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Preservation of the femoral neck in hip arthroplasty: results of a 13- to 17-year follow-up

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Abstract In prosthetic surgery of the hip, it is important to remove only the pathological tissues, preserving as much as possible the osteo-articular architecture, in particular the femoral neck and the subchondral cancellous acetabulum. This allows the bone to easily adapt to the new biomechanical situation created by the prosthesis. Our long-term study of patients who underwent total hip replacement has confirmed such presuppositions. For this study, we used a biodynamic prosthesis, composed of a Lord hemispheric screwed cup with a biequatorial liner and an anatomical stem in Cr-Co-Md with a completely madreporic surface. This prosthesis is ideally configured to preserve the femoral neck. We followed 44 prostheses for 13–17 years. The clinical results were excellent or good in 82% of cases. Thigh pain, reported in only 14% of cases, spontaneously resolved. The mobility of the prosthetic hip and the consequent functional recovery were excellent, since conserving the neck re-stabilized the natural off-set, providing good equilibrium of the hip and the periarticular muscles. Radiographic analysis revealed survival of the femoral neck in approximately 80% of cases. The madreporic surface, when associated with correct positioning of an undersized stem, allowed for osteointegration with significant bone remodeling in the long term. Distal cortical hypertropy, found in 48% of cases, made it necessary to limit the madreporic surface finish to the stem's proximal two-thirds, leaving the distal one-third smooth.

Key words Total hip arthroplasty • Femoral neck preservation • Biequatorial liner • Madreporic surface

Introduction

In prosthetic surgery of the hip, the primary strategy advocated by us is to remove only the pathological tissue (femoral head, cartilage of the facies lunata acetabuli, osteophytes and geodes), while preserving and utilizing the healthy tissues. The most important advantage of preserving the osteo-articular architecture is that, afterwards, the body has only to adapt to the new biomechanical situation created by the prosthesis; this favors both osteointegration and, above all, bone remodeling [1]. In this way, the prosthesis does not substitute the joint, but integrates with it. Therefore, one may call this type of hip replacement "conservative" [1].

Conservative hip replacement requires both cortical bone for primary stability and cancellous bone for bone growth and for the distribution of loads along the trajectory system. Therefore, the hip structures "to conserve", according to the preceding arguments, include the femoral neck and the subchondral cancellous lamina of the facies lunata acetabuli.

The advantages that derive from conserving the femoral neck and the subchondral cancellous acetabulum are: maximizing the triplanar mechanical stability, maintaining the bone stock and optimizing the distribution of the mechanical loads [2–6].

Materials and methods

During the 5-year period 1983–1987, we performed 56 consecutive total hip replacements using an approach which conserved the femoral neck. All prostheses were implanted using an anterolateral approach. At 20 days from surgery, patients were permitted to apply a partial load to the hip; on the sixtieth day they began to apply a full load. In the period 1999–2000, we evaluated the long-term status of 44 (78%) prosthesis in 40 patients, of which 4 had been operated bilaterally.

Prosthesis

We used a biodynamic prosthesis. The modular cup of this prosthesis is composed of a Lord hemispheric screwed shell of Cr-Co-Md alloy. The cup contains a biequatorial polyethylene liner, i.e. there is a 20° dissociation between the external and internal equators (Fig. 1). This allows the cup to be installed with an inclination of 55° ± 5° on the horizontal plane, just like the natural acetabulum. The prosthesis does not excessively intrude or protrude, and at the same time the orientation of the internal cavity is 35° ± 5°, as required by a correct implant. This strategy preserves the lamina of the subchondral cancellous acetabulum.

The anatomical stem of the prosthesis is made of Cr-Co-Md alloy, with a completely madreporic surface. The stem is configured to conserve the femoral neck, with a medial curve corresponding to the average femoral curve; the anteversion angle is 12°. The stem is available in 3 sizes (small, medium, large), and in right and left versions. The collar of the stem is elliptical, the head is 26 mm in diameter, and the neck is available in 3 lengths.

