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ORIGINAL PAPER

Influence of the tibial stem design on bone density after cemented total knee arthroplasty: a prospective seven-year follow-up study

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Abstract We prospectively measured the changes in bone mineral density (BMD) in the proximal tibia of 20 total knee arthroplasties, ten with cruciform stems and ten with cylindrical stems. The measurements were made one, four and seven years after surgery. We observed a uniform density decrease in three regions of interest from one to seven years of follow-up. Cylindrical stems showed an asymmetrical density decrease between the three regions of interest, with no change in the central region, a slight decrease in the lateral region, and large decrease in the medial region. Multivariate analysis with general linear model showed the stem type factor as statistically significant for medial region of interest (p=0.006). The cylindrical stem produces heterogeneous BMD changes under the tibial platform in knee arthroplasties, and this could be a potential risk factor for asymmetrical subsidence of this component.

Résumé Nous avons de façon prospective mesuré les modifications de la densité minérale osseuse (BMD) au niveau de la partie proximale du tibia chez 20 patients ayant bénéficié d'une prothèse totale du genou, 10 avec une quille cruciforme et 10 avec une quille cylindrique. Les mesures ont été réalisées de 1.4 à 7 ans après l'intervention chirurgicale. Nous avons observé une diminution uniforme de la densité minérale osseuse dans trois zones, durant cette période de 1 à 7 ans de suivi. La quille cylindrique montre que la densité minérale osseuse diminue de façon asymétrique dans ces 3 régions sans modification au niveau de la région centrale, avec une légère diminution de la région externe (latérale) et une diminution plus importante de la région interne (médiale). Une analyse de régression multi variable montre que le type de quille est l'élément le plus significatif au niveau de la région interne (p=0.006). La quille cylindrique étant un facteur statistiquement significatif et entraînant des modifications hétérogènes de la BMD, sous le plateau tibial. Ces modifications peuvent être un risque potentiel de migration du composant tibial.

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Introduction

Mechanical loosening of the tibial component is a frequent cause of failure of total knee arthroplasty (TKA) [7], and it is related to malalignment and unbalanced ligaments, with an unstable fixation or with bone quality decrease near the prosthesis. The mineral density of trabecular bone is directly associated with bone quality and its mechanical properties, and these are considered to be important predictors of TKA failure. Various systems have been designed to increase the stability of the tibial tray by adding cylindrical or cruciform stems, pegs, and peripheral or central screws. Lee et al. [5] demonstrated in experimental studies that there are large differences in stability depending on the type of fixation. Changes in bone density must exceed over 50% in order to be recognisable on a standard X-ray [13]. Bone quality is important for the success of joint prostheses implantation, and the assessment of bone density after TKA with dual X-ray absorptiometry (DEXA) may be useful for monitoring implant stability [16]. Therefore, bone mineral density (BMD) measurement should not be done only once but should be repeated periodically in order to evaluate bone density changes during the follow-up. Our objective was to measure BMD changes in time and magnitude in the periprosthetic areas of a tibial platform of a cemented TKA using cylindrical stem or cruciform stem designs. In this way, we established the different loading distribution in these two stem types.

Materials and methods

One hundred and ninety Interax (Stryker, Allendale, NJ, USA) TKA were implanted in 1998 and 1999, half of them with cylindrical tibial stems and the other half with cruciform stems, depending on their position number in the surgical waiting list: 85 patients with even numbers were assigned to cruciform stems and 85 patients with odd numbers to cylindrical stems. From these 190 TKA, we obtained a subgroup of 78 (Fig. 1), satisfying inclusion criteria of age range 60–70 years, female gender, weight between 70 and 90 kg, preoperative femoro-tibial angle 180°±5°, and diagnosis of osteoarthritis. From this homogeneous group, a random sample of ten cruciform stems and ten cylindrical stems (Fig. 2) was obtained. Mean age was 67 and mean weight was 81 kg.

All patients progressed without complications. No revision surgery was necessary. The achieved postoperative femoro-tibial angle was between 180°±3° in all patients. The implanted prosthesis was always the same model, with cruciate-retaining and cemented femoral component, tibial platform, and patella. DEXA scanning was performed at one, four and seven years of follow-up using a Norland XR-26 MARK II (Cooper Surgical, Inc, Trumbull, CT, USA).

