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Original Research

Bone Remodeling of Two Anatomic Stems: Densitometric Study of the Redesign of the ABG-II Stem

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ABSTRACT

Background: Periprosthetic bone remodeling, which is a phenomenon observed in all femoral stems, has a multifactorial origin as it depends on factors related to the patient, the surgical technique, and the design of the implant. To determine the pattern of remodeling produced by 2 models of anatomic cementless implants, we quantified the changes in bone mineral density (BMD) in the 7 areas of Gruen observed at different moments after surgery during the first postoperative year.

Methods: A prospective, comparative, controlled, 1-year follow-up densitometric study was carried out in 2 groups of patients suffering from primary unilateral hip osteoarthritis. In the first group, with 68 patients, an ABG-II stem was implanted. In the second, with 66 patients, the ANATO stem was used. The contralateral, healthy hip was taken as a control.

Results: Both groups showed a decrease in BMD at 3 months in all the areas, which recovered at the end of the study, except in zone 7: there was a 17.7% decrease in the ABG-II group and a 5.9% decrease in the ANATO group. In zones 2 and 6, where more loads are transmitted, conservation of BMD is observed in response to Wolff's law. The differences in the pattern of remodeling between groups were maintained despite the age, gender, and BMI of the patients or the size of the implants.

Conclusion: The ANATO stem achieved a more efficient transmission of loads at the metaphyseal level, which promotes bone preservation at the proximal femur, than the ABG-II stem.

Introduction

Bone remodeling after a hip arthroplasty occurs with all models of cementless femoral stems because of the change in the pattern of load transmission produced after the surgery. The magnitude of these adaptive changes is multifactorial, with factors attributable to the patient, to the surgical technique, and to the implant [1-4].

On another note, it is accepted that a decrease of 30%-40% in the bone mineral density (BMD) is necessary to appreciate changes in the bone density in a simple radiograph [5]. For this reason, dual-energy radiograph absorptiometry is considered the ideal method to quantify the changes in BMD produced by different stems over the years [6-8]. For the location of the changes, the Gruen zones have been used as a reference. Zone 1 corresponds to the greater trochanter, zone 7 to the lesser trochanter, and zone 4 is distal to the tail of the implant. Zones 2 and 3 correspond to the external portion of the middle and distal third of the femur around the implant, respectively. Zones 6 and 5 correspond to the internal portion of the middle and distal third, respectively.

In the last 2 decades, several clinical studies and results of national registries of the ABG-I stem (Stryker, Kalamazoo, MI) showed good clinical and radiological evolution [9,10]. However, in densitometric studies, this implant produced a 12% decrease in BMD in zone 1 and 27% in zone 7 at the end of the first postoperative year. The redesign of this implant (ABG-II; Stryker) in the late 1990s maintained good clinical and radiological results, improving the results of bone remodeling [11] but still showing a decrease in BMD of 7% in zone 1 and 16% in zone 7 [12].

In 2015, the evolution of the ABG-II stem (ANATO, Stryker, Kalamazoo, MI) was marketed. This new implant has 2 options of the femoral neck, is made with a different titanium alloy, and also has a biological coating of greater porosity, which is different from the grit-blasted surface of the ABG-II stem. Finally, the length of the

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ANATO stem does not increase after size 4, always measuring 120 mm from that size onward. When this new stem was used in our department, a pilot study was carried out with the first 37 patients who received this implant. The results showed a reduced decrease in bone mass at the proximal femur, particularly in area 7 [13], compared with the ABG-II stem [11,12].

With the intention of confirming these findings and avoiding the bias of studies carried out in different time periods, by different surgeons and with modifications in the surgical technique and postoperative care, a prospective comparative study including both implants was designed and subsequently carried out in 2017. The purpose of this study was to quantify the variation of the periprosthetic BMD caused by these 2 implants throughout the first 12 postoperative months, taking the contralateral, healthy hip as a control.