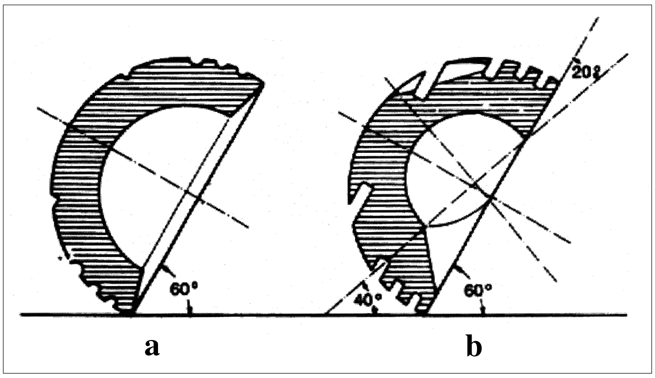

Fig. 1a,b *Biequatorial dissociation of the prosthesic cup.* Compared with a traditional cup (**a**), the biequatorial one (**b**) shows a 20° dissociation between the joint external (55° ± 5° inclination) and the internal equators (35° ± 5° inclination) in comparsion with the horizontal ones

Follow-up radiographic analysis

At the long-term follow-up, we examined the cup and stem radiographically to appraise the specific conditions of the femoral neck. In particular, we evaluated the 3 quadrants of the cup according to Charnley [7] and the 7 zones of the stem as described by Gruen [8]. We further distinguished Gruen's zone 1 into areas a and b (in proximal-distal sense) and zone 7 into areas a and b (in distal-proximal sense).

Results

To verify the importance of conserving the femoral neck during hip replacement, we examined the long-term clinical and radiographic results of a series of patients treated by us in the period 1983–1987 [9] and re-examined in 1999–2000. The follow-up period was 13–17 years. Of the original 56 implants, we were able to re-evaluate at follow-up 40 patients (78%), including 4 operated bilaterally (total, 44 prostheses). Of these patients, 26 were women (59%) and 18 were men (41%). The average age of the patients at operation was 62.5 years (range, 59–69 years). Hip replacement was performed predominantly on the left side (25 cases) in comparison to the right (19 cases). The prevailing diagnosis was of coxarthrosis (41 cases, 93%); other hip replacements were performed for rheumatoid arthritis (2 cases, 5%) and for dysplastic coxarthrosis (1 case, 2%).

The immediate post-operative outcomes were determined radiographically (Table 1). The inclination of the cup on the horizontal plane, a function of the biequatorial liner, was 50°–60° in 26 cases (59%), less than 50° in 16 cases (36%) and greater than 60° in 2 cases (5%). The cup

Table 1 Post-operative X-ray data

	Cases, n	(%)
Cup inclination		
50°–60°	26	(59)
< 50°	16	(36)
> 60°	2	(5)
Cup depth		
Normal	31	(70)
Deeper	4	(10)
Less deep	9	(20)
Stem position		
Normal	34	(77)
Varus	4	(09)
Valgus	6	(14)
Stem size		
Templated	22	(50)
Undersized	19	(43)
Oversized	3	(7)

depth, a function of the conservation of the bone stock, was correct in 31 cases (70%), excessive in 4 cases (10%) and protruding from the acetabulum in 9 cases (20%). In these later cases, 1–2 screw threads were uncovered. The stem position was normal in 34 cases (77%), varus in 4 cases (9%) and valgus in the remaining 6 cases (14%). The stem size was templated in 22 cases (50%), while in 19 (43%) it was undersized and in 3 cases (7%) it was oversized with tip wedging.

Neck preservation was obtained in all cases, although to different extents. In fact, in reference to the lateral portion which we consider to be the most discriminating criterion, the distance from the osteotomy to the edge of the greater trochanter varied from 5 to 25 mm.

The clinical results at the long-term follow-up were evaluated using the scale of Harris (Table 2) [10]. The outcome was excellent for 16 implants (37%), good for 20 (45%), fair in 6 (14%) and bad in 2 (4%). Thigh pain was reported by 6 patients (14%) in the immediate post-operating period; it lasted for about 1 year and then completely and spontaneously resolved.

The radiographic results at the long-term follow-up are reported in relation to Charnley's 3 quadrants of the cup [7] and to Gruen's 7 stem zones [8] (Table 3). On radiographic analysis, the cup showed areas of radiolucency in 6 cases (14%). In 2 of these cases, the radiolucency was 1 mm thick in quadrants 1–2, while in 4 cases it was continuous in the 3 quadrants, of maximum thickness 2 mm. In an additional 2 cases (4%), there was detachment with mobilization of the acetabular component. There were no cases of osteolysis.

