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Tibial component positioning in total knee arthroplasty: bone coverage and extensor apparatus alignment

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Abstract Correct positioning of the tibial component in total knee arthroplasty (TKA) must take into account both an optimal bone coverage (defined by a maximal cortical bearing with posteromedial and anterolateral support) and satisfactory patellofemoral tracking. Consequently, a compromise position must be found by the surgeon during the operation to simultaneously meet these two requirements. Moreover, tibial tray positioning depends upon the tibial torsion, which has been shown to act mainly in the proximal quarter of the tibia. Therefore, the correct application of the tibial tray is also theoretically related to the level of bone resection. In this study, we first quantified the torsional profile given by an optimal bone coverage for a symmetrical tibial tray design and for an asymmetrical one. Then, for the two types of tibial trays, we measured the angle difference between optimal bone coverage and an alignment on the middle of the tibial tubercule. Results showed that the values of the torsional profile given by the symmetrical tray were more scattered than those from the asymmetrical one. However, determination of the mean differential angle between the position providing optimal bone coverage and the one providing the best patellofemoral tracking indicated that the symmetrical prosthetic tray offered the best compromise between these two requirements. Although the tibiofemoral joint is known to be asymmetric in both shape and dimension, the asymmetrical tray chosen in this study was found to fulfill this compromise with more difficulty.

Key words Total knee arthroplasty · Bone coverage · Patello-femoral tracking

Introduction

The implantation of a total knee arthroplasty (TKA) requires, among other considerations, correct positioning of the tibial component to provide the best long-term stability of the prosthesis [12]. Lotke and Ecker [19] insist upon adequately setting the tibial component in the frontal plane, while other authors identify mispositions of the tibial tray in the transverse plane [8] as another possible source of failure. Indeed, malrotating the tibial component with respect to the femoral one [4, 18, 23] can lead to premature tibial polyethylene wear, one of the most common causes of revision in TKA [5].

Concerning the position of the prosthetic tibial tray in the transverse plane, the surgeon should basically integrate two factors simultaneously when implanting it. Both an ‘optimal’ bone coverage ensuring thorough stability and a satisfactory extensor apparatus alignment providing a harmonious patellofemoral tracking should be supplied by the tibial component.

Optimal bone coverage is achieved when the tibial component covers most of the underlying tibial plateau [9, 12, 16] or, more precisely, when it provides a maximal cortical bearing over the plateau circumference [2, 6]. In such a position, the most even load distribution [15] is obtained, together with optimal fixation possibilities [12].

On the other hand, when choosing between two possible tibial tray sizes, the surgeon should select the smaller one to prevent excessive overhang of the prosthetic component, which could be deleterious to the surrounding soft structures [21, 24]. In such a case, there is no consensus as to how well the component should fit on the underlying tibial plateau, since undersizing prevents an optimal cortical coverage. Some authors [10, 11, 15, 20] recommend an equidistant position of the implant from the cortices of the underlying tibial plateau, the subchondral bone of the tibial plateau being more resistant in the center of the condyles directly underneath the maximal weight-bearing zones.

Blœbaum et al. [3] showed that the cortical bone is significantly thicker in the posterior and medial areas of the tibial plateau. These areas should therefore support the tibial component, which is acknowledged to be the part most susceptible to loosening [1]. However, by only seeking support on the posteromedial areas, there is a high risk of anterolateral subsidence [22, 24]. This risk could be diminished by positioning the tibial implant not only on the posteromedial areas but also on the anterolateral cortical bone, in order to distribute loads more evenly over the proximal tibia and prevent an anteroposterior tilt of the plate.

Maintaining a satisfactory patellar tracking is the second major condition to fulfill in order to implant the tibial component correctly in the transverse plane. Such a position is achieved by aligning the tibial implant on the tibial tubercule (TT) [13]. However, this particular position does not necessarily match the one calculated to achieve the optimal bone coverage explained above. Consequently, a compromise position must be found by the surgeon during the operation to simultaneously meet these two requirements, regardless of the femoral component.

Moreover, the anatomical tibial torsion may influence the positioning of the tibial tray. Indeed, according to Jakob et al. [14] and Lerat and Taussig [17], tibial torsion acts mainly in the proximal quarter of the bone, precisely where the tibial cuts are performed for a TKA. There are great variations in its values between individuals, and this may therefore interfere with the optimal positioning of the tibial tray.

