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Original article

Flexion gap stabilization by oversizing posterior condylar offset in deep-dished total knee replacement does not compromise flexion: A single-surgeon, retrospective, observational, mid-term series

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ABSTRACT

Introduction: In total knee replacement surgery, medio-lateral knee balancing is recognized as the key to achieving satisfactory functional results. But it may not be enough to stabilize the flexion gap using deep-dished implants. We achieved flexion gap balance by oversizing the femoral component, thus increasing the posterior condylar offset (PCO). The purpose of this study was to describe the applicability of this technique and to test whether it produced adverse effects on medium-term outcomes. We hypothesized that it would not compromise the results if used properly. We therefore asked: (1) at how many cases of flexion gap balance would require oversizing the femoral component; (2) if femoral components over-sizing would modify the mid-term results as per forgotten joint score (FJS) scores and whether flexion gain would be comparable to patients in whom it was not increased.
Materials and methods: Ninety-four patients (120 knees) were operated between September 2009 and 2011 (age 68 ± 9 years) using the cementless Hyperflex version of the Natural Knees (Zimmer, Warsaw, IN, USA). Postero stabilization was achieved using deep-dished inserts. The Gender configuration has provided narrow inserts to better adapt the female anatomy. A special navigation system measured the displacement of the lateral and medial femoro-tibial contact points with infra-millimetric precision. Adopting a tibial cut first, gap-balancing technique with anterior referencing, the decision to oversize the femoral component relied on the 90° flexion drawer test, which showed more than 6 mm sagittal laxity before the femoral bone cuts. Eighty-one (105 knees) patients were reviewed with average 63 ± 27-month follow-up.
Results: Femoral components were augmented by 1 size in 60 cases and by 2 sizes in 7 cases. At final review, knees with an oversized femoral component (60) achieved the same results as those implanted with a non-oversized femoral component ($n = 45$) in terms of mean flexion gain ($-5° \pm 34$ versus $-4° \pm 23$, $p = 0.78$), mean FJS (63 ± 26 versus 61 ± 23; $p = 0.56$).
Conclusion: Balancing the Flexion gap by oversizing the femoral component did not compromise flexion range and functional results.
Level of evidence: IV, Retrospective cohort study.

1. Introduction

The total knee replacement (TKR) gap-balancing technique relies on adjusting the medio-lateral equilibrium of both extension and flexion gaps. This procedure was initially proposed for the implantation of PCL subtituting (PS) implants, later on for PCL retaining (CR) and also for PCL sacrificing deep-dished (DD) implants. Frequent persistence of sagittal laxities in the latter was measured by dual fluoroscopy [1]. In the living knee with CR TKR, antero-posterior (AP) motion has been shown to occur in para-doxical directions [2,3]. It has also been noted that conventional implantation of DD posterior-sacrificing prostheses fails to control posterior laxity [4], which is found to be greater in PCR and DD than in conventional PS implants [5], and, among other causes, is incriminated in mid-term wear as well as osteolysis [6]. In fact, AP translation is suspected to increase subsurface shear stresses, subsequently inducing delamination and wear [7].

Thus, minimizing sagittal laxities appears to be important, but requires specific techniques involving precise intra-operative measurements of AP translation of both medial and lateral femoro-tibial

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contact points throughout the whole range of motion (ROM) [8]. With such navigation, extensive intra-operative recording of knee kinematics in a small series of patients revealed that it is possible to stabilize the flexion gap anterior posteriorly by oversizing the femoral component, and subsequently increasing posterior condylar offset (PCO) [9]. In fact, removing the same thickness of bone from the distal and posterior femur does not necessarily provide equal flexion and extension gaps [10]. Tibial cuts divide the anterior fibers of the PCL if a protecting bone island is not preserved, which also contributes to some flexion gap laxity. Ma et al. [10] observed that PCL resection significantly enlarges the flexion but not the extension gap. Consequently, balancing flexion and extension gaps may require less posterior than distal femoral resection.

However, tightening the flexion gap with an oversized femoral component remains controversial because it also carries the risk of provoking flexion stiffness and/or inducing excessive stresses, leading to aseptic loosening. In particular, Fujimoto et al. [11] discerned that flexion gap is strongly influenced by PCO and that excessive flexion gap tightening jeopardizes flexion range in cruciate retaining implants.

