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Minimally invasive total hip replacement

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Abstract At present, minimally invasive surgery is the main trend of orthopaedic surgery and involves almost all its fields, joint replacement included. A total hip arthroplasty should be considered minimally invasive only if bone resection is limited to pathologic tissues (conservative replacement) and the procedure is performed without major sacrifice of soft tissues. This last statement suggests that the term "mini-incisions" be substituted with "mini-approaches", meaning surgical approaches that respect not only the skin, but also fascia, tendons and muscles. Bone preservation may be obtained through proximal load, neck-retaining and resurfacing implants. Evaluating bone sacrifice both on the femoral side and on the acetabular side, neck-retaining arthroplasties seem to warrant the most balanced maintenance of bone tissue. Neck-preserving implants through a lateral or posterior mini-approach seem to be the most consolidated solution in minimally invasive total hip replacement.

Key words Femoral neck • Minimally invasive surgery • Resurfacing • Total hip replacement

Introduction

Conventional total hip replacement (THR) is considered a safe and effective procedure, able to solve pain and disability without exposing patients to significant risks. Thus, minimally invasive developments of such a predictable procedure are not only requested to add further advantages but also to not compromise the already achieved results.

Before discussing the practical application of these techniques, it is necessary to agree on the definition: total hip replacement is considered minimally invasive only if bone resection is limited to pathologic tissues (conservative arthroplasty) and the procedure is performed without major sacrifice of soft tissues. Both bone and soft tissues take part in this definition, and to avoid any misunderstanding with mini-incision, it has been recently proposed to rename this wider concept as tissue-sparing surgery (TSS) [1].

Soft tissue preservation has been considered a synonym of mini-incision for a long time. This is incorrect, since skin is the least noble tissue of our body and its healing power is well known. Muscles, tendons and fasciae should be the true target of a soft-tissue-sparing dissection because of their importance in recovery speed and functional outcome of THR. Although the superficial wound only affects the aesthetical result, it ought not to be completely neglected, as patients' overall satisfaction, especially for young women, depends on the aesthetics too.

There is a general agreement that 10 cm is the length limit to define a "mini-incision" in THR, regardless of the deep dissection [2]. From the point of view of TSS, the concern about deep dissection prevails over the concern about the superficial wound. For this reason, "mini-approach" should substitute "mini-incision" and more

attention should be paid to the anatomical exposure of the joint than to the size of the wound.

Regarding the implants, all the prosthetic devices that allow significant bone preservation may be considered "conservative arthroplasties". Femoral bone preservation has been addressed more than the acetabular one, probably because the proximal femur is grossly sacrificed in conventional hip replacement. Today, neck-retaining and head-retaining (resurfacing) implants are available, but only few of them have been validated by long and wide experience.

Mini-approaches

The advantages of a minimally invasive exposure of the joint have been widely discussed by surgeons and surgical tool manufacturers:

- Smaller aesthetical scar
- Fast functional recovery
- Short hospitalisation
- Reduced blood loss and transfusion rate
- Reduced infection rate.

Unfortunately most of these advantages are far from being proved [3]. While the first three points can be reasonably accepted, even if there is no strong evidence for them, the last two points are unfounded for at least two reasons. First, in THR most blood loss is from the bone itself and a gentle management of the soft tissues cannot prevent but a small part of the total blood loss. Second, the infection rate is not related only to soft tissue damage, but also to surgical time and to frequency of contamination opportunities (such as skin-prosthesis contacts, difficult to be avoided at the time of insertion if the incision is very short).

Several mini-approaches have been described: anterior, anterolateral, straight lateral, posterolateral and two-incision.

Anterior mini-approach

The anterior approach to the hip had been widely used in the past, since Smith-Petersen published this technique in 1949 [4]. In the last two decades, it was mostly abandoned in favour of less invasive approaches, but it kept being performed in pelvic osteotomies and acetabular revisions. Recently the anterior portal to the hip joint has gained renewed interest because of its possible conversion to TSS [5–7].

