Proximal bone remodelling differed between two types of titanium long femoral components after cementless revision arthroplasty

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Abstract In revision surgery with proximal femoral bone loss, progressive bone atrophy due to stress shielding remains a concern. We compared 2-year radiological results between two types of cementless long titanium stems with different configurations and surface coatings. Of 17 hips implanted with a wholly hydroxyapatite-coated stem, 12 (71%) exhibited stress shielding of the second degree or higher according to Engh's criteria, and the mean relative bone mass index decreased from 22.1% pre-operatively to 14.6% at 2 years post-operatively. In 23 hips implanted with a sand-blasted, conically shaped stem, no hip showed stress shielding of the second degree or higher. The mean relative bone mass index increased from 21.6% to 31.4%. These results indicate that the configuration and surface coating of the stem have a significant influence on proximal bone remodelling after revision surgery.

Résumé Dans la chirurgie de révision de la hanche le mécanisme de stress shielding entraîne une perte de substance osseuse fémorale avec atrophie corticale. Nous

avons comparé les résultats radiologiques à deux ans de deux types de prothèses sans ciment en titane avec différents effets de surface. Dans 17 hanches complètement recouvertes d'hydroxyapatite, 12 d'entre-elles (71%) montrant un stress shielding de grade II ou plus selon les critères de Engh avec une densité osseuse qui a diminué de 22.1% en préopératoire à 14.6% à 2 ans post-opératoire. Sur 23 hanches prothésées avec une prothèse de type conique en titane sablée, il n'y a pas eu de stress shielding de second degré ou plus. La densité osseuse a augmenté de 21.6% à 31.4%. Ces résultats montrent que la forme et l'effet de surface de la pièce fémorale ont une influence significative sur le remodelage osseux proximal après une chirurgie de reprise de hanche.

Introduction

Use of total hip arthroplasty (THA) to treat hip diseases often produces successful clinical outcomes with marked pain relief and functional recovery [3, 9, 23]. However, loosening of the components, with or without osteolysis, remains a common problem. In revision surgery after failure of femoral components, it is often difficult to achieve initial stable fixation of the components using conventional proximally coated stems, due to severe bone loss in the proximal part of the femur [12, 16, 25]. One technical option for such challenging cases is use of a long cementless stem, which reliably achieves strong fixation in a relatively intact femoral diaphysis. Using such diaphysal locking components, several investigators have obtained favourable mid-term outcomes of revision surgery for failed total hip arthroplasty [2, 6, 7, 9, 17, 19, 20, 24, 27].

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There are theoretical reasons for concern when using a long cementless stem in revision surgery. Although rigid fixation may be obtained in the femoral diaphysis, it is likely to evoke stress shielding and lead to progressive bone atrophy in the proximal region of the femur [6, 8, 19, 20]. Further bone resorptive change due to stress shielding in the damaged proximal femur after revision surgery may cause severe bone loss and lead to difficulty if further revision surgery is required. In clinical reports, there is controversy as to whether proximal bone remodelling occurs after implantation of diaphysial locking components. Some investigators have reported progressive bone resorption after revision surgery [6, 20], whereas others have reported favourable bone restoration in the proximal part of the femur [2]. These conflicting results may be partly due to differences in configuration and surface coating of the diaphysial locking components. We used two types of cementless titanium components with different configurations and surface coatings to perform revision THA to treat patients with femoral defects. The purpose of this study was to retrospectively compare bone remodelling patterns of those two types of long cementless stems.

Materials and methods

From 1988 to 2002, a total of 44 cementless revision THA procedures were performed to treat 41 patients at our institution, using two types of long titanium femoral stems. The reasons for the revision were aseptic loosening of the stem in 32 hips, stem fracture in 1 hip and cup loosening in 11 hips.

Twenty cementless femoral revisions (19 patients) were performed using the PerFix mid-sized stem (Mid-stem, Kyocera, Kyoto, Japan), which is a wholly hydroxyapatite (HA)-coated cementless stem. The Mid-stem is made of titanium alloy (Ti6Al4V) with an inert gas shielded arc sprayed surface covering the proximal one-sixth of the stem. It has the advantage of anchoring at the interface between titanium and HA [14]. It is available in lengths of 145–175 mm.

Twenty-four cementless femoral revisions (22 patients) were performed using the Wagner self-locking revision stem (Wagner stem, Centerpulse, Zurich, Switzerland), which is designed for cementless implantation by conical anchorage in the medullary canal of the femur. The Wagner stem is made of titanium alloy (Ti6Al4V) with a sand-blasted surface, is conically shaped with an angle of 2°, and has eight sharp longitudinal ribs that cut into the bone during implantation and guarantee rotational stability. It is available in lengths of 190–265 mm in Japan.