Here, we report the mid-term results in a series of patients who were followed for an average of 5 years. We investigated if neutralizing sagittal laxity by oversizing the femoral component rather than by increasing insert thickness would compromise the outcome using deep-dished implants. We hypothesized that this technique would not compromise the results if used wisely. We therefore asked:

- at how many cases of flexion gap balance would require oversizing the femoral component;
- if femoral components oversizing would modify the mid-term results as per forgotten joint scores (FJS) and whether flexion gain would be comparable to patients in whom it was not increased.

2. Materials and methods

All consecutive patients scheduled for standard primary knee arthroplasty, performed by the senior author between September 2009 and 2011, were included if they agreed to submit to a protocol involving a new navigation system described elsewhere [8]. The exclusion criteria were previous knee surgery (apart from arthroscopy), stiff knees with less than 90° of preoperative flexion, and patients who declined to participate. Apart from 1 tuberculosis, 3 rheumatoid arthritis and 3 chondrocalcinosis, aetiologies consisted of primary osteoarthritis. Of the 94 enrolled patients (120 knees), 31 were in neutral alignment, whereas 73 had varus

deformities (mean hip knee ankle [HKA] angle $171 \pm 4°$), and 16 had valgus deformities (mean HKA angle $186 \pm 4°$), as measured on preoperative long-leg-standing radiographs. According to Devane et al. scores [12], 66% of patients were sedentary and 31% were semi-sedentary before the onset of osteoarthritis. The protocol was approved by the institutional ethics committee (No. IRB00006477). Patients received the hyperflex version of the natural knee (Zimmer, Warsaw, IN, USA). Cementless porous-coated tibial and femoral components were used, declined in the Gender configuration, i.e. with narrow sizes available to better adapt to the anatomy of the woman. Antero-posterior stability was checked using a deep-dished ultra-congruent design. Patellae were not resurfaced.

Prostheses were implanted via a medial subvastus approach with a gap-balancing technique involving a tibial cut first sequence, except for knees with a valgus deformity, which were implanted via a lateral approach. A 9-mm orthogonal cut was made from the less affected tibial glenoid (medial in valgus deformities, lateral in varus deformities). Navigation helped contain postoperative femorotibial alignment between 178 and 182°, tibial slopes between 2 and 4°, and ankle knee internal angles (measuring tibial component alignment in the coronal plane relative to the tibial anatomical axis) between 88 and 92°. The PCL was not resected. However, its anterior fibres were divided as the tibial cut did not preserve a bone island.

Sagittal laxities were measured and balanced by the just-mentioned special navigation system (Praxim, La Tronche, Isère, France) [8]. This gap-balancing technique is based on the kinematics tensor concept, which assumes that sound intra-operative kinematics (defined as the absence of paradoxical movement, i.e., contact points in flexion being anterior to their referenced position in full extension) testifies to adequate balancing. Moreover, the kinematics tensor analyzes continuous motion (throughout the entire ROM) rather than sporadic measurements in these 2 positions (full extension and 90° flexion) which are not involved in normal gait. The navigation protocol required a bone-morphing procedure (i.e., palpating the articular surface to obtain a model of the patient's anatomy) and allowed the measurement of instantaneous displacements of medial and lateral femoro-tibial contact points. All displacements were measured in a 3-dimensional tibial reference frame. Thus, measurements of the antero-posterior drawer in the intermediate and final steps of the operation were undertaken with this software [8] (Fig. 1).

