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How to reduce osteopenia in total knee arthroplasty?

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Abstract

Background Osteopenia of the front half of the distal femur is a well-known problem after total knee arthroplasty (TKA) with secondary issues after years, especially when must be addressed fractures or revisions for loosening. Stress shielding has been recognized as a cause in different biomechanical studies of the bone.

Question/purposes It was logical to look for a solution by changing the design to minimize stress shielding behind the femoral shield.

Patients and methods It was proved that radiological measure of bone density was reliable although not so early and accurate as densitometry. We used a shield without posterior fixation of the trochlea in a series of 21 TKA with radiological measures, preoperative, at 3 months and at 5 years. We compared the results with those of a series of classical TKA in the same category of age and sex.

Results The TKA without trochlea posterior fixation presented a significantly reduced osteopenia compared to the classical design of the femoral shield.

Conclusion It seems that the non-fixation of the posterior surface of the trochlea may reduce osteopenia in TKA and so the risk of fractures and complications when revision surgery.

Level of evidence 2a.

Keywords Total knee arthroplasty · Osteopenia · Biomechanics · Prosthesis design

Introduction

The mechanical impact on the quantity and quality of the bone has been known since the end of the nineteenth century. Orthopedic surgeons identified the issue following a total knee arthroplasty (TKA) after only a few years, and they noted systematical osteopenia of the front half of the distal femur (Fig. 1). Engineers have studied and explained the problem, as this loss of bone substance, in quantity and quality, is problematical in tardive revision for loosening or when a fracture of the knee prosthesis occurs several years after surgery. Our working hypothesis is that by modifying the mechanical constraints of the prosthetic shield on the bone we can improve bone loss after a TKA.

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Materials and methods

Prosthetic implants of the femoral shields of a FHK total knee prosthesis (FH Orthopedics, 68,990 Heimsbrunn, France) have a classical design with a slightly asymmetrical and sparsely grooved trochlea; the characteristic of these chrome cobalt shields is that the posterior face of the upper half of the prosthetic trochlea which will be in contact with the distal femoral bone, is different from the rest of the face.

- It is smooth and is not coated with titanium and hydroxyapatite (HA) and therefore does not allow bone fixation, for the "cementless" version (Fig. 2).
- It comprises a location area with an identical surface, well defined, smooth, and with the same surface that will not be covered in cement, for the "cemented" version (Fig. 3).

The chosen method to measure the osteopenia is densitometry with X-rays [10], but it is proved that quality lateral

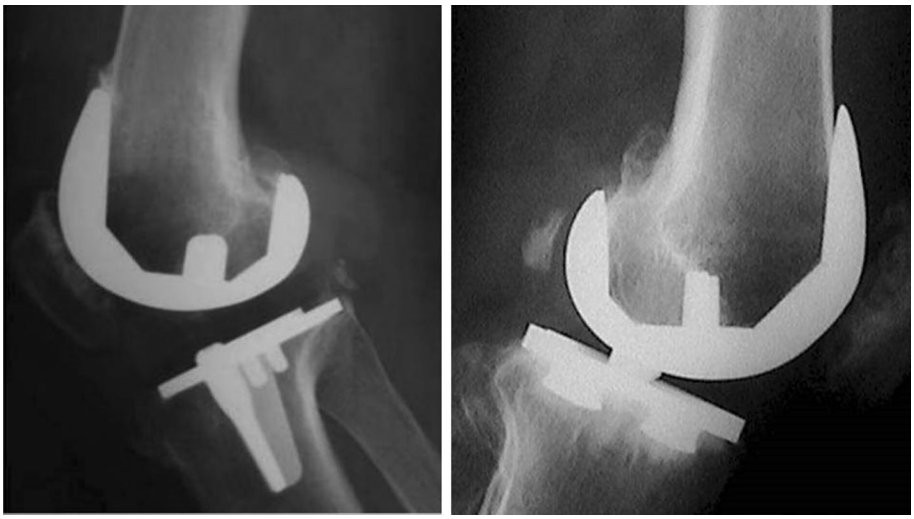

Fig. 1 Two cases of TKA osteopenia of the front half of the distal femur after 5 years