Both components provide strong initial fixation in the diaphysial area of the femoral bone. The Mid-stem was

used in all revisions performed before 1999, and the Wagner stem was used in all revisions performed after 2000. In revisions performed in 1999 and 2000, the choice between the Mid-stem and Wagner stem was made at random.

The patients were followed up annually post-operatively, and four were excluded from the study due to failure of follow-up. The Mid-stem group comprised 16 patients (17 hips; 1 man and 15 women), with a mean age at the time of surgery of 61 years (Table 1). The Wagner stem group comprised 21 patients (23 hips; 4 men and 17 women), with a mean age at the time of surgery of 67 years. There was no significant difference in age at the time of surgery (Mann-Whitney U test) or gender ratio (Fisher's exact test) between the two groups. The pre-revision femoral defects were classified using the system of Paprosky et al. [21] (Table 1). There was no significant difference in frequency of hips with severe bone loss of type 3A or higher (Fisher's exact test) between the two groups.

All revision operations were performed using a posterolateral approach without detachment of the greater trochanter. In the bone defect around the femoral component, grafting of milled allograft bone was performed in 5 hips of the Mid-stem group and 6 hips of the Wagner stem group, and grafting of hydroxyapatite or β -TCP granules was performed in 8 hips of the Mid-stem group and 11 hips of the Wagner stem group. In both groups, patients were allowed partial weight bearing 3 weeks after the operation and full weight bearing 6 weeks post-operatively.

Based on previous studies that bone remodelling changes have nearly reached equilibrium in the first 2 years

Table 1 Materials and methods

		Mid-stem (<i>n</i> ^a =17)	Wagner stem (<i>n</i> ^a =23)
Gender ^b	Male	1	1
	Female	15	20
Average age (years)		61 (50–74)	67 (49–83)
Reason for the revision ^a	Loosening	14	15
	Stem fracture	0	1
	Accompanying cup revision	3	7
Paprosky classification ^a	1	0	1
	2	6	3
	3A	9	13
	3B	2	5
	4	0	1
Graft ^a	Allograft	5	6
	Hydroxyapatite or β -TCP	8	11

^a Number of hips

^b Number of patients

post-operatively [26], the clinical and radiological findings obtained 2 years post-operatively were compared between the two groups. The Merle d'Aubigné score [4] was used for the clinical assessment of the hip. On anteroposterior radiographs, migration of the femoral component was defined as subsidence of >2 mm. Radiolucency surrounding the stem was analysed using the Gruen method [11]. Stress shielding was graded semi-quantitatively according to the criteria of Engh et al. [5]: *first degree*, femoral neck round-off; *second degree*, loss of calcar density; *third degree*, cortical density loss above the diaphysis; *fourth degree*, diaphysial cortical absorption. Bone remodelling of the proximal part of the femur was assessed quantitatively on anteroposterior radiographs by dividing the width of the cortical bone by the outside diameter of the femoral shaft at a point 1 cm distal to the inferior margin of the lesser trochanter (relative bone mass index). These measurements were compared between the two groups, using Fisher's exact test for distinct categories, and using the nonparametric Mann-Whitney U test for continuous data. A p value of <0.05 indicated significance.

Results

Clinical results

The mean Merle d'Aubigné score improved from 9.4 points (range: 7–11) pre-operatively to 13.8 points (range: 11–17) at 2 years post-operatively in the Mid-stem group and from 10.3 (range: 8–13) pre-operatively to 15.0 (range: 14–18) 2 years post-operatively in the Wagner stem group. There was no significant difference in the Merle d'Aubigné score at 2 years post-operatively between the two groups. No hips underwent additional revision surgery during the 2-year follow-up.

Radiological results

In the Mid-stem group, migration of the stem was observed in two hips (6 mm, 10 mm), and a radiolucent line was observed in two hips. One hip exhibited an extensive radiolucent line at Gruen 2, 4 and 5, and one hip exhibited a limited radiolucent line at Gruen 4. Twelve hips (71%) exhibited stress shielding of the second degree or higher. The mean relative bone mass index decreased from 22.1% pre-operatively to 14.6% at 2 years post-operatively (Fig. 1a,b) (Table 2).

In the Wagner stem group, no hips exhibited stem migration, a radiolucent line or stress shielding. The mean relative bone mass index increased from 21.6% pre-operatively to 31.4% at 2 years post-operatively (Fig. 2a,b).

Fig. 1 **a** Post-operative anteroposterior radiograph of a 54-year-old woman after revision THA with the Mid-stem. **b** At the 2-year follow-up, the radiograph shows stress shielding (fourth degree) at the proximal femur

There were two significant differences between the two groups: in distribution of hips exhibiting stress shielding of the second degree or higher ($p<0.001$) and in the change in relative bone mass index ($p<0.001$).