The decision to oversize the femoral component relied on the drawer test. It was measured at an intermediate step of the operation, i.e., with tibial trials in place, with the patella reduced, and
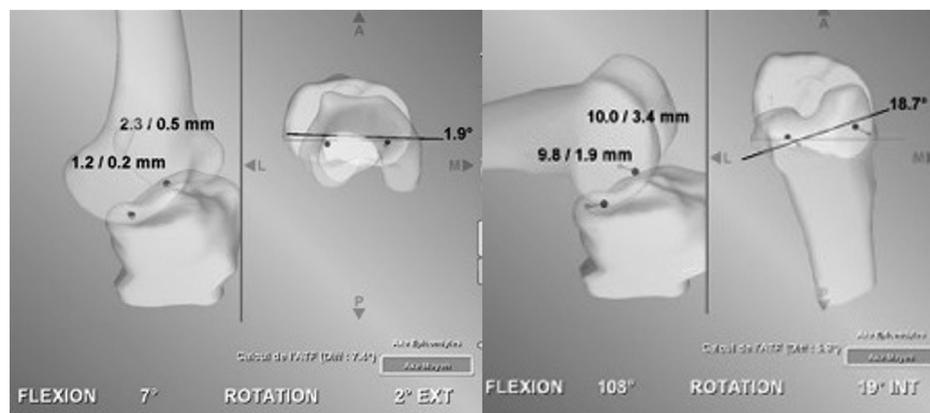
Fig. 1. The tibio-femoral contact points were defined in a three-dimensional tibial reference frame as the median and lateral condylar points with the smallest vertical distance from the tibial glenoid corresponding to time *t*. After a manual test of the 90° – drawer to the front and rear stops (with the foot held in neutral rotation), these contact points moved from their initial position. The drawer was measured as the distance between their extreme front and rear positions.
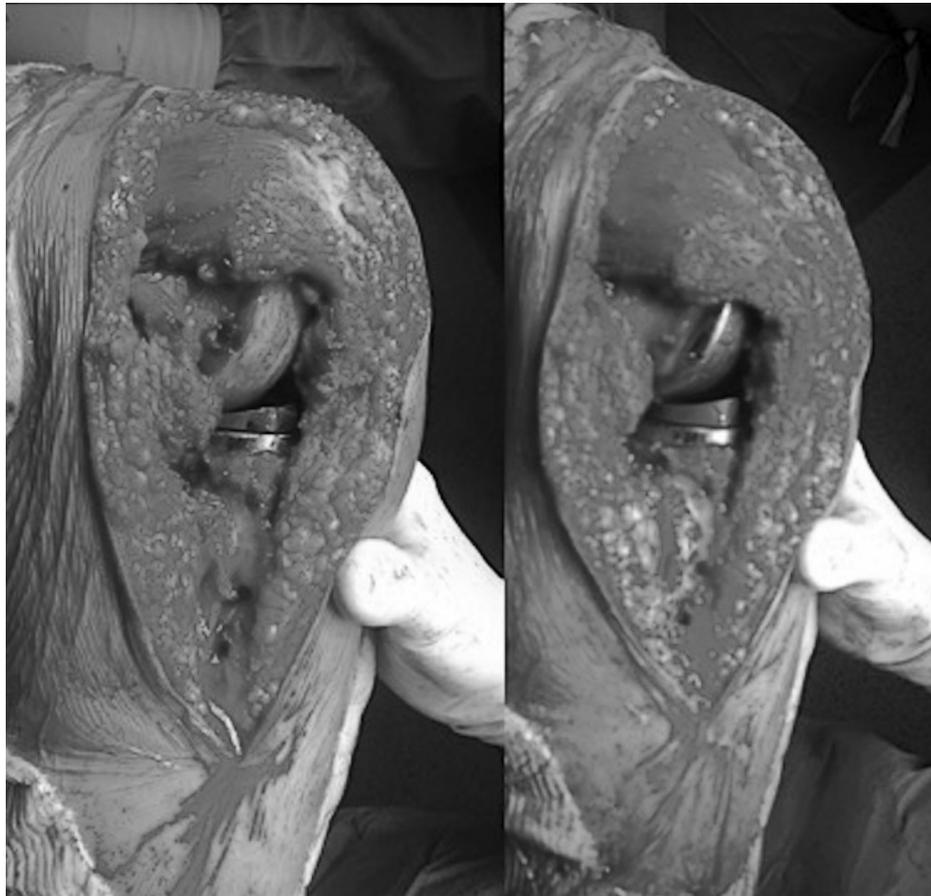
Fig. 2. Intra-operative views showing the knee in an intermediate step of the operation (patella reduced, tibial component in place, femur intact), when the AP drawer was tested, and then in the final step of the operation with both trial components in place.