Our anatomical, surgical, and radiological study was carried out to improve understanding of the relationship between an ‘optimal’ bone coverage of the tibial plateau by the prosthetic tray and an ‘acceptable’ patella tracking. In the first part, the proximal tibial torsion of 20 fresh-frozen specimen knees was quantified. In the second part, for each specimen, we determined at the standard tibial resection depth in a TKA (i.e., 8 mm according to Insall et al. [13]) the angle between the position providing optimal bone coverage and that ensuring satisfactory patella tracking obtained by alignment on the tibial tubercule. Finally, the influence of the tibial prosthetic design, symmetrical or asymmetrical, on this angle was assessed.

Materials and methods

Twenty Caucasian fresh-frozen cadaver knees (10 male and 10 female, mean age 70.1 ± 7.1 years) with no radiological evidence of pathology were obtained for the study. The anatomical axes of the femur and tibia were defined by intramedullary PVC rods. Each specimen was placed into a radiotransparent Plexiglas measuring jig for immobilization in hyperextension (Fig. 1.). For reproducibility purposes, the steadiness of the joint positioning in the jig was checked by anteroposterior (AP) and lateral X-rays.

The knees were then examined by a high resolution computed tomography (CT) scan (matrix 512 × 512, field of view 256 mm) that produced jointed 1 mm horizontal cuts of the proximal tibial epiphysis. The harvested data was processed by a Silicongraphics station (Mountain View, Ca., USA) and then visualized by Ultra 2.0 Voxelview software (Vital Images, Fairfield, Iowa, USA) that enabled a three-dimensional (3D) reconstruction with a Voxel size

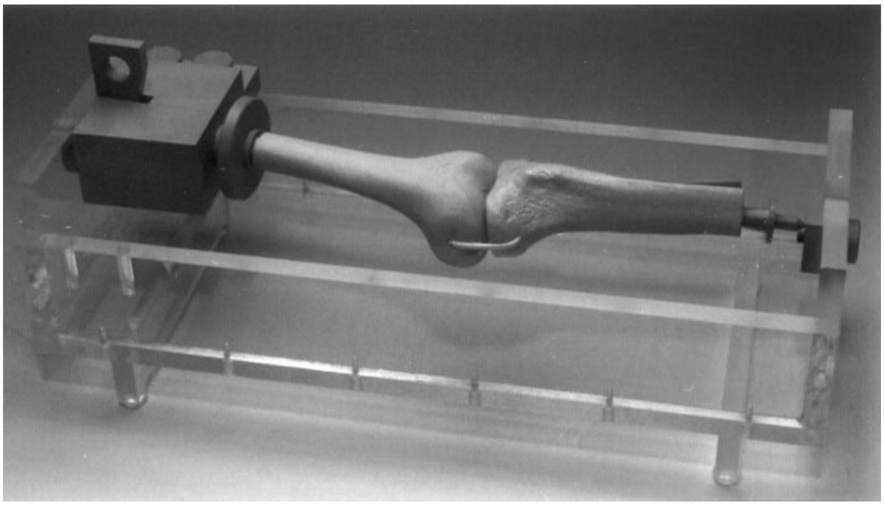

Fig. 1 Radiotransparent Plexiglas jig used for reproducible positioning with a knee model inside

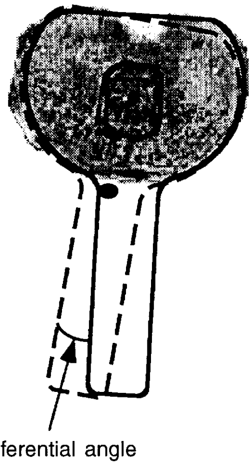

Fig. 2 The "differential angle" is defined as the angle between the position of the tray providing the optimal bone cover (*solid line*) and the one aligned on the center of the tibial tubercule (*dashed line*), represented in this figure by a *point*

of 0.5 × 0.5 × 0.5 mm. Fifteen 1-mm-thick transverse slices starting immediately beneath the subchondral bone were selected from each proximal tibia. For the first part of this study, two types of previously digitalized prosthetic tibial trays (symmetrical: Insall-Burstein II, Zimmer, 5 sizes; and asymmetrical: Natural-Knee, Intermedics Orthopedics, 6 sizes) were positioned on each slice to provide an optimal tibial plateau coverage, irregardless of the alignment on the tibial tubercule. The positioning of these virtual trays was performed by an experienced knee surgeon.

The criteria for optimal plateau coverage were defined by:

1. Centering of the tray whose size matched the underlying tibial plateau contour the best;
2. Maximal cortical bearing over the plateau circumference with an anterolateral and a posteromedial support;
3. In case of inadequate size necessitated by the choice between two sizes, the smaller one was preferred.

