Is "symmetric" gap balancing still the gold standard in primary total knee arthroplasty?

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Abstract: A rectangular and symmetrical gap in flexion as well as in extension is mandatory to achieve good outcomes and good long-term results in total knee arthroplasty (TKA) using classical designs. Recently, as showed in several fluoroscopic studies, different modern designs (medial congruent or sagittally stable implants) have been demonstrated to better reproduce the more physiological medial pivoting (MP) biomechanics of the normal knee when compared to classical postero-stabilized (PS) and cruciate-retaining (CR) designs. These modern designs, characterized by different level of conformity, might require adopting a different surgical technique in terms of soft tissue balancing technique for primary TKA. In such cases, the current authors suggest to reproduce a slightly asymmetric extension and flexion gaps with a tighter medial then lateral compartment to re-establish the MP kinematics of the normal knee.

Keywords: Knee; total knee arthroplasty (TKA); gap balancing; medial pivot (MP)

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Introduction

Total knee arthroplasty (TKA) is a successful and reproducible procedure used to treat severe tricompartmental knee osteoarthritis aimed to restore knee joint function and to reduce knee pain. Several progresses have been recently made, from improving the component designs to projecting different levels of constraint able to treat different degrees of instability and deformity. However, patient satisfaction after TKA increased only from 81.2% to 85% in the last decade (1), leaving 15% of the patients not fully satisfied (1). Reasons of dissatisfaction might be classified in subjective and objective: the first one is directly related with the patient's expectations; generally, patients are less satisfied with treatment outcomes than surgeons (2), Harris *et al.* (3) reported discordance between patient and surgeon satisfaction: at 12 months, 94.5% of surgeons while only 90.3% of patients were satisfied with the outcome. Objective reasons for patient dissatisfaction are malalignment of the components (4), alterations in patellofemoral tracking (5) and residual instability due to soft tissues imbalance. Soft tissue balancing remains entirely subjective and extremely operator dependent and it has been estimated to cause up to 35% of early TKA revisions in the United States (6). Finally, the "paradoxical femoral roll back" described as a lack of a physiological posterior femoral rollback and a more anterior tibio-femoral contact point during deep knee flexion (7) falls in a separate category: it probably plays an important role causing discomfort and a high un-satisfaction rate after TKA, but it is not related with clear technical errors.

Gap balancing technique *vs.* measured resection technique

Surgeons, in order to recreate the "perfectly balanced" TKA, have historically utilized two surgical techniques: a "measured resection technique" and a "gap balancing technique". The measured resection technique (8) is a surgical procedure based on the use of bone landmark references to achieve the proper alignment of the components: on the femoral side, the transepicondylar axis (TEA), the antero-posterior axis (Whiteside's line) and the posterior condylar axis (PCA) are generally used to drive the correct positioning of the implants.

The TEA (9) is a line perpendicular to the knee mechanical axis that better approximates the axis around which the tibia moves in space during flexion-extension of the knee. Two TEAs can be identified: a clinical one and a surgical one, as described in 1993 by Berger *et al.* (10). The clinical TEA is a line connecting the lateral epicondylar prominence with the most prominent point on the medial epicondyle, while the surgical TEA is defined as the line connecting the lateral epicondylar prominence with the sulcus of the medial epicondyle: the literature is not homogeneous in defining which TEA is more accurate for the correct rotational alignment of the femoral component during primary. However, Churchill *et al.* (9) studied, using two-dimensional analysis (2D), the real function of the TEA, finding no statistically differences between the TEA and the true flexion-extension axis (FEA) of the knee; in a different study, Eckhoff *et al.* (11), using three-dimensional (3D) CT analysis, suggested that the cylindrical axis (CA), defined as a line equidistant from contact points on the medial and lateral condylar surfaces during active range of motion (ROM) between 10° and 120° of knee flexion, is a better surrogate for FEA.

A second bone landmark suggested by many authors for proper rotational alignment of the femoral component is the antero-posterior axis of the femur: this axis (AP axis or Whiteside axis) (12) represents a line connecting the deepest point of the trochlear groove to the top of the intercondylar femoral notch. Arima *et al.* (12), describing this bone landmark in 1995, reported a significant reduction of patellofemoral complications following primary TKA using this anatomical reference. On the other side, few authors described severe errors in the rotational alignment of the femoral component using this antero-posterior femoral reference: an excessive external rotation of the femoral component when this reference is used in the presence of severe trochlear dysplasia (13) or grade 4 medial compartment knee osteoarthritis (14).