before the femoral bone cuts (Fig. 2). Each drawer was repeated 3 times. The variations did not exceed 2 mm and only the highest value of the medial contact point displacement was taken into account. The final goal was to decrease 90° flexion-sagittal laxity below 6 mm without overtightening the flexion gap (no tilt of the trial insert in high flexion with the patella reduced). Below 3 mm, the insert was constantly tilted in high flexion indicating excessive tightening, which led to the 3–6 mm threshold being defined as the ideal target, assumed as the residual anterior laxity resulting from ACL resection. In fact, when the drawer magnitude fell below 6 mm, it was assumed that the posterior laxity was neutralized by the high anterior edge of the insert. In cases with persistent sagittal laxity of more than 6 mm, the posterior femoral condyles were undercut and an oversized femoral component was inserted. In the range 6–10 mm, a single-size increase was sufficient to reduce the drawer magnitude below 6 mm. In cases with more than 10 mm, an attempt was made at oversizing twice the femoral component if this did not provoke lateral overhanging. If it was not possible, a single-size increase had to be accepted despite some residual AP laxity in the order of 6–10 mm. At the end of the operation, residual laxity, if any, was definitively controlled by increasing insert thickness. It was ascertained that increased insert thickness, if needed, did not compromise full extension.

More than 10° of flexion contracture in 6 patients was associated with varus deformities. Circumferential release of the deep aspect of the medial collateral ligament (MCL), linked with resection of the posterior osteophytes, allowed complete extension at the end of the operation. In these patients, the distal femoral cut was augmented by 2 mm. However, flexion gap balance was achieved as in the other patients.

Patients were followed prospectively with yearly evaluations, including International Knee Society (IKS) scores [13], manual measurement of active flexion range, lateral, AP and skyline views, and 1-year long-leg-standing radiographs. Forgotten joint scores (FJS) were assigned to patients who were reviewed [14]. Radioscopically-guided AP and lateral views were obtained at 3 years, to scrutinize Ewald [15] zones of the fixation interface.

3. Statistical analysis

The results are reported as means and standard deviations using the flexion range and the flexion gain as primary assessment criteria and FJS and IKS as secondary criteria. Correlations between the amount of posterior resection on the medial condyle and flexion range were assessed by Pearson's correlation coefficients. Pearson's t-test and the Chi^2 test with Yates modification respectively compared quantitative and qualitative variables. When comparing these patients with an oversized femoral component to the patients with a non-oversized femoral component, it seemed reasonable to look for 15° difference from an average of 115° based on ±5° error in measuring flexion range. Setting power at 80% and alpha error at 5% required at least 16 patients.

4. Results

Overall, average posterior cut was 10 ± 2 mm for the medial and 8 ± 3 mm for the lateral condyles, with replacement by a 12-mm-thick femoral component. In 53 cases, the drawer test showed repeatedly a 3–6 mm laxity and there was no need to oversize the femoral component. In 10 cases, the AP laxity was in the 6–10 mm

Insert thickness (mm)	9	11	13	16
FC Non-oversized	53			
FC Oversized (one size)	10	15	23	12
FC Oversized (two sizes)	2	5		
Total	65	20	23	12

FC: Femoral Component

Fig. 3. This table shows the insert thickness in relation to the femoral component size. Grey zones indicate these cases with a more than 10 mm-drawer at initial testing.

range. The femoral component was augmented of one size above to its native dimensions (PCO + 3 mm), which was sufficient to reduce the drawer amplitude below 6 mm. In 57 cases there was more than 10 mm of AP laxity and the femoral component was planned to be augmented by 2 sizes. It was possible in 7 cases only (PCO + 6 mm) without provoking lateral overhang. In the other cases, a single-sized increase in femoral component size had to be combined with substantial increase in insert thickness (11 mm in 20 cases, 13 mm in 23 cases, and 16 mm in 12 cases) (Fig. 3).