The angle made by the tibial tray on the different slices (first slice S1 to last slice S14) were measured and called, respectively, α_1 to α_{14}. The angle of the tibial tray on the first slice (S1) was chosen as the reference. Subsequently, the relative torsional profile of the proximal tibia was defined as the difference between the angle α_1 (slice S1) and all following angles to α_{14}.

In the second part of the study, for each tibial specimen, we focused on the 8-mm-deep resection slice (S8), this distance representing the average tibia resection depth when implanting a TKA [13]. On this particular slice, the angle between the position of the tray providing the optimal bone cover (as in the first part of this study) and the one aligned on the center of the tibial tubercule was measured for each knee and for each design of implant (symmetrical and asymmetrical). This angle was called the differential angle (Fig. 2). Student's *t*-test was used to determine its correlation between male and female samples.

Results

The results for all specimens, at a depth of 8 mm beneath the subchondral bone, are summarized in Table 1.

Table 1 Differential angle for the symmetrical and asymmetrical prosthetic trays at 8 mm depth (S8) for the 20 specimens (*r* right knee, *l* left knee, *m* male, *f* female)

Specimen no.	Differential angle with the symmetrical tray (deg)	Differential angle the asymmetrical tray (deg)
304 rm	7	13
304 lm	12	20
311 rm	4	15
311 lm	13	19
322 rm	13	24
322 lm	12	24
56 rm	12	22
56 lm	7	20
7 rm	12	22
7 lm	14	20
49 rf	1	20
49 lf	2	20
349 rf	10	15
349 lf	12	15
340 rf	9	20
340 lf	16	21
331 rf	5	15
331 lf	10	21
327 rf	12	15
327 lf	13	17
Mean ± SD	9.8 ± 4.1	19.1 ± 3.1

Relative torsional profile

The relative torsional profile for the symmetrical tibial tray is displayed in Fig. 3 for one male and one female specimen. Three types of torsional profile were obtained among the overall population of specimens.

The most common one (50% of the specimens), represented by the female specimen in Fig. 3, is characterized by nonexistent torsion during the first slices, followed by an almost linear torsion increase until the last slice (S14). The level of the torsion increase was variable among the specimens, but generally between S5 and S10.

The second type of profile (30% of the specimens), represented by the male specimen in Fig. 3, is characterized by nonexistent torsion during the first few slices (S2 or S3), then an increase until S10 or S11, followed by a decrease to S14.

The third type of profile (20% of the specimens) showed an almost nonexistent torsional profile.

Interestingly, we observed that the torsional profiles were symmetrical for the left and right knees of each specimen.

The relative torsional profile for the asymmetrical tibial tray is displayed in Fig. 4 for the same male and female specimens studied for the symmetrical tray. Here, only one type of torsional profile was identified, corresponding to the first torsional profile of the symmetrical tray. The level at which the torsion began to increase was almost constant for the female specimens (between S0 and S3) and more scattered (S3 to S7) for the male specimens.