We defined three regions of interest (ROI) of 1 cm^2 area each under the tibial component coinciding with Ewald's zones 2, 3, and 6 [2]: ROI-1 at the medial, ROI-2 at the lateral, and ROI-3 at the central positions. ROI-1 and ROI-2 were situated 1 cm underneath the tibial plateau and 1 cm of the internal and external border of the stem, respectively. ROI-3 was localised 1 cm below the stem. Density was measured in grams per centimetre squared (g/cm^2). For statistical analysis, we used SPSS software version 12 for Windows (SPSS Inc, Chicago IL, USA). Descriptive statistics were calculated for the density in the three ROIs in the follow-up, including mean, standard deviation, and 95% confidence interval (CI) for the mean. Bone density change was calculated as percentage, with 95% CI from beginning to end of follow-up. Nonparametric tests were used due to the study sample size. Density change from the first to the fourth and to the seventh year was analysed in each ROI with Friedman's test without taking account of stem type.

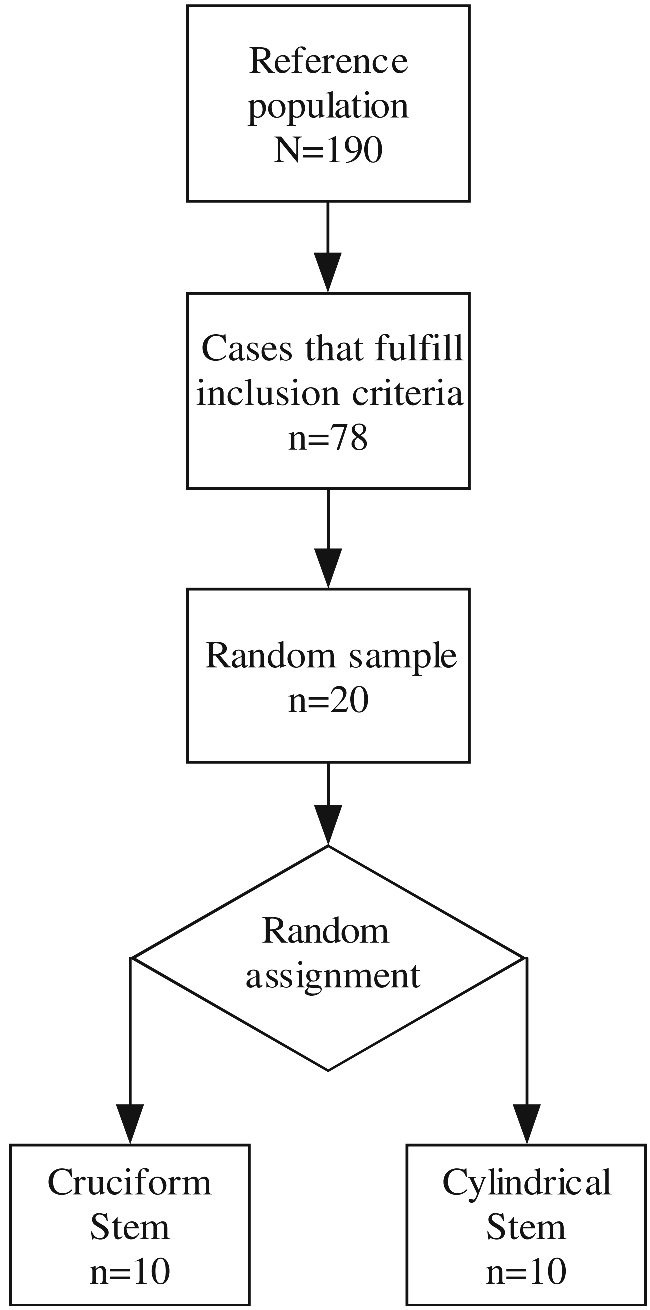

Fig. 1 Patient sample selection

Multivariate general linear model (repeated measures) was used to asses the change of density in each ROI, defining the stem type as the between-subjects factor and the density change over time as the within-subjects factor.