Seven patients died and 5 were lost to follow-up. One patient complained of instability. It was controlled by increasing insert thickness from 9 to 13 mm. Two other implants were removed because of osteolysis related to progressive tuberculosis and late haematogenous infection, respectively. Two re-operations (tibial tuberosity and medial translation) were required owing to patellar maltracking without femoral malrotation. One obese patient with major patellar syndrome initially underwent a 1-stage bilateral procedure, and then had both patellae resurfaced secondarily due to anterior knee pain. At final follow-up, 105 implants were still in place for evaluation with 63 ± 27-month average follow-up.

The effect of oversizing the femoral component was investigated by comparing patients with an undersized medial posterior condylar cut (less than 10 mm) – which necessarily resulted in implantation of an oversized femoral component (Fig. 4) – to those with an anatomical (not oversized component), in whom the posterior medial cut was greater than 10 mm (Table 1). While the maximal tibial cut averaged 9 mm in both groups, mean insert thickness was lower in the group with oversized femoral components (10 ± 2 mm versus 11 ± 2 mm) but it was not significant ($p = 0.07$). The rate of major deformities (varus deformity 10° or higher) was greater in the group with oversized components but it was not significant (40% versus 29%; $p = 0.22$). On the other hand, mean flexion range, mean flexion and IKS score gains, and mean FJS scores were similar in both groups (p-values respectively 0.19, 0.78, 0.18 and 0.56; Table 1).

Comparing patients with 13- to 16-mm-thick inserts to those with 9- to 11-mm-thick inserts disclosed that the rate of big deformities (more than 10°) was substantially greater in the former but it was not significant (48 versus 30%, $p = 0.07$) (Table 2).

Overall, global IKS score was 182 ± 28 (Table 3). Fifty-two patients claimed that they had forgotten their knees (including the patient who had both patellae resurfaced secondarily). In fact, these 52 patients scored an average of 80 ± 6: 44 were rated as Devane 2 (semi-sedentary) and 8 as Devane 3 (leisure activity level). Range of active flexion was $115 \pm 16°$ with average −3° gain. Flexion range was not correlated with the amount of posterior resection on the medial condyle ($r = 0.01$).

Radiographically, postoperative HKA angle was $180 \pm 2°$. No measurable migration was evident. Thin (<2 mm) and stable radiolucencies were observed on AP views below the tibial baseplate in zones 1 and 4 (15 cases) and on lateral views in zones 1 and 2 (16 cases). There were none around the tibial stem.
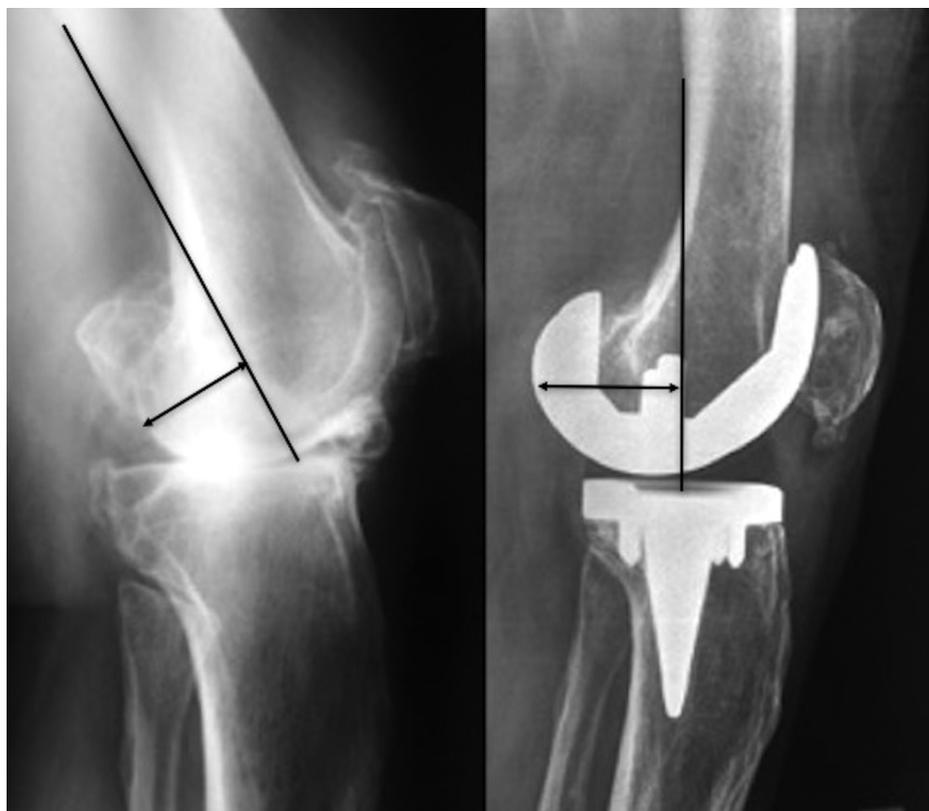
Fig. 4. Lateral preoperative and 5-year radiograph of the left knee in a 62-year old patient, showing a 3-mm increase in PCO. Active flexion range was 120°.