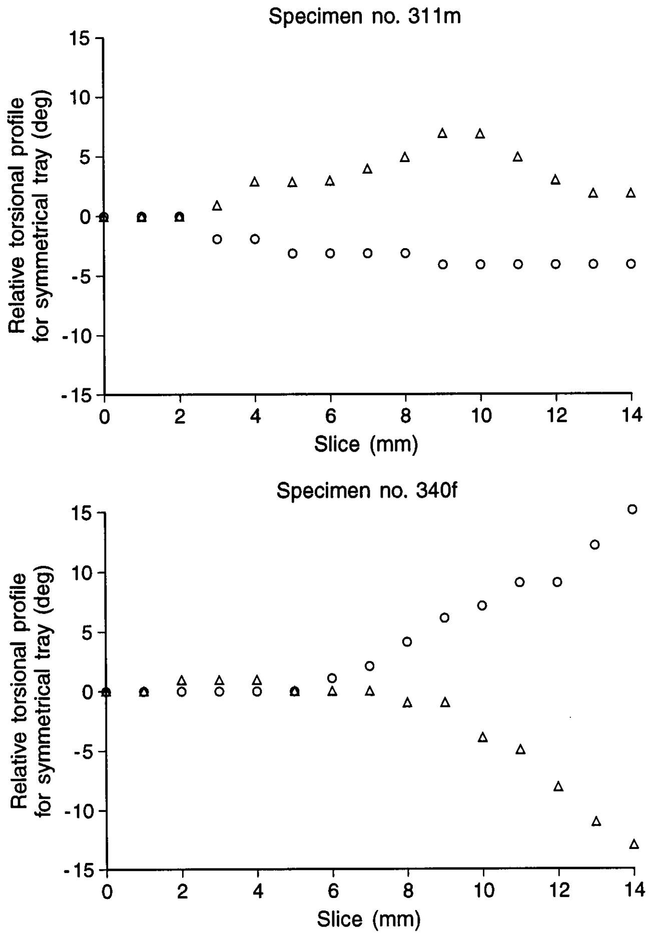

Fig. 3 Relative torsional profile for the symmetrical tibial tray for one male specimen (no. 311m) and for one female specimen (no. 340f) as a function of the cut slice (○ left knee, △ right knee). The male specimen had a lateral torsion and the female specimen a medial torsion with regard to reference slice S1

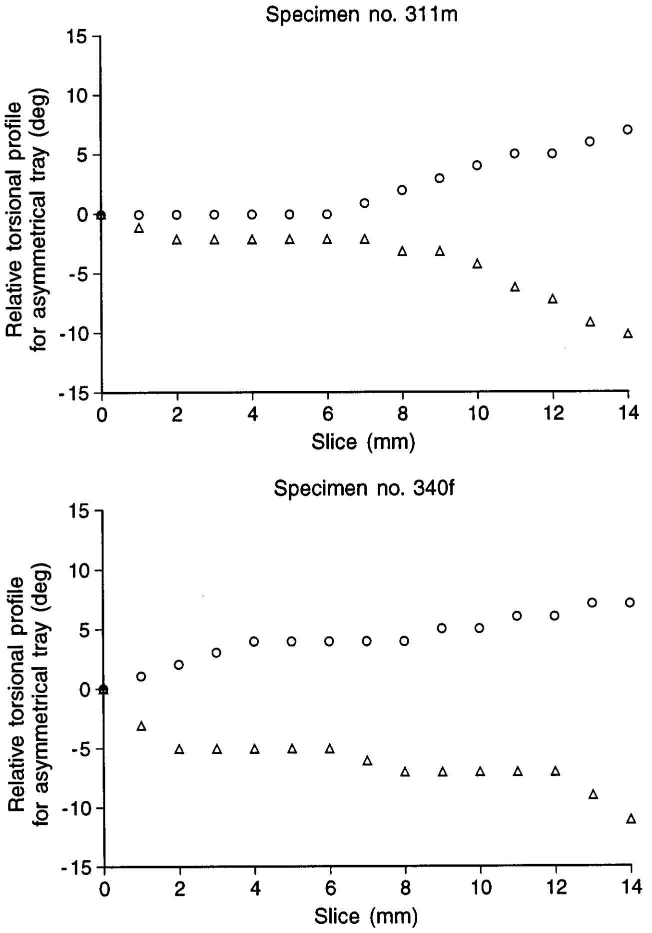

Fig. 4 Relative torsional profile for the asymmetrical tibial tray for one male specimen (no. 311m) and for one female specimen (no. 340f) as a function of the cut slice (○ left knee, △ right knee). The two specimens had a medial torsion with regard to reference slice S1

As for the symmetrical tray, the torsional profiles were symmetrical for the left and right knee of each specimen for the asymmetrical tray.

The relative torsional profile of the overall male and female populations for the symmetrical tray are shown in Fig. 5. Only the left knee results are displayed, as the corresponding right knees had symmetrical profiles. We observed that the dispersion of the torsional profiles concerned not only the profiles themselves, but also the quantitative values of the torsion. Indeed, these values varied between 4 deg of lateral torsion to 10 or even 15 deg of medial torsion. This is particularly true for slice S8, in which the values varied from 3 deg laterally to 5 deg medially for the female specimens, and from 3 deg laterally to 3 deg medially for the male ones.

The relative torsional profiles of the overall male and female populations for the asymmetrical tray are shown in Fig. 6. Here again, only the left knee results are displayed. For the asymmetrical tray, the profiles were more homogeneous from both qualitative and quantitative points of view. Indeed, if slice S8 is considered, the torsional values varied between 1 and 6 deg for the female specimens and between 2 and 4 deg for the male specimens, all of these values corresponding to a medial rotation with regard to reference slice S1.

The differential angle

The differential angles at level S8 for the symmetrical and asymmetrical trays are displayed for all specimens in Table 1.