Material and methods

To quantify the periprosthetic bone remodeling caused by the ABG-II and ANATO stems, a prospective, comparative, densitometric study was designed, taking the contralateral, healthy hip as a control. The patients included in the study were operated between March and September 2017. The clinical data were obtained from the clinical history and radiograph. The study was completed with the functional assessment of the operated hip using the Merle D'Aubigne Postel score and radiographs anteroposterior of the pelvis and axial of the affected hip) at the same time that each densitometric study was carried out. The study was approved by the ethics committee.

Densitometric evaluation

The variation of the BMD was used as a criterion of evolution in boxes of 30-by-30 pixels in each of the 7 areas of the Gruen zones in both the healthy and the operated hips. BMD determinations were performed using the LUNAR DPX enCORE densitometer (GE Healthcare, Madison, WI) using metal exclusion software. The analyses were made with a careful superimposition of the stem in all the scans of each patient to analyze the same regions of interest. The scans in both hips were made preoperatively and 1 year after the surgery. In the operated hip, 3 additional determinations were made: in the immediate postoperative period and 3 and 6 months after the surgery. The densitometric results were compared grouping the patients based on the stem used and analyzing any possible differences between the age, gender, weight, and size of the implant.

To ensure the reliability of the scans [14] and reproduce the position of the hip during the densitometric study, all the patients were placed in the supine position on the scanner table, with the knees and hips in extension and the whole limb in a neutral position supported on a rigid plastic device that immobilized the leg with Velcro tapes.

Study population

The patients included in the study suffered from unilateral hip osteoarthritis, Dorr A femoral morphology, with no radiological signs of osteoporosis. They had a healthy contralateral hip and accepted to participate in the study.

The patients were included in 2 groups depending on the day of inclusion on the surgical waiting list (even days: ABG-II [Stryker]; odd days: ANATO). It was proposed to include a minimum of 60 patients in each group, and finally 68 were included in the ABG-II group and 66 in the ANATO group. All patients completed the 1-year follow-up.

The implant used in the first group was the ABG-II stem and, in the second group, the ANATO® stem (Stryker), with uncemented cup (TRIDENT PSL®, Stryker, Kalamzazoo, MI) and ceramic-polyethylene bearing couple (the latter 2 were not part of the study). The ABG-II stem is an uncemented anatomical stem, of metaphyseal press fit, made with an alloy of titanium-molybdenum-zinc-iron, with a 7-degree femoral neck anteversion. At the metaphyseal level, it has a scale-like design on the anterior and posterior sides of the implant, with a grit-blasted surface and a hydroxyapatite coating of 70 microns. The ANATO stem is made of titanium-aluminum-vanadium (Fig. 1a and b). It has 2 femoral neck options: neutral or with 7 degrees of anteversion. At the metaphyseal level, it also has a scale-like design on the anterior and posterior sides of the implant, which helps transform the axial forces into transverse ones, improving the stability of the implant. At this level, the surface is rough, created with a 300-micron titanium spray and a 50-micron PureFix® (Stryker, Kalamazoo, MI) hydroxyapatite coating. From size 4, the total length of bigger implants does not increase, always limited to 120 mm. It has the same offsets and neck lengths as the ABG-II® stem.

Surgical technique

All the patients were operated on using a posterolateral approach performed by the same group of 5 surgeons. Antibiotic prophylaxis with cefazolin, or teicoplanin in case of allergy, was used in the first 24 postoperative hours, and antithrombotic prophylaxis with low-molecular-weight heparins was used for the following 30 days.

The patients rested in bed for the first 24 hours, after which the drainage of the wound was removed. From that moment, sitting on the edge of the bed or in a high chair was started. Next, walking with crutches or a walker was authorized, in partial weight-bearing, according to tolerance. To minimize micromovement that can affect bone growth on the surface of the implant, and the risk of periprosthetic fractures, the patients continued using the crutches for 6 weeks, and later, using just one crutch, progressive full loading was authorized. After 3 months, complete weight-bearing without any supportive help and free movement was authorized.