Table 2 Radiological results

		Mid-stem ($n=17$)	Wagner stem ($n=23$)
Migration (>2 mm) ^a		2	0
Radiolucent line ^a		2	0
Stress shielding ^a (Engh's classification)	First degree	0	0
	Second degree	4	0
	Third degree	3	0
	Fourth degree	5	0
Relative bone mass	Pre-operative	22.1% (8–43)	21.6% (7–40)
	2 years post-operative	14.6% (4–40)	31.4% (21–41)

^a Number of hips

Fig. 2 **a** Post-operative anteroposterior radiograph of a 72-year-old woman after revision THA with the Wagner stem. **b** At the 2-year follow-up, the radiograph shows bone restoration of the proximal femur

Discussion

One of the main problems with revision THA is the difficulty in obtaining strong initial fixation of the femoral component, due to the high likelihood of proximal bone loss and poor bone quality. Use of a long femoral component with cementless fixation in the diaphysis has been suggested as a solution to this problem [7, 19]. However, several investigators have voiced the concern that this type of stem is associated with progressive stress shielding [1, 8, 16, 18, 20, 22, 27]. Decreased stress at the proximal part of the femur may result in bone atrophy, as expressed by Wolff's law [10]. Progressive bone loss

around the femoral component after revision surgery may result in component loosening or difficulty in re-revision surgery. Moreland et al. [20] reported a series of 175 femoral revisions with the AML solution prosthesis; at a mean follow-up of 5 years, severe stress shielding occurred in 7.6% of the hips. Engh et al. [8] reported the results of 18 revision THAs using extensively porous-coated AML long stems, with a minimum 5-year follow-up; the incidences of moderate and severe stress shielding were 22.9 and 5.6%, respectively. In contrast to these reports of adverse effects on bone remodelling, Hartwig et al. [13] reported good bone remodelling with strong, newly formed bone structures in the old stem bed in 32 of 37 revision THAs using the Wagner stem, with a mean follow-up of 27 months. In a series reported by Bohm et al. [2], the mean relative bone mass of the proximal part of the femur increased from 24.9% pre-operatively to 46.6% at a mean follow-up of 4.8 years. We speculate that these conflicting results are partly due to differences in configuration and surface coating between femoral components.

Our study allowed clear comparison of results between two types of cementless long femoral components, using the same surgical methods and assessment criteria, with similar patient profiles. Although reliable stability of the stem was observed in both groups at 2 years post-operatively, there was a distinct difference in bone remodelling between the two groups. According to Engh's semi-quantitative assessment, 12 hips in the Mid-stem group exhibited progressive resorption of the proximal part

Fig. 3 Two-year post-operative lateral radiograph after THA using the Wagner stem. Most hips exhibit contact between stem and proximal posterior femur (arrow) with sclerotic bone response

of the femur, whereas no hips in the Wagner stem group exhibited prolonged resorption. In the quantitative assessment at 1 cm below the lesser trochanter, the cortical width around the stem decreased by approximately 7% of the femoral diameter in the Mid-stem group, whereas the cortical width increased by approximately 10% in the Wagner stem group. From a biomechanical point of view, the use of larger, stiffer stems increases the risk of marked bone resorption, and nearly “isoelastic” stems lead to less stress shielding [1, 22] because stress transfer occurs at the proximal part of the femur. We speculate that the favourable femoral bone restoration of the Wagner stem was due to proximal transmission of force resulting from the low elasticity of the stem, the diameter of which (without the fin) is less than that of the Mid-stem. Although the Wagner stem produces low filling of the medullary canal of the proximal femur, most of the present hips exhibited contact between the stem and the proximal posterior femur on the lateral radiographs (Fig. 3) with sclerotic bone response, suggesting that transmission of the load occurred in that area. Other investigators have also reported favourable bone restoration of the proximal part of the femur after revision THA using the Wagner stem [2, 13, 17, 27].

The extensive HA coating of the Mid-stem may contribute to unfavourable bone remodelling after revision surgery. The HA coating on the implant surface can improve implant fixation due to its bone conduction, especially after revision THA. However, there may be a risk of proximal stress shielding, because stress transfers tend to concentrate at the distal end of the coating area [15].

The limitations of our study were the small number of patients and its retrospective nature. Furthermore, the majority of the hips had pre-revision femoral defects ranging in severity from type 2 to type 3B. If type 4 femoral defects had been included, the radiological stability of the stem may have significantly differed between the two stem groups, and proximal remodelling patterns may consequently have differed between the groups.

In conclusion, when using a cementless long stem with distal fixation, proximal bone remodelling varies according to the configuration and surface coating of the stem. Among the present cases with femoral defects mainly ranging from type 2 to type 3A, the sand-blasted, conically shaped long stem more frequently produced favourable proximal bone remodelling than the extensively HA-coated stem.

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