As far as the symmetrical tibial tray is concerned, the differential angle had a mean value (± 1 SD) of 9.8° ± 4.1°. The mean male and female differential angles, 10.6° ± 3.3° and 9.0° ± 4.8°, respectively, were not statistically different (paired Student's *t*-test, $P = 0.114$).

The differential angle for the asymmetrical tibial tray had a mean value (± 1 SD) of 19.1° ± 3.1°, the mean male

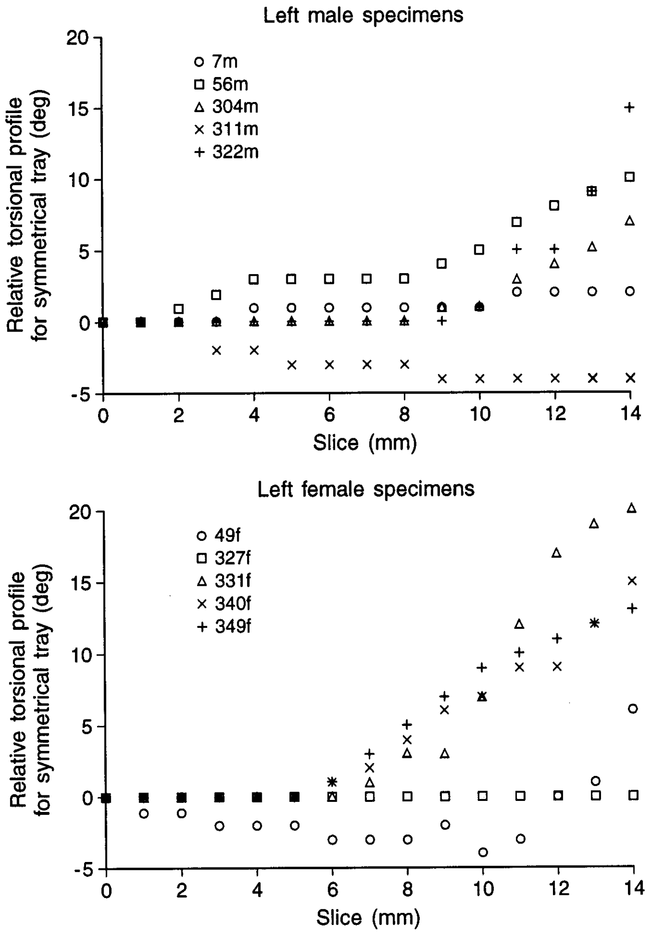

Fig. 5 Relative torsional profile for the symmetrical tibial tray for the left male and left female specimens. The male specimen no. 311m and female specimen no. 49f showed lateral torsion with regard to reference slice S1, while all other specimens had a medial one

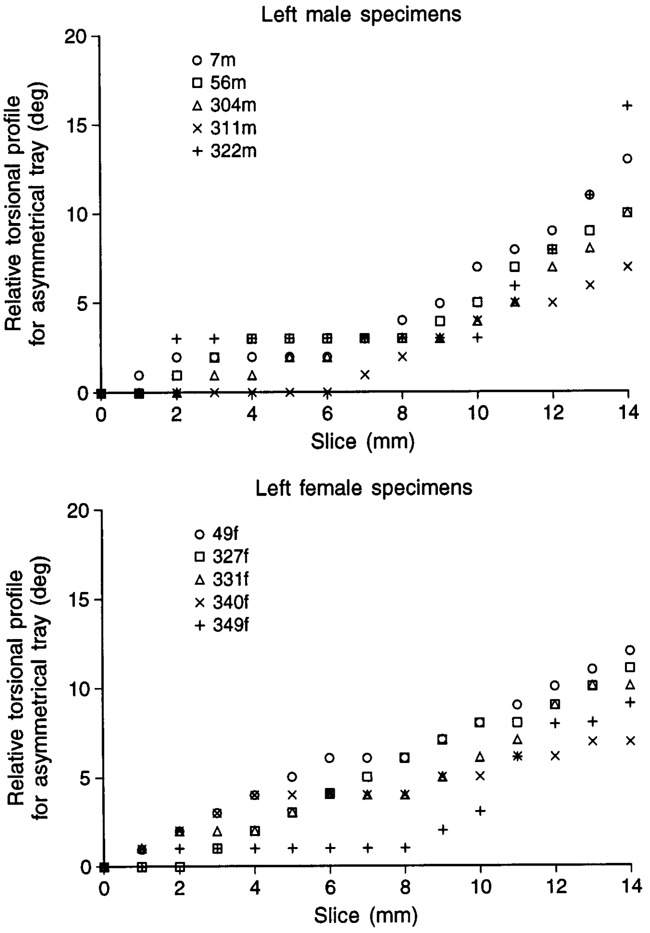

Fig. 6 Relative torsional profile for the asymmetrical tibial tray for the left male and left female specimens. All specimens showed medial torsion with regard to reference slice S1

angle being 19.9° ± 3.5° and the mean female angle, 18.3° ± 2.5°, which are not statistically significantly different (paired Student's *t*-test, $P = 0.599$). The mean differential angle yielded by the asymmetrical tibial tray was approximately twice that given by the symmetrical one.