Figure 1. (a) ABG-II stem. (b): ANATO stem.

Table 1
Demographics of the patients included in the study.

	ABG-II (n = 68)	ANATO (n = 66)
Men/women	47/21	56/10
BMI	28.1 kg/m^2	32.8 kg/m^2
Age	59 (SD: 10.8; min: 28, max: 76)	57 (SD: 8.4; min: 36, max: 75)
Diagnosis	100% osteoarthritis	100% osteoarthritis
Size of the stem	2: 2 patients 3: 13 patients 4: 25 patients 5: 17 patients 6: 19 patients 7: 2 patients	3: 10 patients 4: 26 patients 5: 15 patients 6: 11 patients 7: 4 patients (100% with 7 degrees anteverted neck)

Statistical analysis

The statistical study was carried out using the SPSS program, version 20.0. For the comparison of percentages, the chi square test was used; for the means with homogeneous parameters, Student's t-test was used; and for the means with nonhomogeneous parameters, the Kruskal-Wallis test was used.

Results

The demographics of the patients are shown in Table 1. In both groups, the male-female distribution was not homogeneous, showing a clear male predominance. The reason for these differences is that the choice of the implant is made considering the bone quality observed on the preoperative radiograph and the femoral morphology. As a result, we use this implant in 52% of our patients, most of whom were male. The rest of demographic variables (BMI, age, diagnosis, and the size of implant used) did not show any differences between groups.

The bone-mass evolution in both groups throughout the follow-up is shown in Tables 2 and 3. As osteoarthritic hips are almost always extrarotated and flexed, the preoperative values were not considered and the postoperative values were taken as a reference for monitoring BMD in the operated hip. Three months postoperatively, a generalized bone loss was observed in all the areas, being more marked in zone 7. This decrease in BMD was attributed to the surgical aggression of the rasps to the cancellous bone and endosteal blood supply and to a reduced physical activity in the postoperative period.

At the 6-month determination of the ABG-II group, a partial bone recovery was observed in zones 1-2-3-4-5-6, which was more evident—with positive remodeling—in zones 2 and 6. On the contrary, in zone 7, a moderate additional bone loss was observed, already statistically significant (decrease of 15.3%). One year postoperatively, this pattern of remodeling was stable, showing slight losses in zone 1 and distal areas, bone preservation in zones 2 and 6, and statistically significant proximal atrophy in zone 7 only (decrease of 17.7%).

The evolution of BMD at 6 months in the ANATO group also showed a recovery in all areas, with positive remodeling in zones 1, 2, and 6. In zone 7, a significant bone loss of 6.3% was observed. One year postoperatively, this pattern of remodeling was maintained, with minimal losses in distal areas; bone preservation in zones 1, 2, and 6; and a statistically significant decrease in bone mass of 5.9% in zone 7.

Table 2
Changes in BMD in the ABG-II group.