Radiolucency was evident in the stem at follow-up in 3 cases (7%) in zones 1, 2 and 7, with thickness not superior to 3 mm. There was no case of loosening. Demarcation lines, present in 14 implants (32%), were primarily located in zones 1a-b, 2, 6 and 7a-b and were sometimes around the whole stem (Fig. 2).

Among the more frequent and important radiographic signs, cortical hypertrophy was present in 21 cases (48%) (Fig. 3), primarily in distal zones 3 and 5. In 6 of these cases, there were also clear signs of stress shielding, or proximal atrophy, prevalently in zones 1 and 7. In 2 cases (5%), distal cortical hypertrophy was associated with a pedestal in zone 4. In 1 further case (2%), there was complete cancellization of the cortical bone in all 7 zones.

Table 2 Harris hip score at follow-up

	Cases, n	(%)
Excellent	16	(37)
Good	20	(45)
Fair	6	(14)
Poor	2	(4)
Total	44	(100)

Table 3 X-ray results at follow-up

	Cases, n	(%)
Cup		
Radiolucency	6	(14)
Loosening	2	(4)
Osteolysis	0	(0)
No abnormalities	36	(82)
Stem		
Radiolucency	3	(7)
Loosening	0	(0)
Demarcation line	14	(32)
Osteolysis	4	(9)
Pedestal	2	(5)
Cortical cancellization	1	(2)
Cortical hypertrophy	21	(48)
Calcat round-off	12	(27)
Spot weld	24	(55)
Neck structural changes	10	(23)
Complete (zones 1–7)	3	
Medial (zone 7b)	4	
Lateral (zone 1a)	3	

Fig. 2 Radiogram of the biodynamic prosthesis at a 16-year follow-up shows the presence of demarcation lines, prevalently in zones 1–5 with calcar round-off

Fig. 3 Radiogram at a 15-year follow-up shows cortical hypertrophy in zones 3 and 4 with demarcation lines in zones 1 and 2

The most important observation at follow-up was the survival of the femoral neck, i.e. the conservation of its morphology and structure, in 34 (77%) cases (Fig. 4). In contrast, structural alteration of the neck (Fig. 5) was observed in 10 cases (23%). In 3 implants (7%), there was complete alteration, both medially (7b) and laterally (1b), with an average 5-mm reduction of neck length in comparison to the post-operative length. In 3 further cases (7%), the alteration occurred only laterally (1a) for an average of 3 mm, while in 4 cases (9%), it occurred only medially (7b) for an average of 5 mm. In the latter cases, the neck alterations were attributable to osteolysis from debris. Calcar round-off in zone 7b was evident in 12 implants (27%).

Fig. 4a,b Radiogram at a 13-year follow-up shows an undersized but axially positioned stem. The femoral neck is intact and spot welds are evident in zones 2-6. **a** Antero-posterior position. **b** Axial position

Fig. 5a,b Radiogram at a 13-year follow-up in which the stem is proven to be biodynamic and oversized with distal wedging. The cortical hypertrophy in zones 3-5 corresponds to a structural alteration of the neck in zones 7a,b with proximal stress shielding. **a** Antero-posterior position. **b** Axial position

Finally, spot welds, i.e. a framework of cancellous bone oriented from the stem toward the cortical bone in proximal-distal sense along the lines of force transmission, were observed in more than half of the cases (24 implants, 55%). This sign was seen prevalently in zones 2, 3, 5 and 6 (Figs. 6–8). Typically, there were 2 spot welds, oriented from the tip of the stem toward the cortical bone. The spot welds were present in both appropriately sized and undersized stems. We considered these signs to be evidence of good bone remodeling and a favorable radiographic result.

Fig. 6 Radiogram at a 15-year follow-up shows normal-sized stem in axial position with spot welds in zones 2, 3, 5 and 6