Results

Friedman's test for related samples showed no statistically significant differences between densities at one, four and seven years (p=0.35). In the cruciform stems, we observed

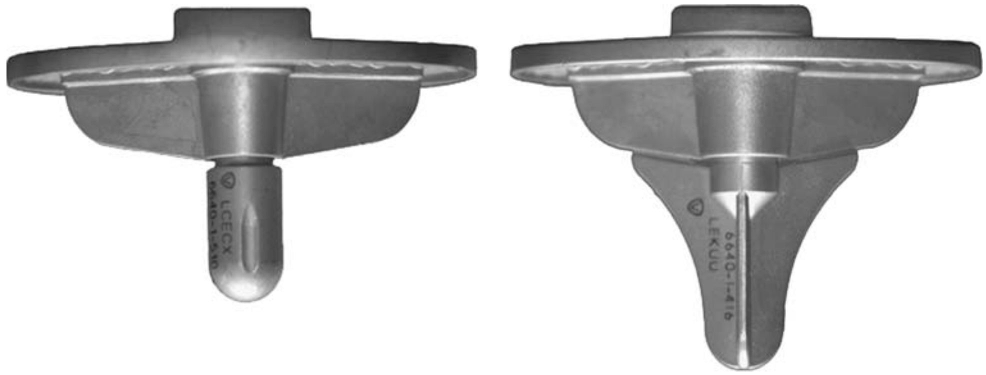

Fig. 2 Tibial platform in total knee arthroplasty (TKA). Types of stems analyzed

a uniform density decrease in the three ROIs from one to seven years of follow-up (Table 1). But cylindrical stems showed an asymmetrical density decrease between the three ROIs, with almost no change in ROI-3, a slight decrease in ROI-2, and large decrease in ROI-1 (Table 2). Using the multivariate general linear model, we found statistical significance for stem type (between-subject factor) only for ROI-1 (p=0.006). We found no statistical difference for the density change in the follow-up (within-subject factor) or for the interaction between stem type and density change in any ROI.

Discussion

The method of implant fixation is a critical determinant for tibial implant stability of TKA. The aim of the tibial platform's design is to ensure good stability and provide a homogeneous loading distribution. To reach these goals, different types of tibial stems have been designed. In knees with cemented fixation, the bone cement can compensate for variations in-bone quality, and consequently, the subsidence of the tibial platform is homogenous [7]. In some studies, the most rigid implant fixation was achieved using four peripheral screws in cancellous bone. The addition of a cementless central stem adds stability but only in cases of poor-quality bone [1, 5], and it was associated with increased micromotion, especially under eccentric loading. In the same way, short and long stems do not enhance initial fixation in cemented or cementless implants in primary TKA [15]. Other studies indicate that stability of surface-cemented tibial components may be related to the depth of cement penetration [10]. For others authors [9], a pegged design may offer advantages without a

Table 1 Mean, confidence interval (CI), and standard deviation (SD) of bone density by follow-up, region of interest (ROI), and stem type

Follow-up	ROI	Type	Mean	95% CI for Mean		SD
				Lower bound	Upper bound	
1-year	1	Cylindrical	0.885	0.730	1.040	0.217
		Cruciform	0.744	0.680	0.808	0.090
	2	Cylindrical	0.796	0.564	1.029	0.325
		Cruciform	0.885	0.796	0.974	0.125
	3	Cylindrical	0.996	0.805	1.187	0.266
		Cruciform	1.039	0.900	1.179	0.195
4-year	1	Cylindrical	0.842	0.692	0.992	0.210
		Cruciform	0.707	0.666	0.749	0.058
	2	Cylindrical	0.781	0.512	1.050	0.376
		Cruciform	0.849	0.795	0.903	0.076
	3	Cylindrical	0.968	0.770	1.166	0.277
		Cruciform	1.000	0.787	1.212	0.297
7-year	1	Cylindrical	0.805	0.674	0.935	0.183
		Cruciform	0.699	0.629	0.769	0.098
	2	Cylindrical	0.776	0.539	1.013	0.331
		Cruciform	0.833	0.742	0.924	0.127
	3	Cylindrical	0.992	0.820	1.164	0.241
		Cruciform	0.971	0.840	1.101	0.182

Table 2 Percentage of density decrease in the three regions of interest (ROIs) from 1 to 7 years, with 95% confidence intervals (CIs)

ROI	Type	% decrease	95% CI	
			Lower bound	Upper bound
1	Cylindrical	9.12%	7.72%	10.09%
	Cruciform	6.08%	7.47%	4.90%
2	Cylindrical	2.55%	4.41%	1.53%
	Cruciform	5.91%	6.79%	5.19%
3	Cylindrical	0.42%	−1.78%	1.92%
	Cruciform	6.62%	6.64%	6.61%

higher rate of complications when compared with stemmed implants. Therefore, in our study, we obtained good results with both stem designs in the analysed follow-up.