Eventually, few other surgeons prefer to use the posterior femoral condyles and the PCA to set femoral component rotation in primary and revision TKA. Historically, the PCA has been described as a line along the posterior aspect of the femoral condyles (15). When surgeons decide to use this third available bone landmark, they usually externally rotate (between 3 and 5 degrees) the femoral component in relation to the PCA to guarantee to be perpendicular to the mechanical axis of the knee. Griffin *et al.* (16), using the PCA as the primary landmark to determinate the rotation of femoral component, reported that this landmark might lead to erroneous femoral component internal rotation, especially in cases of severe valgus deformity with erosion or hypoplasia of the lateral femoral condyle.

The gap balancing technique is based on a correction of the alignment of the knee following a stepwise soft tissue balancing instead of pure bone resections: historically, surgeons following a classical gap balancing technique, tend to recreate a symmetrical and rectangular space both in flexion as well in extension (15). Recently, modern bioengineered technology (computer assisted surgery, patient specific instrumentation, load sensing device) has been developed to achieve this objective.

A correct gap balance in the knee might be obtained first in extension or first in flexion. In the first case, the femoral cut is made using an intramedullary guide followed by the resection of the proximal tibia at 90 degrees to the mechanical tibial axis; in this case, the extension gap is first evaluated and soft tissue releases are made as needed (17); following this, a symmetric flexion gap is achieved using gap spacers or laminar spreaders to guide soft tissue releases, with the goal to obtain an equal soft tissue tension on the lateral and medial compartment of the knee, both in flexion as well as in extension. On the other side, when the surgeon decides to balance the flexion gap first, the tibial resection is originally made at 90 degrees respect to mechanical tibial axis: a special attention should be paid to not cut the proximal tibia with a varus or valgus malalignment. In fact, an erroneous cut might affect the subsequent rotational alignment of the femoral component. Subsequently, when a symmetric gap is eventually achieved with gradual soft tissue release, the femoral cuts are then made parallel to resected proximal tibia. In both techniques, the TEA and AP axis are used as secondary references to orient the femoral component.

Normal knee *vs.* TKA biomechanics (fluoroscopic evaluation)

Numerous kinematics study using static and dynamic fluoroscopy have found several differences between normal knee motion and TKA kinematics (18).

A progressive posterior translation of the lateral femoral condyle on the tibial plateau characterizes the normal knee motion during active and passive flexion ("posterior femoral rollback"), while the concomitant posterior motion of the medial femoral condyle is negligible ("medial pivoting"). The authors of the current paper (19) quantified this motion in a dynamic MRI study performed in healthy subjects: at 145 degrees of knee flexion, the average lateral condyle rollback was 15 mm while the average medial condyle rollback was 3 mm.

In TKA, two different characteristics affect and modify the kinematic of the replaced knee: the design of the femoral condyles on the sagittal plane (single or multi radii) and the level of constraint in the polyethylene insert [cruciate retaining (CR), postero-stabilized (PS), medially congruent (MC), medial pivot (MP) and sagittally stabilized (SS)] (20).

When using cruciate-retaining (CR)-TKA designs, many authors (21,22) reported a lack of posterior femoral rollback and a more anterior tibio-femoral contact point during deep knee flexion when compared with normal knees ("paradoxical rollback"). This unwanted finding has been attributed to the incompetent restraining function of the posterior cruciate ligament.

When using posterior-stabilized (PS)-TKA systems, the design would apparently reproduce the normal biomechanics of the knee using a "cam/post" system that engages the femoral component and the tibial insert during deep knee flexion. Unfortunately, PS TKA designs showed a femoral rollback similar to CR knees because of lack of cam-post engagement during early-to-mid flexion arc (23).