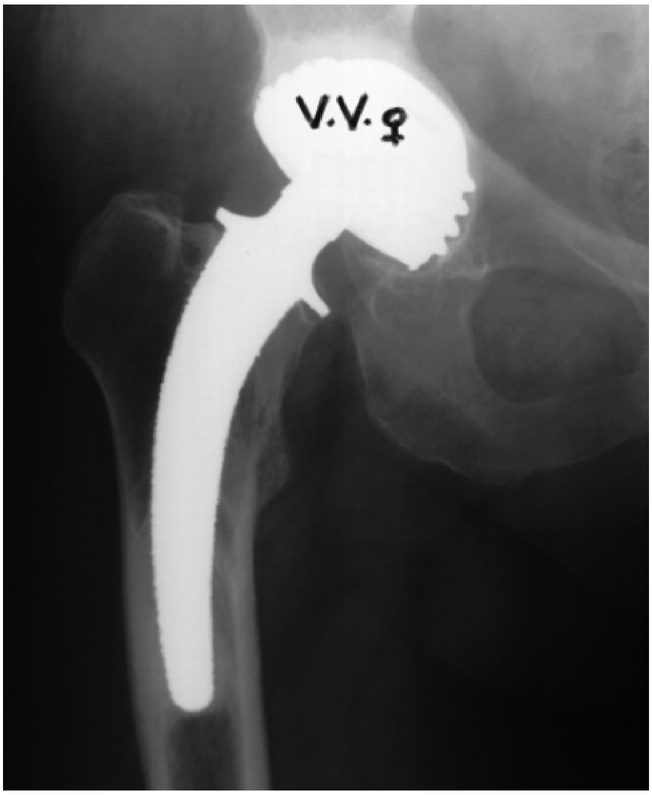

Fig. 7 Radiogram at a 13-year follow-up reveals spot welds in zones 3 and 5

Fig. 8 Radiogram at a 13-year follow-up reveals spot welds in zones 3-5

Discussion

A long-term analysis (over 10 years) was carried out on 44 (78%) implants out of an original case population of 56; 12 cases were lost to follow-up. The clinical results were excellent in 37% and good in 45% (total of excellent and good of 82%), fair in 14% and bad in 4%. In these last 2 cases, there was detachment and migration of the cup. Thigh pain was experience by 6 patients, although in all cases it spontaneously resolved within 1 year. Among the patients with thigh pain, 1 had an oversized stem with consequential tip wedging, while 5 had undersized, varus stems. In 3 of these last cases, radiography showed demarcation lines associated with cortical hypertrophy in zones 3 and 5. Therefore, we interpreted thigh pain to be an expression of transitory instability of the stem more than a phenomenon correlated to tip wedging.

Clinically, the case series at follow-up was characterized by good mobility of the prosthetic hip and excellent functional recovery. The biodynamic prosthesis, which preserves the femoral neck, re-establishes the natural off-set; this leads to good equilibrium of the hip and to correct tension of the medial and pelvitrochanteric muscles. Preservation of the femoral neck maintains its length and angle (the off-set and the lever arm of the lateral gluteus muscles are identical to the anatomical conditions) and conserves the force equilibrium between the lateral pelvitrochanteric muscles (musculi gluteus minimus and maximus) and the medial transverse muscles (extrarotatory muscles). In this manner, joint equilibrium is correctly maintained between the force of gravity J (which passes through the hip's center of rotation) and the muscular force M (Fig. 9) [11].

Changing the length or angle of the femoral neck has an important effect on hip forces, because of alterations in the moment-arm of the muscles and in the direction of the load. In fact, a varus femoral neck increases the lateral tension and decreases the joint force; in contrast, a valgo neck decreases the lateral tension and increases the joint force. Furthermore, when the neck is shorter, tension force is reduced; as a result the lateral muscle tension decreases and the joint force increases. Therefore, sacrificing the femoral neck during hip replacement brings the femur closer to the long axis of the body, reduces strength M of the abductor and extrarotatory muscles, and increases force J on the hip joint (Fig. 10a). In contrast, maintaining the femoral neck preserves the forces of the abductor and extrarotatory muscles; this leads to an equilibrium which maintains force J (Fig. 10b) and reduces the wear [12].

We believe, for reasons given in the preceding paragraphs, that there was a significant reduction in wear of the polyethylene liner in our case series. As a result, there were few cases of osteolysis induced by debris (only 9%), the forces on the cup were reduced, and the directions of the loads were improved. This optimized the mechanical situation and the interface of prosthesis with bone. This mechanical situation is likely responsible for the good radiographic and clinical results observed after more than 10 years. Our results using