Gruen zones	Pre-Iqx	Post-Iqx Reference	3 mo	6 mo	1 y
Zone 1	971	941	898	909	903
Variation			−4.6%	−3.5%	−4.1%
SD	193	180	193	191	199
Max-min	512-1498	492-1464	343-1198	396-1231	311-1299
P			.097	.403	.795
Zone 2	1877	1836	1821	1873	1842
Variation			−0.9%	+2%	+0.4%
SD	276	256	265	297	281
Max-min	1109-2365	1056-2207	1021-2256	1116-2372	1310-2650
P			.854	.447	.297
Zone 3	2187	2130	2063	2080	2090
Variation			−3.2%	−2.4%	−1.9%
SD	293	267	263	271	246
Max-min	1398-2432	1265-2327	1234-2598	1370-2689	1420-2657
P			.263	.583	.803
Zone 4	2107	2076	1985	1991	2002
Variation			−4.4%	−4.1%	−3.6%
SD	297	293	287	293	290
Max-min	1296-2710	1287-2675	1146-2479	1235-2570	1234-2607
P			.142	.130	.356
Zone 5	2172	2144	2048	2060	2115
Variation			−4.5%	−4%	−1.3%
SD	301	290	281	288	290
Max-min	1256-2654	1198-2594	1341-2527	1339-2517	1580-2678
P			.105	.130	.482
Zone 6	1802	1761	1749	1795	1812
Variation			−0.7%	+1.9%	+3.1%
SD	312	305	297	334	313
Max-min	1293-2278	1119-2070	1162-2093	1211-2365	1363-2425
P			.741	.236	.131
Zone 7	1476	1459	1274	1237	1202
Variation			−12.7%	−15.3%	−17.7%
SD	287	275	295	310	300
Max-min	719-1962	830-1680	536-1982	407-1994	690-1936
P			**.001**	**.001**	**.000**

Pre-Ipx, pre-operative; Post-Iqx, post-operative (reference value).
Bold values indicates the statistical significance.

Table 3
Changes in the BMD in the ANATO group.

Gruen zones	Pre-Iqx	Post-Iqx Reference	3 mo	6 mo	1 y
Zone 1	967	936	916	959	957
Variation			−2.2%	+2.4%	+2.2%
SD	200	164.9	178	202	212
Max-min	523-1617	611-1372	447-1427	419-1421	407-1424
P			.239	.400	.673
Zone 2	1913	1856	1809	1871	1895
Variation			−2.6%	+0.9%	+2.1%
SD	295	256	262	259	258
Max-min	1010-2315	1305-2396	1145-2459	1176-2335	1336-2713
P			.228	.930	.318
Zone 3	2210	2194	2085	2172	2177
Variation			−5%	−1.1%	−0.8%
SD	281	281	281	287	277
Max-min	1331-2467	1570-2839	1325-2659	1463-2872	1501-2790
P			.061	.266	.249
Zone 4	2122	2105	2030	2058	2080
Variation			−3.6%	−2.7%	−1.2%
SD	273	296	294	291	295
Max-min	1489-2750	1488-2835	1345-2659	1382-2607	1459-2791
P			.131	.119	.165
Zone 5	2161	2140	2042	2095	2106
Variation			−4.6%	−2.1%	−1.6%
SD	305	285	301	299	306
Max-min	1267-2692	1458-2647	1317-2593	1430-2619	1480-2739
P			.101	.125	.168
Zone 6	1780	1683	1649	1719	1774
Variation			−2.1%	+2.1%	+5.2%
SD	284	348	265	257	262
Max-min	1002-2248	1478-2374	879-2264	1201-2400	1234-2338
P			.434	.216	.057
Zone 7	1432	1400	1263	1313	1318
Variation			−9.8%	−6.3%	−5.9%
SD	201	212	218	258	248
Max-min	790-1717	1028-2045	491-1843	761-2002	670-1904
P			.001	**.002**	**.005**

Pre-Ipx, pre-operative; Post-Iqx, post-operative (reference value).
Bold values indicates the statistical significance.