The tissue-sparing version of the Smith-Petersen approach retains the muscular insertion on the iliac crest, and the dissection is led straight to the capsule between the tensor fasciae latae and glutei muscles laterally, sand between the sartorius and rectus femoris muscles medially. No muscle or tendon is transversally cut, and the dissection is mainly blunt, save the obvious incision of the fascia over the medial aspect of the tensor. Since the lateral muscular mass is innervated by the superior gluteal nerve and the medial one by the femoral nerve, this approach is perfectly anatomical, since it exploits an intermuscular and internervous interval. Skin incision may be performed both longitudinally (distally and laterally from the anterior superior iliac spine) and transversally (along the groin fold), thanks to the highly elastic superficial layers. The second choice is preferred by women as it is less evident, but in case of need it does not allow an easy extension.

The supine position of the patient makes it easy to control leg length and pelvic orientation. While acetabular preparation is not demanding, the femoral preparation requires an orthopaedic table, in order to exploit the hyperextension of the limb to improve the exposure.

Anterolateral mini-approach

Conventional anterolateral approach was developed by Watson-Jones in 1936 [8]. It exploits the intermuscular (but not internervous) interval between the tensor fasciae latae and the glutei medius and minimus.

The minimally invasive version, published by Bertin and Rottinger [9], is performed in lateral position through an incision directed from the greater trochanter towards the anterior superior iliac spine. The lateral decubitus position allows femoral preparation in hyperextension-adduction-external rotation of the hip, with the leg accommodated in a sterile bag on the back side of the contralateral one. This position avoids impingement between reamers or broaches and the gluteus minimus. The lateral decubitus position, however, makes it difficult to immobilize the pelvis and to evaluate the length of the limb, but ensures reduced bleeding for hydrostatic effect and a better exposure in obese patients because the subcutaneous tissue hangs away from the incision. The presence of the superior gluteal nerve at the top of the field makes a proximal extension dangerous in case of need [10], while no anatomical structure stops the distal extension.

Straight lateral mini-approach

The transgluteal approach was first decribed by Bauer and Hardinge in the late 1970s and early 1980s [11, 12]. The

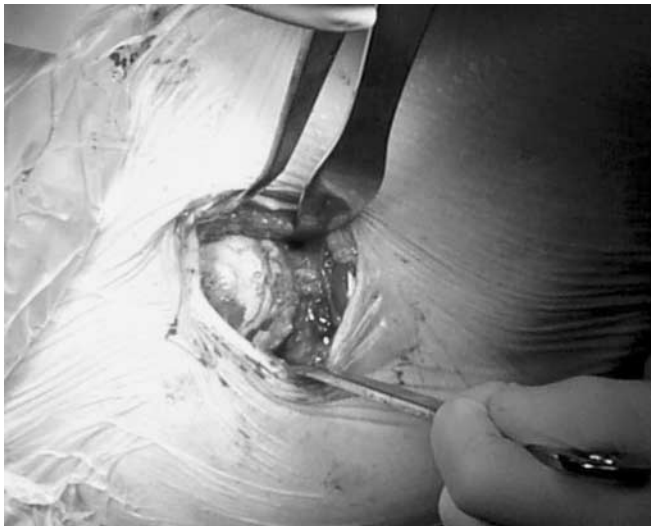

Fig. 1 Straight lateral mini-approach in supine position

traditional portal was not significantly modified while being converted to the minimally invasive version: the glutei muscles together with the vastus lateralis are split along their fibers and the anterior part of their insertion is detached from the greater trochanter to expose the joint capsule (Fig. 1).

The patient may be placed in either supine or lateral decubitus position. The latter allows better exposure and lower intraoperative blood loss for the previously mentioned reasons, but length evaluation and acetabular orientation are less accurate.

Length restoration may be helped by the transversal section of the gluteus minimus tendon, which is lately reconstructed to the previous length: since this tendon is hardly extensible, it is a useful length mark. Unfortunately this technique potentially damages the abductor mechanism.