The clinical survival of joint arthroplasties is clearly associated with the quality of the surrounding bone environment. BMD is an important measure of bone strength and quality [3]. The results of many studies confirm that DEXA scanning is reliable for the evaluation of bone mass around prosthetic implants [16] to precisely measure small bone mineral changes around TKA; it makes it possible to follow bone remodelling, and it may provide a feasible method for monitoring the implant during follow-up [13].

Some authors [4, 11] found significant bone density decrease in the periprosthetic tibial area during the follow-up. Tibial bone loss can be caused by load changes on the metaphyseal bone, and long-term studies show that after an initial stable period, the bone density of the proximal tibia consistently decreased at a rate of 5% per year [6]. Our results did not coincide with these findings. We observed an overall density decrease of periprosthetic bone below the tibial component of 5.1% at seven years after the surgery. This decrease was quite uniform in cruciform stems and asymmetric in the cylindrical model (Table 2). At ROI-3 in the cylindrical type, BMD did not modify at seven years while it diminished 6.6% in the same ROI in the cruciform type. At ROI-1 in the cylindrical type, there was a large decrease, 9.1%, while at ROI-2, it was only 2.5%. In the cruciform type, BMD decrease was 6.1% at ROI-1 and 5.9% in ROI-2.

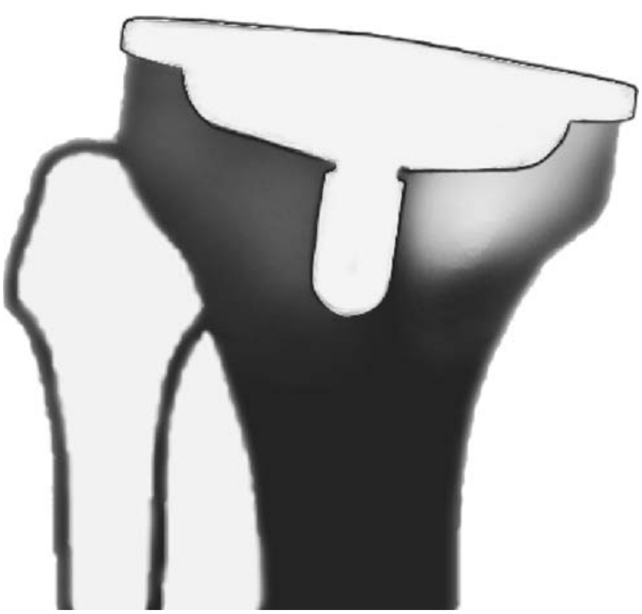

Fig. 3 Asymmetrical subsidence in the cylindrical stem with “peal-of-bells” effect

There are few works that compare BMD changes depending on the type of metallic platform fixation. Lonner et al. [8] contrasted central stems and pegs. Results showed that there was a significantly reduced density of bone in the tibial metaphysis in the cemented-stem group but not in the pegged group. This study supports the argument that the use of a cemented stem reduces proximal stresses but may result in proximal bone resorption. Although the use of a stem provides excellent resistance to lift-off and shear, it comes at a price. The proximal resorption may contribute to tibial component loosening as a primary threat to survival and as a complication factor for revision surgery.

We have not found any work in the literature that compares BMD in medium-term follow-up between two different stem types and the same model of tibial tray. Our global results cannot be compared with any other studies, although a larger decrease of BMD at the medial tibial side was published in some studies [12, 14]. Our findings suggest that the cruciform stem allows a more uniform loading distribution, resulting in a more homogeneous BMD decrease in the three analysed ROIs. On the other hand, the cylindrical stem produces a slight BMD decrease in the lateral area, an insignificant decrease below the stem, and a large decrease in the medial side. This heterogeneous BMD change could produce a tilted subsidence showing a “peal-of-bells movement” effect (Fig. 3). This asymmetry in BMD decrease in this type of stem is a factor to be taken into account for the future.

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