Table 1
Comparison at follow-up of patients with an oversized femoral component to patients with an anatomical femoral component.

	Oversized femoral component (n = 60)	Anatomical femoral component (n = 45)	p-value (two-tailed)
Age (years)	69 ± 13	68 ± 10	0.27
BMI	29 ± 7	32 ± 8	0.29
	2 missing data	*1 missing data*	
Gender (male/female)	16/44	12/33	1
Aetiology (% primary osteoarthritis)	95	92	0.25
Initial HKA (°)	−6 ± 7	−4 ± 7	0.11
Lateral tibial resection (mm)	9 ± 1	9 ± 21	0.61
Medial condyle posterior resection (mm)	8 ± 1	11 ± 1	<0.00001
Insert thickness (mm)	10 ± 2	11 ± 2	0.07
Deformities > 10° (%)	40	29	0.22
Follow-up (months)	62 ± 21	69 ± 25	0.11
Final flexion range (°)	117 ± 14	116 ± 18	0.19
Final mean flexion gain (°)	−5 ± 34	−4 ± 23	0.78
	2 missing data	*2 missing data*	
Final IKS score gain	73 ± 47	60 ± 36	0.18
	2 missing data	*2 missing data*	
FJS 12	63 ± 26	61 ± 23	0.56
	2 missing data	*2 missing data*	
Varus/valgus deformities	52/8	37/8	0.5
Lost or deceased or revised	7	8	

BMI: body mass index; HKA: hip knee ankle; FJS: Forgotten Joint Score.

Table 2
Comparison of 2 groups in the global patient population with respectively thin and thick polyethylene inserts.

	Thick polyethylene (13–16 mm) n = 35	Thin polyethylene (9–11 mm) n = 85	p-value (two-tailed)
Gender (male/female)	11/24	25/60	0.87
Initial HKA (°)	−7 ± 9	−5 ± 6	<0.3
Lateral tibial resection (mm)	9 ± 1	9 ± 0.5	1
		2 missing data	
Medial condyle posterior resection (mm)	9 ± 3	9 ± 2	0.5
		2 missing data	
Deformity > 10° (%)	48	30	0.07
Valgus/varus deformities (%)	13	16	0.7

HKA: hip knee ankle.

Table 3
Clinical results at final visit.

	IKS knee score	IKS function	IKS total	Active flexion (°)
Preoperative score	35 ± 13 (13–87)	48 ± 20 (5–90)	83 ± 28 (18–150)	116 ± 20 (0–150)
Final score	93 ± 12 (63–100)	90 ± 18 (25–100)	182 ± 28 (80–200)	115 ± 16 (80–135)
Average gain	58 ± 17 (0–100)	41 ± 25 (−50 to 100)	100 ± 38 (0–200)	−3 ± 27 (−50, 120)

IKS: International Knee society.

5. Discussion

Our most surprising finding is that a more-than-6 mm AP residual laxity was observed in more than half of the cases using a 9-mm-thick tibial component, as shown by the drawer test. In these cases, we did not follow the conventional technique combining implantation of an anatomical-sized femoral component with an increase in insert thickness, but chose to oversize the femoral component by decreasing the posterior femoral cuts so as to minimize joint line elevation. Our second finding was that this last protocol based on the drawer test (and not the flexion gap height) did not compromise mid-term flexion range or function. Using this technique offers the advantage of providing useful information before performing the femoral bone cuts. In contrast, flexion gap height measurement supposes the use of spacer blocks, which can be positioned only once the femoral bone cuts have been done. It is therefore too late to adapt the size of the femoral component.