The supine decubitus position offers many possible advantages, such as the absolute stability of the pelvis, which permits precise orientation of the prosthetic cup, the fast positioning of the patient, and easy length evaluation. Thus no transversal dissection is needed, and the whole gluteus minimus is anteriorly displaced together with the anterior part of the gluteus medius. Those tendons are kept in continuity with the vastus lateralis insertion, sparing their abductor effect [2, 13].

The skin incision is longitudinally located over the greater trochanter, but straight stems may require particular tricks to avoid any impingement between soft tissues and broaches or reamers: a slightly oblique skin incision (from posterosuperior to anteroinferior) with a longer supratrochanteric extension is useful to preserve the skin, while fascia and tendons should be incised along the midline and not anteriorly, since the posterior parts of both might impinge against femoral instruments.

The lateral approach may be safely extended both proximally and distally, since the superior gluteal nerve is 5 cm from the tip of the greater trochanter [10]. While large approaches performed in the past posed a significant risk of heterotopic ossifications and Trendelemburg limp [14], regular and minimally invasive incisions show no real difference with respect to the posterolateral approach [15, 16].

Posterior mini-approach

The posterior (or posterolateral) approach is very popular among hip surgeons for several reasons:

- Short operative time
- Need for few assistants (sometimes just one is sufficient)
- Full sight and access to the operative field for the assistants (that can better help the surgeon)
- Minimal postoperative pain
- No injury to the gluteus medius and minimus muscles (faster functional recovery without limp)
- Low risk of heterotopic ossifications [17].

Moreover, the posterior approach shares the advantages and the disadvantages of all the lateral decubitus approaches discussed previously. Specific problems such as the higher incidence of posterior dislocation, ischiadic nerve injury (especially in revision surgery) and wound infection should not be underestimated.

The traditional procedure described by Gibson in 1950 [18] underwent very few changes to be converted to the minimally invasive technique. Some authors suggested a longitudinal skin incision along the posterior border of the trochanter [19–21], while others prefer an oblique incision from the tip of the trochanter towards the posterior superior iliac spine [22]. The quadratus femoris is to be spared, while the triceps coxae and the piriformis are taken down from the femur by almost all surgeons.

Soft tissue reconstruction is an important concern, because posterior wall weakening may lead to dislocation when the patient sits. No action related to anterior dislocation is so frequent in daily life, and this probably explains the inferior dislocation rate associated with anterior, anterolateral and straight lateral approaches.

Two-incision approach

The two-incision procedure was developed by Dana Mears in 1997 and was firstly used in clinical practice by Richard Berger in 2001. It spread quickly over the world

thanks to a specific training program provided by Zimmer (Warsaw, IN, USA) [23].

The technique begins through an anterior portal centred over the femoral neck and parallel to it. The proper location of the incision is fluoroscopically checked and the Smith-Petersen interval is exploited to expose the hip. The neck is cut in situ, then the femoral head is removed and the acetabulum is reamed under fluoroscopic control. A hemispherical cup is finally impacted and secured by screws.

The second incision is performed posterolaterally to the greater trochanter, in order to ensure a straight access to the piriformis fossa and then to the femoral canal. Canal reamers are inserted through a split in the gluteus maximus, then should slide between the gluteus medius and the piriformis before entering the bone. The whole reaming needs fluoroscopic guidance as does the stem implantation. A straight stem is eventually inserted.

The anterior portal is exactly like the original anterior mini-approach, while the posterior one derives from the intramedullary nailing experience. Both being intermuscular, the functional recovery is fast and the hospital discharge is early, often in the same day of surgery or in the subsequent one.

On the other hand, important disadvantages are known [24]:

- Significant risk of complications (e.g. intraoperative fractures, nerve palsies)
- Need for intensive fluoroscopic assistance
- Demanding surgery with long learning curve
- No compatibility with conservative arthroplasties.