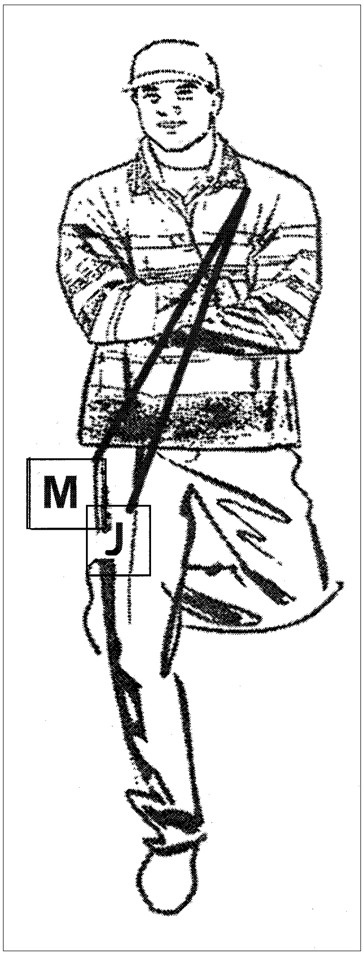

Fig. 9 Joint force (*J*) and muscle force (*M*) are kept in equilibrium when the femoral neck is preserved. (From [9] with permission)

the Lord screwed cup contrast with mid- and long-term results reported in the literature for screwed cups [13]. The biequatorial nature of the polyethylene liner [14] is also an important factor in determining outcome. The liner, which makes the articular rim more horizontal, contributes to reducing wear and debris, and increases contacts between the prosthesis head and the inside cavity of the cup.

By radiographic analysis, we found the structure of the femoral neck to be conserved at the long-term follow-up in 77% of cases, while in only 10 implants (23%) there was a structural alteration. Among these, 3 cases (7%) showed a reabsorption of the whole circumference of the neck, while in the other 7 (16%) it occurred only in the lateral or medial zone, prevalently in zone 7b. We interpreted the 4 cases of structural neck alteration in zone 7b to be osteolysis by debris, because the change was on average 5-mm thick and because the radiographic characteristics were not ascribable to alterations of mechanical origin. The calcar round-off observed in 12 implants (27%) is instead a phenomenon common to all cementless prostheses; it may be the expression of a scarce compression of the medial portion of the collar on the calcar femorale after the primary stability phase.

We conclude that the femoral neck survives and preserves its structure in approximately 80% of cases. Its reabsorption correlates to the position and dimensions of the stem, the totally madreporic surface, and the wear debris disease.

In a rather elevated percentage of cases (43%), the stem was undersized, i.e. with a space greater than 2 mm between the inferior third of the stem and the cortical bone of the femur. This result is not completely negative and is important