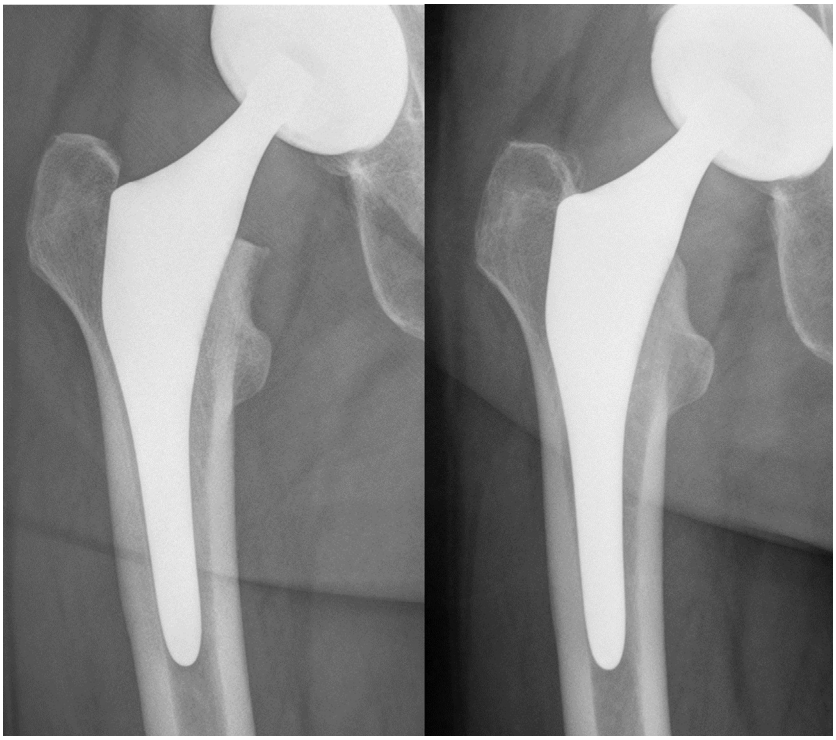

Figure 2. Radiographic changes around the ABG-II showing rounding of the calcar and light atrophy at the greater trochanter. Immediate postoperative image on the left; 1-year postoperative image on the right.

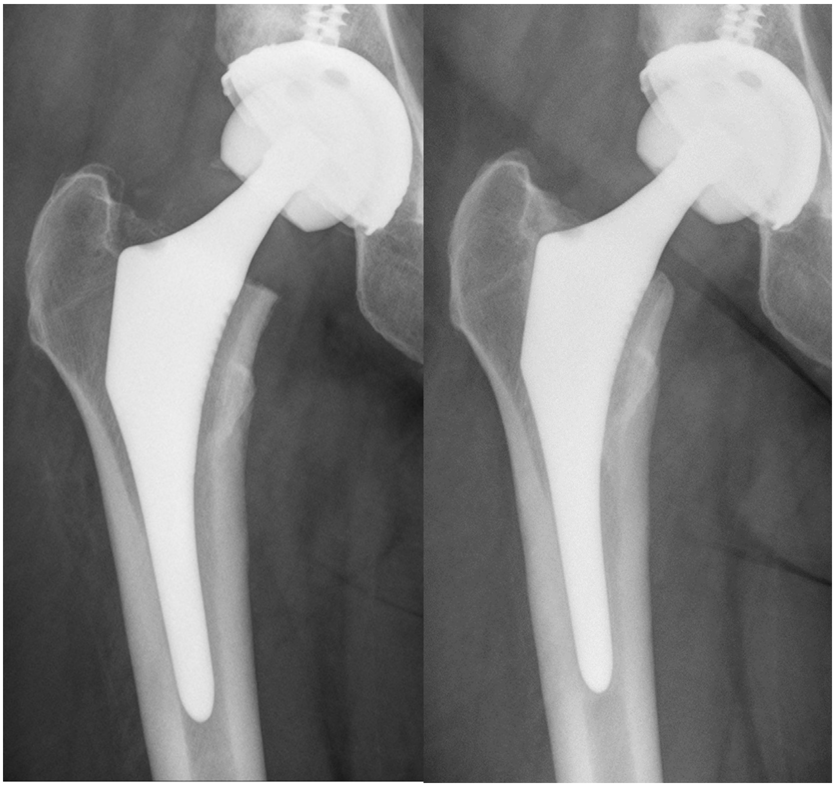

Figure 3. Radiographic changes around the ANATO stem showing a reduced calcar atrophy and bone apposition at the shoulder of the stem. Immediate postoperative image on the left; 1-year postoperative image on the right.