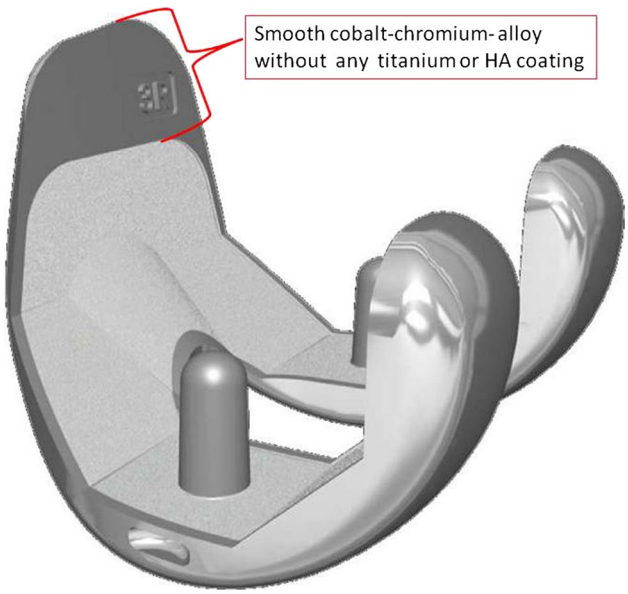

Fig. 2 Non-coated femoral shield for the "cementless" version

Fig. 3 Femoral shield surface for the "cemented" version

radiography enables a good indication of this bone density [3].

All study subjects had a lateral radiograph taken before and 3 months after surgery. The radiograph was taken following a previously established protocol: Fluoroscopy was used to ensure rigorous profile correct adjustment to the lateral plane.

The radiographs were photographed with a digital camera with a fixed focal length 55 mm and aperture f 2.8. The images were captured in a 256-level grayscale without any compression. The digital image analysis was performed on a PC using the public domain Image J 1.43 program for Windows (developed at the U. National Institutes of Health).

We defined two regions of interest (ROIs) of 1 cm^2 area situated in the distal femoral epiphysis on a straight line XY, parallel to the distal surface of the prosthetic femoral shield, cutting the shield at the lowest part of the prosthetic trochlea in points X in front and Y behind; on this segment, point A is situated at the junction of the anterior 1/3 and middle 1/3; point P is situated at the junction of the middle 1/3 and posterior 1/3 (Fig. 4). The optical density was measured (value of α at point A and value of π at point P) in the defined ROIs over a 0–256 grayscale. Through assimilation, in this study, the measurement of bone densities will be the measure of gray levels α and π.

It consists in a relative measure between two same areas at different moments; it does not consist in measures in absolute values, which are not comparable from one time to another, seeing the diversity of the radiographic pictures according to where they were performed.

All X-ray images were studied by an independent radiologist; he calculated the density ratio α/π between the two points at a set time; the same measure and the same

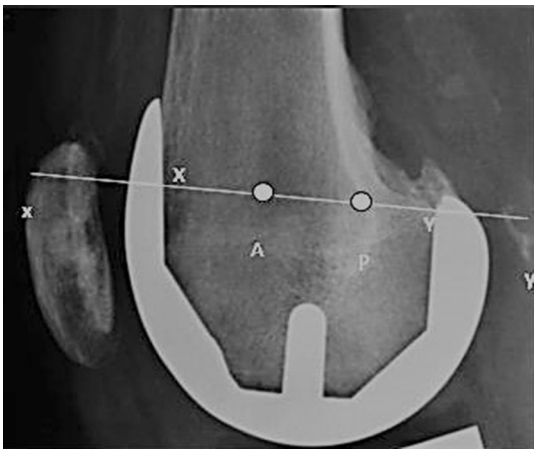

Fig. 4 Pattern of osteopenia measure on TKA lateral view

calculation at a later time (follow-up at 3 months, 1 year and more). It enabled us to compare these relations and their evolution in time and therefore to quantify the speed at which osteopenia appeared and escalated in zone A with respect to zone P, as described in the literature.

We analyzed the radiographs of a continuous prospective series (series I) of 21 cementless cruciate retaining TKA (FHK by Orthopedics, Heimsbrunn, France), performed by one single senior operator, without clinical or radiological complications. The average age of the patients was 68.3 (52–80) and 2/3 were women. Radiographical pictures were taken immediately after surgery then a radiographical follow-up was performed at 3 ± 0.5 months after lateral radiographs were retained.

This series I of the FHK prosthesis was also studied using lateral radiographs with the same technical requirements, at 5 ± 0.25 years follow-up to study on evolution over time of the bone densities at the same points of distal femoral epiphysis.