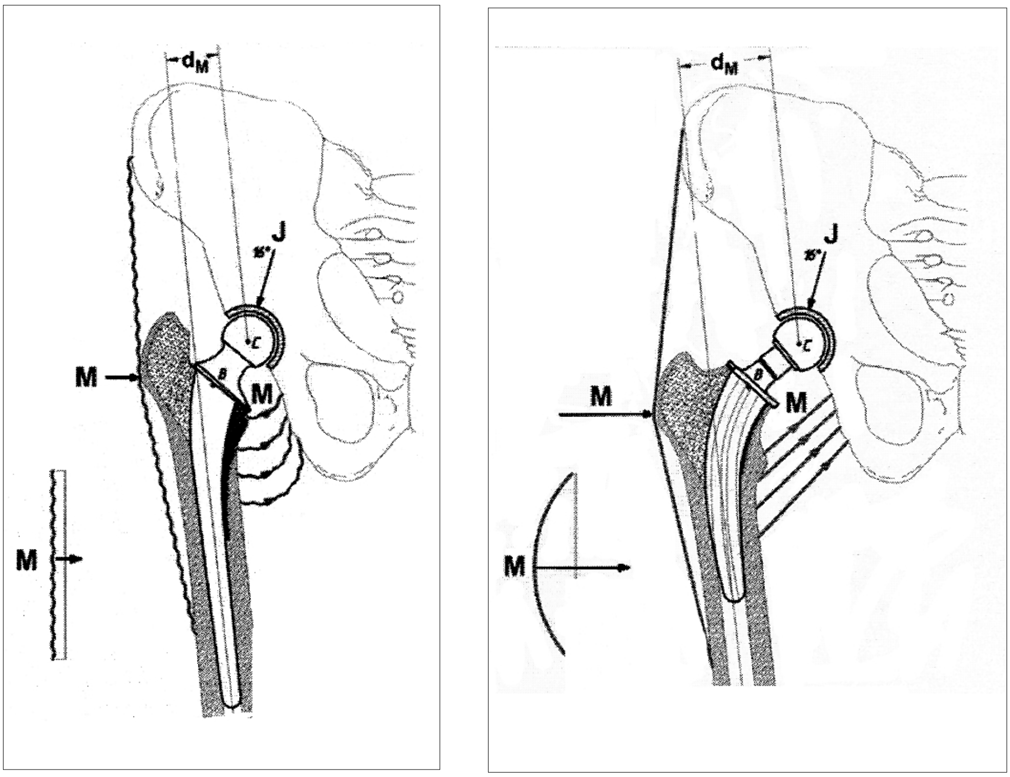

Fig.10a,b The equilibrium condition of the prosthetic hip without (**a**) and with (**b**) maintenance of the femoral neck. *J*, joint force; *M*, muscle force; *C*, center of rotation; *B*, osteotomy line; d_M, stem off-set. (Courtesy of Waldemar Link GmbH & Co, Hamburg) for the interpretation of the demarcation lines in 32% of the stems. There is, in fact, a correspondence between undersized stems and demarcation lines, observed in the varus implants in zones 1a-b and 2. These demarcations lines represent the radiographic expression of an initial transitory instability of the stem, with a relative excess of micromotion. This induces, in the first phases of osteointegration, a temporary arrest of osteocondution, with formation of fibrous tissue in the interstices and consequent formation of periprosthetic density lines. When the instability is minor and transitory (for self-blocking phenomena of the stem), the process of osteocondution actually recommences, to allow secondary biological stability to establish. The space between the density line and the conversion layer of the stem will appear radiographically to be filled by non-organized bone. When instead instability proceeds and the micromotion increases beyond 30–50 µm, the radiograph will demonstrate true radiolucency. This latter situation is a true expression of instability and fibrous ingrowth that leads to loosening, while the demarcation line is the radiographic sign of a temporary interruption of osteocondution with secondary, non-fibrous or only partly fibrous, mechanical stability.

In the 3 cases (7%) with oversized stems, wedging of the porous tip caused phenomena of stress shielding in zones 1 and 7 and circumferential cortical hypertrophy in zones 3 and 5. Such hypertrophy, in absence of tip wedging, manifested in a greater number of cases (21, 48%) in zones 2, 3 and 5. In particular, in these last cases the cortical hypertrophy in zone 2 correlated, according to us, to the biomechanics of the prosthesis with neck conservation, which induces a distribution of the compression forces toward the lateral cortical bone in zone 2. This phenomenon also occurs with other conservative prostheses, such as the “disk compression” and the “conservative hips” prostheses.

There was only one case of cancellization and periprosthetic atrophy in all zones, a controversial phenomenon which is difficult to interpret. We propose that stress shielding be considered a phenomenon consequent to stiffening of the femoral sector containing the stem, in comparison to the lower femur.

Bone remodeling was evaluated from the presence of spot welds. We considered, as a positive outcome, cases of remodeling when the cortical bone of the periprosthetic femur in the metaphyseal and diaphyseal zones assumes homogeneous thickness (equal to that of the normal, contralateral femur), without hypertrophy or atrophy. This physiological aspect of the femur, observed in 55% of our cases, was associated with the presence of spot welds. These are therefore the expression of the mechanical role of cancellous bone, organized in trajectory systems for force transmission and for connecting the prosthesis to the cortical bone. The spot welds were particularly evident in undersized, normally positioned stems, with the tip in the center of the medullary cavity in both planes, where they fill the excessive space between prosthesis and bone, leading to biological stability.

In conclusion, a normal-sized and axially positioned stem represents the ideal condition. The oversized stem represents the worse mechanical situation, while the undersized stem induces atypical and particular remodeling but not implant failure. When associated with a varus stem, this situation provokes radiolucency in zones 1b and 2. As we showed previously [6], the neck-conserving approach, when attempted with an undersized stem, leads to a slight increase in micromotion in the anteroposterior and lateral directions, particularly for torsional movements.

This clinical and radiographic long-term study has confirmed, in a retrospective manner, that which was done prospectively: to limit the extent of the madreporic surface to the proximal two-thirds of the stem, leaving the distal third smooth; to modify the stem’s materials (using titanium), and the stem’s geometric parameters, including the antetorsion angle (14°) and to create longitudinal grooves to increase the contact of the prosthesis with the cancellous bone and to increase the overall stability.

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