This PCO-increasing technique has not been clearly described in the literature. According to the conventional technique that looks for equivalent flexion and extension gaps, gap measurements are subject to substantial variations in relation to tensor force and position. Moreover, ancillaries are designed to quantify condyle AP dimensions after cutting the distal femur. This determines the size of the femoral component, with AP dimensions fitting those of the native knee. The only possibility, as described by Rosskopf et al. [16], consists of placing the femoral component in 3° of flexion, which would increase PCO by only 1.6 mm. Residual laxity is eventually controlled by augmenting insert thickness. Several reasons for not oversizing the femoral component further are commonly put forward, such as lateral overhanging, which evokes painful conflict with soft tissues. In the present series, the availability of narrow Gender configurations was of great help, as they allowed femoral component oversizing without provoking lateral overhanging. Second, it is commonly admitted that excessive flexion

gap tightening can provoke flexion stiffness [17], while decreased PCO could increase ROM [18]. In contrast, in living patients, fluoroscopic analysis showed that the magnitude of PCO correlated with range of flexion [19]. In fact, increased PCO was shown to delay posterior impingement between the posterior insert rim and the femoral cortex [20]. In our series, mean flexion range was comparable to what is currently observed in other series of PS [21,22] or DD implants [23,24].

Increased insert thickness was also required in almost 50% of cases. It was substantial in 35 cases, 17 of them corresponding to major deformities (more than 10°), in which laxity on the convex side was associated with laxity of the concave side due to circumferential release of the deep aspect of the MCL (varus) or of the tensor facia lata (valgus) that was operated through a lateral approach. Here, femoral component oversizing prevented excessive elevation of the joint line. However, additional increase of PCO was not possible because the size of the femoral component would not have been compatible with tibial baseplate size.

Adjusting PCL tension and tightening the flexion gap may modify the flexion range by other ways, because it also modifies knee kinematics of CR implants. When they used spacer blocks to adjust the flexion gap, Heesterbeck et al. [25] described a decreased step-off distance at 90° of flexion (i.e. a posterior translation of the femoro-tibial contact points). Using our technique of increasing the PCO displayed the same effect in full extension [8]. Consequently, the posterior migration of contact points starts later in the course of flexion, and their overall AP translation is decreased [9]. Trying to balance CR prostheses, Yanagisawa et al. [26] made the same observation and demonstrated that such features improved ROM.

This study had several limitations. First of all, it was a retrospective, observational investigation. However, testing a flexion gap-stabilizing technique comparatively supposes that some control patients would be deliberately left with some degree of flexion laxity, which sounds quite critical. Second, long-term results are wanting, and it is not yet possible to determine the effect on wear. Third, quality-of-life scores were not considered. Attention was rather focused on the technical aspects and feasibility. Fourth, we are aware that variations may eventually occur in relation to the amount of external force applied on the tibia during the drawer test. Inter-observer measurement reproducibility was not tested in this single operator series. However, the level of force to be applied on the tibia to reach clinical relevance remains unknown. Finally, residual AP laxity was not precisely measured at final follow-up. Correlations between intraoperative measurements and active postoperative kinematics are definitively needed. From a practical point of view, it raises the problem of conveying a large number of patients to centres equipped with sophisticated measurement tools (gait analysis platform).

In conclusion, we propose implementation of the balancing technique to address sagittal laxities. Increasing PCO may contribute to flexion gap stabilization rather than excessively increased insert thickness, but it requires specific designs, such as narrow Gender components. So far, it appears not to be detrimental to mid-term clinical outcomes in terms of flexion range and gain, function and radiographic results. It may contribute to minimize wear, which remains to be verified by longer-term observation.

Disclosure of interest

Philippe Massin has received royalties from Microport, Ceram-concept and Evolutis.

The other authors declare that they have no competing interest.

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Contribution

PM: operator, wrote the paper, examined the patients.
EL and JS: contributed to patient's review.

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