Conservative arthroplasties

A conservative arthroplasty is a device allowing bone preservation at the time of implantation and during future bone remodelling. The goals of bone-sparing designs are:

- Availability of bone for possible revisions
- Proximal load to prevent stress shielding and thigh pain
- Restoration of the native hip joint biomechanics to ensure the best functional performance (e.g. resistance to torsional stress, proper tension of pelvitrochanteric muscles).

Interestingly, bioengineering research about conservative prostheses focused on femoral components, while acetabular bone loss is still widely underestimated. Three main kinds of bone-sparing THR are currently available: proximal load, neck-preserving and resurfacing.

Proximal load arthroplasties

Distal fixation is known to be related to stress by-pass to the femoral shaft. This phenomenon, called “stress shielding”, causes metaphyseal bone resorption and diaphyseal cortical hypertrophy [25]. The first change negatively affects eventual future revisions, since the proximal femur becomes extremely fragile and only long stems may ensure adequate fixation. The second change is sometimes associated with thigh pain due to stress concentration at the tip of the component.

Proximal load stems have been designed according to the biomechanical model developed by Fetto et al. [26], who demonstrated that the proximal femur is loaded by compression forces both medially and laterally, thanks to the tension band effect provided by the iliotibial band.

If the lateral cortex acts as a second compression column, it can be exploited to provide a strong support against subsidence together with the medial cortex (already used by all the previous standard stems). The lateral flare, initially characterizing only the Revelation stem (Encore Medical, Austin, USA), is nowadays recognizable even in other systems. It allows loading the lateral column as well as the medial one, then realizing a true metaphyseal stress transfer. The first reports about early migration and periprosthetic bone mineral density of this stem suggested high primary stability and no significant stress protection of the proximal femur [27, 28].

Santori and Walker made the subsequent step: if the lateral flare leaves the distal part of the stem unloaded, the component might be shortened without compromising the fixation. This evolution led to the Proxima Hip (DePuy, Warsaw, USA) (Fig. 2). Five-year reports coming from the inventors are extremely interesting [29].

Fig. 2 Proximal loading short stem (Proxima, DePuy, Warsaw, USA)

Neck-preserving arthroplasties

Neck preservation is not a recent trend in prosthetic design. In 1986, Freeman explained there is no strong reason in favour of neck resection but convention, fear of impingement and risk of calcar resorption [30]. The convention mainly arises from the history of hip replacement, which began to treat femoral neck fractures; then implant designs were developed to substitute the cervical region and surgical approaches were studied to ensure direct access to the medullary canal [31].

Impingement is a realistic concern if the femoral neck is retained, as head-neck ratio decreases. Two solutions are available to avoid a restricted range of motion and dislocation: reducing the angle subtended by the cup and increasing the head diameter. In the past only the first solution was exploited, because metal-on-polyethylene tribology did not allow high diameters. Thus low-profile cups and biequatorial cups were designed to permit neck retention [30, 32]. Nowadays, ceramic-on-ceramic and metal-on-metal bearings make the second solution feasible too.

Calcar resorption, feared because of the vascular injury resulting from surgical exposure and femoral preparation, is actually extremely infrequent and, whenever it happens, extremely limited [30, 33].

While the reasons to resect seem to be weak, the reasons to preserve – listed above – appear to be several and relevant [16]. Whiteside et al. [34] demonstrated with an experimental test on cadaver hips that neck retention significantly increases the torsional load-bearing capacity of the femoral component. Since torsional stresses are considered particularly dangerous for the primary stability of the stem, these authors recommended neck preservation (at least of the lateral half).

As to stem designs, the most widely known neck-retaining implants are the CFP (Waldemar Link, Hamburg, Germany) and the Mayo Conservative Hip Prosthesis (Zimmer, Warsaw, USA).