Finally, we collected within three surgeons specialized in knee arthroplasty (*members of the AGREG GECO, Mulhouse, France*), 17 X-rays (series II) meeting criteria relative to rigorous lateral radiography and concerning a knee prosthesis (Academia by Orthopedics, Heimsbrunn, France), without the particularity of the FHK prosthesis on the posterior face of the prosthetic shield (therefore with fixation of the prosthesis in the back of the prosthetic trochlea, osseous for cementless and cemented for the others); these pictures with 4–5 years follow-up were analyzed specifically to see whether there were any visible advantages to this particularity when comparing X-rays.

Statistics Nonparametric test for paired data was used, and two-tailed p values less than .05 were considered significant.

Results

In series I, namely in the study of pictures of the FHK prosthesis taken immediately before surgery, (Table 1), ratio of posterior density at point P to anterior density at point A is on average 0.8623 with limit values from 0.614 to 0.996 (SD 0.078); by assimilation these are also the density ratios preoperatively. This means that preoperatively bone density measured by radiograph is averagely 14% (13.77) higher in the back half compared to the front half of the knee.

In the series I, at 3 months $\pm$ 15 days, (Table 2), the ratio of these same FHK prostheses of this series, becomes 0.7683 with limit values of 0.6012–0.9020 (SD 0.053). Therefore, it is now 23% higher in the back area compared to the front of the epiphysis; loss of bone density in the anterior third is near 9% (9.4%) at 3 months compared to the preoperative situation. Table I. Statistics for paired data pre-op and 3 months post-op: Paired-samples t test points α and π: $p = 0.49$; two-tailed probability test: $p = 0.0318$

This loss of density does not worsen in the following years; measures of gray density at 5 years $\pm$ 12 months in 12 cases (Table 3) of the same FHK prosthesis of the series I described above were used to calculate a density ratio at an anterior point A compared to a density ratio at a cases posterior point P of 0.8468 from 0.7922 to 0.9342 (SD 0.774). Loss of anterior density is around 15% at 5 years (15.3%) relative to 9.4% at 3 months. Statistics for paired data pre-op and 5 years post-op. Paired-samples t test points α and π : $p = 0.48$; two-tailed probability test: $p = 0.0681$

However, loss of bone density in the anterior area compared to the posterior area, measured on the lateral radiographs of the 17 TKA (series II) of another type, at 5 year $\pm$ 4 months (Table 4) is more than 42% (42.53) (Fig. 5). The ratio of gray levels at point A compared to posterior point P is indeed on average 0.5864 (from 0.4211 to 0.7317). This difference is highly significant and means a high level of anterior osteopenia.

Discussion and conclusion

Osteopenia due to mechanical failure has been known for over a century [18]: When the bone does not "work" enough because of a mechanical shunt, it resorbs; this is stress shielding. Consequences in knee arthroplasty have been worrying orthopedic surgeons since the end of the last century [3, 14, 16]. Indeed, they all note osteopenia in the front half of the distal epiphysis of the femur. It

Table 1 Grayscale data of FHK prosthesis immediately before surgery

Surname	Name	Sex	Follow-up	Grayscale value		Ratio density Ant/post
				Ant	Post	
log	f	f	Post-op	2305	2456	0.9385
dos	j	f	Post-op	2192	2768	0.7919
bih	s	f	Post-op	2604	2842	0.9163
cla	i	f	Post-op	2299	2619	0.8778
rus	s	f	Post-op	2098	2440	0.8598
are	f	m	Post-op	2349	2561	0.9172
dus	d	m	Post-op	1960	2284	0.8581
mul	s	m	Post-op	1769	2122	0.8336
sen	a	f	Post-op	2506	2796	0.8963
sut	a	m	Post-op	2289	2677	0.8551
les	n	f	Post-op	1824	1891	0.9646
cal	g	f	Post-op	2175	2706	0.8038
bar	c	f	Post-op	2121	2475	0.8570
fuc	jp	f	Post-op	2542	2686	0.9464
blu	r	f	Post-op	3538	3860	0.9166
vig	r	m	Post-op	1689	2749	0.6144
vou	jl	m	Post-op	2633	3218	0.8182
rin	m	f	Post-op	2155	2399	0.8983
loo	y	f	Post-op	2262	2768	0.8172
ste	a	m	Post-op	2364	2548	0.9278
von	p	f	Post-op	1637	1883	0.8694
pod	d	m	Post-op	1477	2341	0.6309
per	m	m	Post-op	2343	3085	0.7595
mat	m	f	Post-op	2217	2234	0.9924
pat	m	f	Post-op	2576	2584	0.9969

appears mostly in the first 3 months following the fitting of a knee prosthesis and within a year the extent and significance levels off with stabilizing at a maximum at 2 years [3, 14]. There is no real difference between cemented and cementless prosthetic shields [9, 13, 14]. The danger is loss of bone, substance through resorption, usually from 20 to 50% [11, 14], which causes reconstruction problems [7, 12] when performing tardive revision for loosening. This osteopenia is also a weak point, which explains the high level of supra and intercondylar fractures, after minor trauma [5], of prosthesis fitted for a number of years.