Discussion

Up to now, tibial torsion has been evaluated through the variations of the posterior, anterior bicondylar axes, or the transtibial axis [7]. Such methods of assessment only take into account unidimensional changes in the shape of the proximal tibia whereas measuring the varying positions of accurately fitted prosthetic implants seems more representative of bidimensional changes of the contour.

In this study, we quantified the prosthetic torsional profiles given by symmetrical and asymmetrical tibial trays within the first 14 mm of the proximal tibia, starting immediately beneath the subchondral bone. The relative tibial torsions yielded by the tibial trays varied greatly.

The tibial torsion produced by the symmetrical tray was the less homogeneous measurement since it was almost equally divided between lateral, neutral, or medial rotations. This is particularly obvious at level S8.

The general orientational trend of tibial torsion for the asymmetrical tray was medial and far higher in mean values. The only explanation we could find for such a contradictory result was the way in which we deliberately fitted our asymmetric prosthetic trays. Because of frequent undersizing, the lateral tibial tray was positioned rather more against the anterolateral cortical rim than the posterolateral one, in order to achieve a better anteroposterior stability, as shown by Blœbaum et al. [3] and Goldstein et al. [10]. For this reason, the medial trend of the tibial torsion given by the asymmetrical trays was probably induced by changes of the anterior bicondylar axis along the studied level of the proximal tibia.

As explained in the introduction, both the posteromedial and the anterolateral supports of the tibial tray are important to prevent a possible anterior subsidence of the tray [22, 24]. Anterior subsidence of the tibial tray could occur if only a posteromedial support is preferred.

In our opinion and from a qualitative point of view, the symmetrical tray on the proximal 14 mm of the tibia appeared to fit the bone contour better whatever the variations of shape according to what can be assimilated to a resection level. We agree on this particular point with Incavo et al. [12], who studied the tibial plateau coverage of various prosthetic trays.

This impression was probably derived from the almost constantly undersized contour of the lateral tray of the asymmetric implant studied (Natural Knee, Intermedics Orthopedics) which we thought was more a 'symmetric' asymmetrical prosthesis than a true asymmetrical one. Therefore, other asymmetrical profiles which seem more 'anatomical' than this particular one deserve to be tested.

As far as the dispersion of the relative torsional profiles is concerned, it is difficult to establish one single torsional profile. Indeed, each specimen tends to have its own torsional profile, as shown in S8, where the values of the relative torsion varied between 0 and 6 deg. As a consequence, the relative torsional profile seems to have little influence on a practical case, like, for example, during a TKA implantation.

The values of the mean differential angle at 8 mm of depth between the position providing the best cortical coverage and the one providing the best patellofemoral tracking were closely linked to the former series of measurements.

With a 9.8° ± 4.1° mean angle, the symmetrical prosthetic tray appears to offer the best compromise between long-term stability and satisfactory patellar tracking, two major requirements for a TKA implant. Although the tibiofemoral joint is known to be asymmetric in both shape and dimension, the asymmetrical tray was found to fulfill this goal with greater difficulty, with a mean differential angle of 19.1° ± 3.1°. However, here again, other designs of asymmetrical plates should be compared for the reasons explained above.

In our study, although the symmetrical tray was acknowledged to better produce concomitantly optimal bone coverage and satisfactory patellar tracking, such results can still be improved. Technological or surgical solutions exist to minimize the mean differential angle and subsequently accomplish both goals simultaneously, but they still have to be examined. Among the technological possibilities, attempts have been made to modify the design of the polyethylene on its metal back. Such is the case with the built-in rotational polyethylene components which integrate the tibial torsion, or the mobile polyethylene components ensuring automatic alignment of the extensor apparatus whatever the position of the knee. Surgery offers a controversial solution [13] through an adaptive osteotomy of the anterior tibial tuberosity performed once the implant has been sealed in a position of optimal coverage.

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