The first device, developed by Pipino, is an anatomical comma-shaped stem. It is made of titanium alloy, and has collar and hydroxyapatite coating in the proximal two thirds (Figs. 3, 4). The anteversion is 14° and the radius of curvature may be short or long, according to the patient's femoral anatomy. The early version of this stem, the so-called Biodynamic Prosthesis, made of Cr-Co-Mb, achieved interesting results: good and excellent outcomes in 82% of cases at the 13- to 17-year follow-up of 44 implants [33].

The Mayo stem, developed by Morrey, represents a completely different design, being a wedge-shaped titanium-made prosthesis studied to engage the proximal femur through a 3-point contact [35]. Tsao et al. [36] recorded satisfactory results in 31 young patients (25–50 years of age), but reported 3 intraoperative perforations of the lateral cortex.

Fig. 3 Neck-retaining stem (CFP, Waldemar Link, Hamburg, Germany)

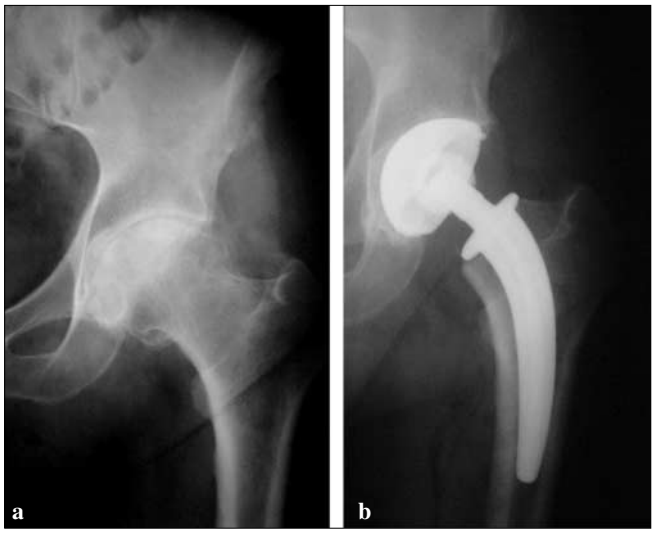

Fig. 4a, b *Neck-retaining total hip replacement*. **a** Preoperative radiogram. **b** 3-year-postoperative radiogram

Resurfacing arthroplasties

Resurfacing is not a new concept. The first generation of these devices was developed about fifty years ago by Charnley (1951), Townley (1960) and Muller (1968). Even though these first experiences were not published,

Fig. 5 Third-generation resurfacing (ReCap, Biomet Manufacturing)

their results were so unfavourable to induce the authors to give up the procedure. In the 1970s the second generation of surface arthroplasties (Gerard, Paltrinieri-Trentani, ICLH, Tharies, Wagner) achieved better but not satisfactory results, likely because the metal-on-polyethylene bearing was not suitable for large femoral heads [37–41].

Nowadays, third-generation resurfacing devices are available (Fig. 5). The main features of these implants are:

- Metal-on-metal bearing
- Short cervical stem
- Hybrid fixation (cemented femoral cup and uncemented acetabular cup).

In 2003, McMinn reported only 7 reoperations in a series of 1209 Birmingham Hip Resurfacing prostheses (Smith & Nephew, Cambridge, UK) implanted from 1997 to 2001 [42]. In 2004, Daniel et al. reviewed a series of 440 hips in patients under 55 years of age: after a mean follow-up of 3.3 years, only one hip had been revised (0.02%) and 87% of the patients participated in sporting activities [43]. In 2004, Amstutz et al. [44] reported a 4-year survival rate of 94.4% among 400 surface replacements in young patients (48 years of age on average).

Not all Authors agree about these outcomes. In particular, concern about postoperative subcapital fractures arose from an article published in 2005 by Shimmin and Back [45]. They analysed all the 3497 Birmingham hip resurfacings performed in Australia from 1999 to 2004 by 89 surgeons, and reported 50 neck fractures (1.46%). Mean time to fracture was 15.4 weeks, and the most important risk factors turned out to be female sex, cervical notching, varus position of the stem and technical problems like difficult exposure in obese patients.