Many authors [3, 4, 6, 9, 11, 14, 15] agreed that stress shielding in the back of the prosthetic trochlea was the mechanical cause of osteopenia. We therefore modified the biomechanical conditions of the shield to avoid any direct contact or bone fixation at the level of the trochlea; we so chose to have just the smooth surface of chrome cobalt alloy without titanium and hydroxyapatite at the back of the prosthetic trochlea for cementless prosthesis, avoiding so any fixation there; we chose not to put methylmethacrylate cement behind the trochlea for cemented prosthesis leaving smooth chrome cobalt alloy surface into contact with bone there < by preventing any bone fixation. We then studied the outcome of this usual area of osteopenia with these new implants.

DEXA densitometry is the standard method to measure bone density [10]. It is more sensitive and shows positive results earlier that simple radiographs [6, 12] but Hernandez-Vaquero et al. [4] as well as Robertson and all [12] studied the gray density on radiographs and confirmed high consistency between the two measures. Densitometry has the advantage of being more sensitive and therefore shows results sooner when measuring a difference [4]; however, its main drawback is its lack of availability everywhere and the prohibitive cost compared to a simple radiograph.

Radiographs have the advantage of being available everywhere and they are inexpensive; they are, however, quite difficult to carry out as we wanted perfectly lateral images to allow comparison over time for one same patient. For tracking and to obtain a perfectly lateral picture, ideally fluoroscopic visualization should first be used.

Our measures of loss of anterior bone density (42%) in the series B (prosthesis with fixation at the back of the trochlea) match those in the literature; Karbowski [6], Soininvaara [14], Petersen [11] found relative loss of 32–44% at 6 months to a year with DEXA densitometry measures.

Table 2 Grayscale data of FHK prosthesis 3 months after surgery

Surname	Name	Sex	Follow-up	Grayscale value		Ratio density Ant/post
				Ant	Post	
log	f	f	3 m	1833	3049	0.6012
dos	j	f	3 m	2099	3016	0.6960
bih	s	f	3 m	2008	2442	0.8223
cla	i	f	3 m	1596	2776	0.5749
rus	s	f	3 m	1610	2321	0.6937
are	f	m	3 m	2221	3107	0.7148
dus	d	m	3 m	1925	2550	0.7549
mul	s	m	3 m	2141	2832	0.7560
sen	a	f	3 m	2135	2812	0.7592
sut	a	m	3 m	1817	2377	0.7644
les	n	f	3 m	2156	2816	0.7656
cal	g	f	3 m	2246	2854	0.7870
bar	c	f	3 m	2641	3147	0.8392
fuc	jp	f	3 m	1992	2313	0.8612
blu	r	f	3 m	2401	2662	0.9020
vig	r	m	4 m	1898	2820	0.6730
vou	jl	m	4 m	2229	3041	0.7330
rin	m	f	4 m	2205	2902	0.7598
loo	y	f	4 m	2055	2550	0.8059
ste	a	m	4 m	2156	2657	0.8114
von	p	f	4 m	2100	2430	0.8642
pod	d	m	4 m	1893	2723	0.6952
per	m	m	4 m	2271	2685	0.8458
mat	m	f	4 m	2255	2618	0.8613
pat	m	f	4 m	2244	2591	0.8661

Table 3 Grayscale data of FHK prosthesis 5 years after surgery

Sex	Delay of F.U.	Grayscale value		Ratio density Ant/post
		Ant	Post	
f	4y	2542	3321	0.7654
f	4y	2548	3068	0.8305
f	5y	2365	2838	0.8333
m	4y	2142	2562	0.8361
f	5y	2051	2818	0.7278
m	4y	1954	2548	0.7669
m	5y	2050	2550	0.8039
f	4y	2193	2805	0.7818
m	5y	2111	3116	0.6775
m	5y	1835	2645	0.6938
f	5y	2106	2673	0.7879
f	5y	2379	3003	0.7922

Cameron and Cameron [3] and also Mintzer and all [9] showed with radiological studies that loss of bone levels was about the same value. But the same applies to our study on the FHK cementless prosthesis (series I): Loss is only 9.4% after 3 months and only 15.3% at 5 years.

