bone (a-b) immediately after operation (c-d) 24 months post op. The stem is fixed by strong and compact cancellous bone, without loosening.

3.3.4. Cortical index

Calculation of the cortical index: Cortical index = $(10 \times (a-b))/a$, where a is the outer diameter of the femur and b is the inner diameter of the medullary cavity 10 cm below the level of the lesser trochanter (Fig. 6).
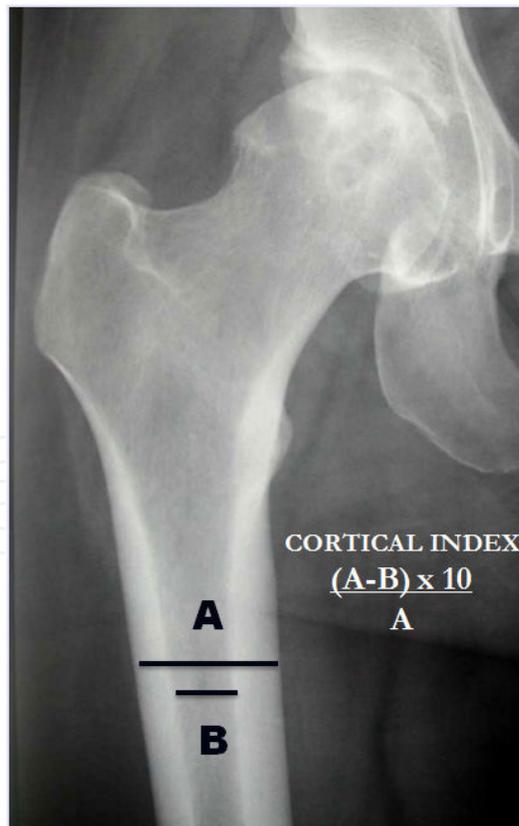

Figure 6. Calculation of the cortical index. Cortical index = $(10 \times (a-b))/a$, where a is the outer diameter of the femur and b is the inner diameter of the medullary cavity 10 cm below the level of the lesser trochanter.

Short-stem hip implantation is contraindicated when cortical index scores are less than 3; in this situation a cemented stem is advisable. If the cortical index is between 3 and 4, an over-sized Proxima™ stem would be suggested; if the cortical index exceeds 4, a normal sized Proxima™ stem could be used.

Among the 50 Proxima™ stem implantations, the only intraoperative complication was a spiral femoral shaft fracture. The stem sank deeper into the femoral shaft than the identical sized broach, causing an infraction, which resulted in a complete spiral shaft fracture during the repositioning maneuver. The cortical index of the affected hip was 3.75; the mean cortical index of the other cases was 6.07.

4. Conclusion

Bone-saving hip arthroplasty using metaphyseal stems is gaining importance because the increasing number of young patients, and hip resurfacing is not always indicated. In the last decade, the practice of hip arthroplasty has changed; younger age-group is more frequently undergo surgery because of the need for a better quality of life. The success of non-cemented total hip arthroplasty relies on osteo-integration of the implants. Prerequisite is primary stability, which can be achieved by the fixation principle of ''press-fitting'' [Morscher et al., 2002]. Clinical studies investigating the migrational behavior of femoral components have shown that the failure rate of uncemented stems correlates with migration [Krismer et al., 1999]. Sychterz found that in vivo bone loss was most extensive in the proximal-medial region [Sychterz et al., 2002]. Following traditional arthroplasty procedures, bone density measurement has shown a bone loss of 16 to 30% [Kim et al., 2003; Schmidt et al., 2002; Sychterz et al., 2002]. Engh's post mortem investigation has found 7 to 52% bone loss around non-cemented femoral components with osteo-integration [Engh et al., 1992]. DXA measurements by Kishida et al. proved that two years after resurfacing procedures 12% raise in bone density developed in the Gruen 7 zone [Kishida et al., 2004].

The previously mentioned facts, along with the experiences obtained from revision surgeries (technical difficulties caused by bone loss due to loosening) and the high cost of the solutions, have led to a change at the level of primary arthroplasty principles to a more preventive approach. As for the material of the prosthesis components, highly cross-linked polyethylene, metal-on-metal and ceramic sliding surfaces have advanced. According to component design, short-shaft stems came into prominence for those young and active patients for whom resurfacing of the hip is contraindicated (large avascular necrosis of the head, osteoporosis, obese patient etc.) The very proximal location of these stems retains the chance for an implantation of a non-revision stem during revision surgery. Short-stem prosthesis with a close anatomical fit to the proximal cortex aim to maximize primary stability, particularly in rotation. It is also proposed that the shorter shaft leads to more physiological loading of the femur, thereby limiting potential bone resorption due to stress shielding. Further advantages are the reduction of the risk of thigh pain and facilitating minimally invasive surgery, particularly when using an anterior approach [Renkawitz et al., 2008].

At our department both resurfacing and short-shaft stem are available for young and active patients. Short stem is implanted when indication criteria are sufficient. The advantages and disadvantages of short-stem arthroplasty are reported through the author's experiences with the metaphyseal stems [Tóth et al., 2010]. It provides vertical stability by the wedge shape of the stem together with the addition of a lateral flare and preservation of the femoral neck. The preservation of the femoral neck provides greater torsional stability and reduces distal migration of the femoral stem. The absence of any diaphyseal fixation attempts to achieve proximal load transfer so as to reduce stress shielding and thigh pain. It also attempts to preserve the femoral canal and femoral elasticity, and ease revision.

The number of cases and the length of follow-up time in the short stem literature are not extensive enough to draw a final conclusion in comparison to traditional arthroplasty procedures. However, it is sufficient enough to conclude that this procedure differs, therefore a number of factors may make sense to be discussed.

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