Discussion

The mini-incision trend has brought some important developments in total hip replacement, especially a renewed interest about surgical approaches. Trying to reduce wound length, surgeons are induced to eliminate unnecessary dissection and to improve the placement of the incision. No mini-approach is absolutely original, since they all derive from a corresponding conventional version through a refining process, but the process itself reflects a positive tendency. The only exception is represented by the two-incision technique, but it is a partial exception, as it regards only the posterolateral portal. Apart from the theoretical evolution, the real advantages of the minimally invasive procedures are still to be fully demonstrated.

Wenz et al. [20] compared 65 THRs through direct lateral approach with 124 THRs through posterior mini-approach. The perioperative outcomes of the mini-incision group turned out to be significantly better as to the overall blood loss (598 vs. 727 ml on average), transfusion rate (1.6 vs. 2.4 units each on average) and recovery speed (three times more mini-incision patients than conventional incision ones could ambulate on post-operative day 1). The length of stay was slightly shorter in the mini-incision group, but the difference was not statistically significant. These results should not be overemphasized, since the control group does not seem to represent the traditional lateral approach, the mean lateral incision being longer than 25 cm and the mean operative time being 164 minutes (40 minutes longer than the mini-incision procedure). Interestingly, this study showed no significant difference in mini-incision THR between obese and non-obese patients as to component alignment (but operative time and blood loss were significantly higher). This result is consistent with the hypothesis that lateral decubitus position induces a favourable displacement of fat tissue, allowing easier implantation in obese patients.

Wright et al. [46] compared 42 mini-incision THRs with 42 conventional THRs, following them for 5 years. Both procedures were performed through posterior approach. Blood loss and hospital stay did not differ significantly, while the postoperative Hospital for Special Surgery score was just slightly better in the mini-incision group. The authors inferred that mini-incision advantages are mainly cosmetic.

The same conclusion was achieved by Woolson et al. [3] after having retrospectively evaluated 135 primary

THR, 50 performed through posterior mini-incision and 85 through posterior standard incision. Although the mini-incision group was selected as to body mass index and American Society of Anesthesiologists score (mini-incision patients were substantially slimmer and healthier), no significant improvement was recorded. On the other hand, wound complications and component malpositions were more frequent in this group than in the control one.

There are fewer published reports about lateral mini-approach than about posterior mini-approach. A retrospective study by O'Brien and Rorabeck [47] inferred that the minimally invasive procedure is safe, since it does not increase the complication rate and does not hinder correct component positioning. Functional recovery was not strictly addresses by these Authors. De Beer et al. [48] did not find any difference even in recovery speed, supporting the conviction that mini-incision leads only to cosmetic advantages.

We found no comparative assessment of anterior and anterolateral approaches, probably because their use has been diffusing just recently.

The minimally invasive versions of traditional posterior and lateral approaches are showing not to give any dramatic benefit but a cosmetic appeal. Anyway, they do not compromise the results and their use can eventually be encouraged for young women.

While incision length is a matter of aesthetics, deep dissection may really influence the functional outcome of the replacement. From this point of view, the posterior mini-approach should be performed sparing the quadratus femoris insertion and repairing the capsule and the other external rotators to the bone, to ensure a higher posterior stability. On the other hand, lateral mini-approach ought to be developed through a pure longitudinal split of the gluteil muscles. Every attempt should be made to avoid detaching the gluteus minimus (preferring the supine position over the lateral one). At the end of the procedure, the anteriorly displaced intermediate tendon needs to be secured to the trochanter with resistant trans-osseous stitches, in order to obtain the functional restoration of the abductor mechanism.

The most recent anterior and anterolateral mini-approaches better fit the concept of TSS, because they exploit anatomical intervals without any muscular injury. Obviously the theoretical advantages need to be confirmed by prospective trials, since both procedures appear to be demanding and technical errors might compromise the overall outcome.