When analyzing the evolution of the BMD between implants at different times of the follow-up, no significant differences were observed in zones 2 to 6. Only in zone 1 of the ANATO group was a positive remodeling found from the 6th month, which did not exist in the ABG-II group. This finding was maintained at the end of the study, with a 2.2% increase in the ANATO group, compared with a 4.1% decrease in the ABG-II group, without achieving statistical significance. However, the changes in BMD in zone 7 between these implants were more pronounced and statistically significant at 6 and 12 months. In the ABG-II group, a 15.3% decrease in BMD was observed at 6 months, while in the ANATO group, the decrease was limited to 6.3% (P .001). At 12 months, the ABG-II group showed a decrease in BMD of 17.7%, in contrast to a decrease of 5.9% observed in the ANATO group (P .002).

When the changes in BMD of these stems were analyzed according to the gender, BMI, and age of the patients, we observed the same differences between stems. When the BMD differences between implants were studied according to the size used, size 4 was chosen as the cutoff point because from that size onward, the ANATO stem does not increase its length, unlike the ABG-II stem. The results obtained showed the same differences between stems.

Related to the evolution of BMD of the healthy hip, taken as a control, a variation in bone mass of −3.2% to +0.6% was observed. The BMD varied from −300 to +23.4 mgr/cm^2 at the end of 12 months in the operated hip in contrast to the healthy hip, which ranged from −30.4 to +47.4 mgr/cm^2. This difference was statistically significant only in area 7, in both groups. In the ABG-II group, the average decrease of BMD in area 7 at the end of the study was 274 mg/cm^2 in the operated hip, but dropping 21 mg/cm^2 in the control hip (P .001). In the ANATO group, the decrease of BMD in area 7 was 148 mg/cm^2 in the operated hip and 13 mg/cm^2 in the control hip (P .01).

The clinical results were similar between implants, obtaining a Merle D'Aubigne Postel (MDP) score of 7.5 (standard deviation [SD]: 1.27, min: 6, max: 12) preoperatively in the ABG-II group, which reached 16.8 (SD: 1.20, min: 12 max: 18) at the end of the first postoperative year. In the ANATO group, the preoperative clinical MDP score was 7.7 (SD: 1.18, min: 6, max: 11) which reached, 1 year postoperatively, 17.1 (SD: 1.21, min: 12, max: 18).

As for the radiological evolution, it was very frequent to find a light bony atrophy at the shoulder of the stem and some rounding at the level of the calcar in the ABG-II group at the end of the first year, without any other changes in middle and distal areas. These radiological changes coincided with the densitometric results. However, in most of the patients in the ANATO group, there was bone neoformation at the shoulder of the stems, and the remodeling changes at the calcar were less intense, all in accordance with the densitometric results (Figs. 2 and 3).

Discussion

The implantation of a femoral stem modifies the model of transmission of loads to the proximal femur, causing an adaptive bone remodeling of multifactorial origin. Among these factors, it is possible to distinguish those derived from the implant such as the design, size, alloy, and extension of the porous coating. To determine the influence of the implant on the femoral remodeling, it is necessary to minimize the variability in the surgical technique and in the postoperative recovery in a group of patients who, clinically, are very similar [15-17]. In addition, to accurately quantify those changes in BMD, it has been proven that dual-energy radiograph absorptiometry is a reliable method.

In densitometric studies with other implants, the variation of the BMD of the proximal femur after the implantation of an uncemented stem, at 3 and 6 months after the surgery, showed a decrease from 4% to 50% in the preoperative bone mass, depending on the implant and the surgical technique [18]. Among the main reasons for these losses, we can mention the partial load during the first weeks after the surgery and the immediate decrease of the bone stock after the femoral preparation with rasps, which may comprise up to 10% of the initial bone stock [19]. It is accepted that most of the remodeling is stabilized at the end of the first postoperative year, when the BMD reaches a plateau in all the areas around the stem, reflecting the changes of the new hip biomechanics, according to Wolff's law [20].