Table 4 Grayscale data of another prostheses 5 years after surgery

Sex	Delay of F.U.	Grayscale value		Ratio density Ant/post
		Ant	Post	
f	4y	720	1710	0.4211
m	4y	873	1811	0.4821
f	5y	910	1440	0.6319
f	4y	987	1800	0.5483
f	4y	1080	1845	0.5854
f	5y	1125	2565	0.4386
f	5y	1217	2025	0.6010
f	5y	1260	2115	0.5957
f	5y	1356	2700	0.5022
m	4y	1440	2340	0.6154
f	5y	1485	2385	0.6226
m	5y	1530	2520	0.6071
m	5y	1530	2295	0.6667
m	5y	1620	2340	0.6923
f	5y	2115	3240	0.6528
m	4y	2250	3915	0.5747
m	5y	2700	3690	0.7317

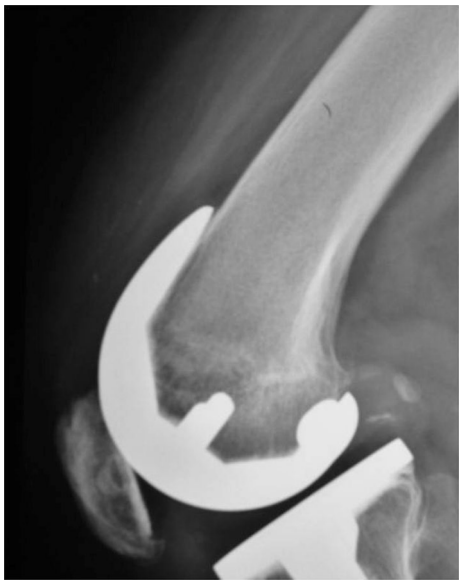

Fig. 5 Cases of cemented FHK shield after 5 years

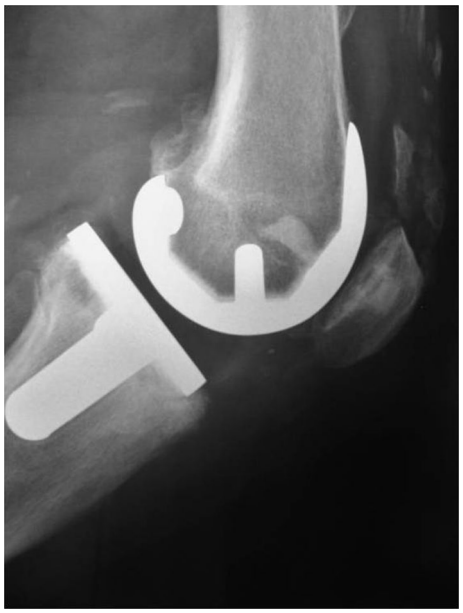

Fig. 6 Cases of cementless FHK shield after 6 years

Van Lenthe et al. [16] as well as Tissakht et al. [15], Petersen et al. [11] and Lewis et al. [8] showed with studies based on finite element analysis that this loss of bone density was caused by stress shielding. Seki et al. [13] and then Abu-Rajb et al. [1] showed that the phenomenon is similar with no significant differences between cemented and cementless prosthesis. Therefore, we did not make another series of cemented TKA.

Barink et al. [2] studied with finite element method and proved that no fixation of the anterior flange of the femoral shield may significantly reduce bone resorption in the distal anterior femur, without jeopardizing the fixation of the femoral implant. The fixation of the femoral component with different bonding characteristics was quantified. The results showed that a bonded femoral component with a debonded inner side of the anterior flange may experimentally significantly reduce bone resorption in the anterior distal femur, without jeopardizing the fixation of the femoral implant.

This loss of density, therefore bone substance, is always underestimated [17] and can cause serious problems when reconstruction is required [9] that must be preempted when considering a tardive revision for loosening. It is also the cause of supracondylar fractures of the distal femur that are complex and difficult to treat as the result of simple falls on the TKA implanted several years before [5, 7, 9]. Prevention of bone loss is the best treatment.

The benefits of this concept of prosthetic shield are confirmed by a very lower measure of loss of density in cemented (Fig. 5) as in cementless TKA (Fig. 6) thanks to non-fixation at the back of the trochlea and consequently the biomechanical advantage compared to classical models of total fixation of the femoral shield of conserving maximal osseous stock.

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Compliance with ethical standards

Conflicts of interest The author declares that funds are coming in due to the licensed patent to FH Orthopedics, 68,990 Heimsbrunn, France, but he did not receive any financial support for this study.

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