The two-incision procedure came out to be extremely safe and effective only in the hands of the surgeons who had developed it. Berger et al. [23] published in 2004 the early results of the "MIS 2-incision technique" combined with an accelerated rehabilitation protocol: 97% of 100 patients reached the goals required for discharge on the day of surgery, the remaining 3% the day after. All assistive devices were abandoned in 9 days on average. No patient was reoperated or readmitted [23]. Unfortunately these results were not reproduced by other Authors. An index case study sponsored by Zimmer and based on data collected from 159 surgeons trained with the Zimmer program showed a long learning curve without significant decrease of major complications in the first ten cases [24]. Among the reported 851 procedures, 35 patients (4.1%) sustained a calcar fracture, 11 (1.3%) a shaft fracture, 9 (1.1%) a greater trochanter fracture, and 7 (0.8%) a cortical perforation. Twenty-seven cases (3.2%) developed a nerve deficit. Regardless of the cause, 8 patients (0.9%) needed to be reoperated. Mean operative time was 148 minutes and mean fluoroscopy time was 2 minutes. Bai et al. [49] reported even worse perioperative outcomes: 10% of 89 patients needed further surgery for fracture, recurrent dislocation, infection or early loosening and 25% sustained an injury of the lateral femoral cutaneous nerve. Finally, an anatomical study performed on cadavers showed that the two-incision procedure leads to wider muscle damage than the posterior mini-approach; femoral percutaneous reaming was found to be associated with significant injury to glutei muscles (medius and minimus) and to the external rotators [50].

On the basis of these data, the direct lateral and the posterior mini-approaches turn out to be the safest techniques for minimally invasive total hip arthroplasty.

As to implants, an important difference should be noticed between proximal load arthroplasties and other conservative designs. The former do not allow relevant bone preservation at the time of surgery, but their proximal transfer of stresses is expected to avoid late decrease in periprosthetic bone density. Thus, the bone-sparing effect of these devices is related to long-term results. Leali and Fetto [28] reported a mean increase in bone mineral density (BMD) of 3% at 52 weeks around a stem with lateral flare. In detail, the BMD was decreased less than 5% in the critical Gruen zones I and VII, while it was significantly increased in all the other regions. These data are remarkably better than those reported for conventional stems [51].

Neck-preserving and resurfacing implants permit to spare bone at the time of surgery. Their designs warrant analogous protection against stress-shielding, because short stems and cervical fixation should transfer the load as proximally as possible [52].

In conservative replacement, the femur has been more addressed than the acetabulum, although acetabular loosening is much more common than stem loosening and for the same reason the acetabular bone loss is a considerably bigger concern.

Low-profile cups have reduced the depth of reaming required for implantation, but the lower depth can not com-

pensate the higher radius of the resurfacing cups. In facts, heads can not be reduced because of notching risk, and corresponding acetabular sizes are 6–8 mm bigger (depending on the type of implant), since thinner cups would not be stiff enough for metal-on-metal bearing. This constant relationship between femoral and acetabular size forces the surgeon to over-ream the socket in order to achieve the required diameter. Loughead et al. [53] showed that resurfacing cups are significantly bigger than conventional cups (56 vs. 52 mm on average) and supplementary bone removal is greater in larger patients. Crawford et al. [54] compared the surgery-related bone loss between a standard cementless cup and a resurfacing cup on artificial pelvis. The mean acetabular bone loss was 311.1% higher in resurfacing than in conventional replacement. This structural problem, together with postoperative fractures, contributes to limit the actual use of surface replacement.

In our opinion, neck-retaining implants actually offer the best compromise between femoral and acetabular preservation, as head sacrifice allows to implant regular, or favourably low-profile cups without any need to over-ream. Moreover, sparing the neck allows easy medial access to the femur (without risk of gluteal damage) if compared with traditional straight stems, while removing the head permits performing remarkably smaller incisions. Unfortunately most of these systems are still provided only with standard heads and ceramic-on-polyethylene bearings. The future introduction of large heads with polyethylene-free tribology might increase range of motion and joint stability.

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