Studies performed with the ABG-I® and ABG-II® models show mild bone loss in zones 2 to 6 in both implants, already present at 3 and 6 months after implantation, with recovery at 12 months postoperatively. In both stems, more pronounced losses were observed in areas 1 and 7, but more intense in the ABG-I stem. The design of the ABG-II stem, with a widening of the metaphyseal anteroposterior diameter and with a shorter and smaller tail than the ABG-I, improved the pattern of load transmission to metaphyseal zones, explaining a lower bone loss in proximal areas [12] that ranged from 7% to 16%. The results of these anatomic models coincide with those observed in other similar anatomic designs, which share the same proximal fixation philosophy. These implants seek a close match of the stem with the proximal endosteal geometry, and stability is achieved through metaphyseal fill and distal curve. As a result, they showed decreases of 9%-23% BMD in the proximal femur at the end of the first postoperative year. With other designs, some variability has been observed in the remodeling of the proximal femur at 12 months of evolution; thus, single-wedge stems, with 3-point fixation along the stem length, cause a decrease of 12%-38%. With tapered stems, drops of 26%-31% have been documented. With rectangular, tapered stems, which obtain 3-point fixation in the metaphyseal-diaphyseal junction and proximal part of the diaphysis, the decrease was between 7% and 30%. With custom-made stems, the proximal atrophy was between 7% and 24% [21,22]. With short stems, a 12.9% decrease in BMD was observed in the femoral calcar with the Metha stem (Aesculap Orthopaedics, Germany), 18%-29% with the CFP stem (Waldemar Link, Germany), and 6%-15% with the Nanos stem (Smith & Nephew, England). With the Mayo stem (Zimmer Biomet, Warsaw, IN,), the proximal atrophy reaches 14%-17%, and with the Proxima (DePuy Synthes, Warsaw, IN, it oscillates between 8% and 14% [23-25].

Analyzing the role that design differences between these implants can cause in the remodeling, it can be suggested that, in coincidence with other authors [26], the increased thickness and porosity of the biological coating of the ANATO stem provides stronger, more reliable osseointegration of superior quality and quantity than the ABG-II stem. This improved fixation of the stem favors the pattern of load transmission to be more similar to the physiological load pattern of the nonoperated femur, minimizes the atrophy at the proximal femur, and favors a positive remodeling. Thus, greater bone preservation in the proximal femur could theoretically reduce the risk of periprosthetic fractures and provide an improved bone stock in case of implant revision.

This study has some limitations to consider. First, in both groups, there are more men than women. Middle-aged men usually have femurs with good bone quality, but this quality was less frequent in the women received in our practice, so the indication for uncemented anatomic implants was lower in female patients. Thus, the results obtained for the total group cannot be extrapolated to the group of female patients. The same happens with age. In both groups, the patients are relatively young, and this pattern of remodeling in older patients cannot be guaranteed. The follow-up of our study is relatively short, and we can expect changes attributable to late remodeling in the longer term. However, it is accepted that most of the adaptative changes of the femur occur during the first postoperative year. Finally, the alloy of the implants was different, but in both cases, the rigidity of the implant exceeds 3 times the rigidity of the cortical bone (20 GPa) and the small difference had no influence on the pattern of remodeling [12].

In conclusion, both anatomic stems achieve an efficient transmission of loads at the metaphyseal level that creates sufficient stimulus for bone preservation. However, the greater porosity of the biological coating of the ANATO stem obtains a better bone fit of the implant at the proximal level. This favors bone preservation at the proximal level, minimizing atrophy due to stress shielding. Theoretically, this greater bone preservation can favor long-term implant fixation and decrease the rate of revisions.

Conflict of interest

The authors declare there are no conflicts of interest.

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