Recently, MP inserts have been designed in order to better reproduce the biomechanics of the normal knee. MP inserts are characterized by a deep dish and a higher anterior and posterior lip on the medial side when compared with the previous two designs (CR and PS TKA), providing more conformity on the medial compartment while laterally the dish maintains partial congruency only. Shimmin *et al.* (24) in a fluoroscopic study evaluating a MP TKA design (SAIPH™, MatOrtho, UK) showed no evidence of anterior femoral translation during deep flexion, in fact the medial femoral condyles translated an average of 2 mm posterior to the tibial sulcus while the lateral femoral condyles translated an average of 6 mm posterior to the tibial sulcus during maximum knee flexion, reproducing the MP biomechanics of the normal knee. These biomechanical characteristics are more evident using medially spherical femoral designs having several unique properties: a completely spherical femoral condyle with a single sagittal radius, a medially spherical tibial insert that ensure a high conformity with the femoral medial condyle reproducing a "ball in socket" design and a completely flat dish on the lateral compartment of the tibial insert. Scott *et al.* (25) evaluating fluoroscopically a particular sagittally-stable TKA design (GMK Sphere, Medacta, Switzerland) design reported a mean of 8° tibial internal rotation, 2 mm medial posterior translation and 8 mm posterior translation on the lateral condyle during active ROM.

Furthermore, interesting findings have been showed by Grieco *et al.* (18) comparing single radius (SR) designs versus multiple radii (MR) designs using a fluoroscopic model in order to evaluate the femoral condyle motion on the tibial plateau from anterior to posterior during knee flexion. In this study, SR designs showed a significant more AP translation when compared with MR designs, but also showed a similar, more physiological axial rotation.

Discussion

Several studies affirmed that obtaining a medio-lateral well-balanced knee, with rectangular and symmetrical gaps in flexion as well as in extension, is mandatory to achieve good early outcomes and good long-term results after primary TKA (26,27).

Jawhar *et al.* (28), evaluating 108 TKA with a mean follow-up of 34 mouths, reported better clinical outcomes in patients with a well-balanced knee (medio-lateral gap difference ≤2 mm) when compared to patient with unbalanced knee (medio-lateral gap difference >2 mm). This study evaluated the medio-lateral space with the components *in situ* using a PS PFC Sigma (De Puy, Johnson and Johnson, Warsaw, USA) prosthesis.

Watanabe *et al.* (29), investigating 44 knees in 34 patients who underwent primary single surgeon PS-TKA, showed better clinical results in balanced knee. They reported well-balanced knees showing less anterior translation of the medial femoral condyle in mid- to deep-flexion, more consistent femoral external rotation, and more neutral valgus/varus rotation compared with unbalanced knees; this finding confirms the importance of achieving symmetric intraoperative joint gaps in deep flexion and proper medio-lateral soft tissue balance throughout the ROM.

Recently, Gustke *et al.* (30), using a modern intraoperative sensing device to equally distribute loads in the medial and lateral compartment of a CR-TKA design, determined that balanced knees exhibit improved short-term clinical outcomes when compared with "unbalanced" knees: at 6-months, the balanced cohort scored 172.4 points and 14.5 points in KSS and WOMAC, respectively while the unbalanced cohort scored 145.3 and 23.8 points in KSS and WOMAC (P<0.001). These authors also confirmed that balanced joints were among the most significant contributing factors to improved postoperative outcomes (P<0.001).

However, as previously shown, normal knee kinematics is not fully reproduced by many TKA designs. The normal posterior femoral rollback of the lateral femoral condyle associated with a MP of the medial compartment is rarely present in patients treated with classical TKA designs. Few newer "medial pivot", "medial congruent", "sagittally stable" TKA designs, characterized by an increased medial conformity between the medial femoral condyle and the deep dish on the medial tibial insert, showed improved kinematics better reproducing the biomechanics of the normal knee. Having a more constrained medial compartment respect to the lateral compartment correlates with a slight asymmetric gap (tighter medial, looser laterally) both in full extension as well as in flexion. The amount of this lateral "pseudolaxity" has to be quantified but, in the current authors experience, approximates 2 mm from full knee extension to deep knee flexion. This desired lateral "pseudolaxity" is given essentially more by the design of the polyethylene insert and eventually by the asymmetry of the femoral condyles in these "medially constrained" designs then by a surgical technique aiming towards a more aggressive soft tissue release in the lateral compartment respect to the medial. Surgeons should be aware that this slighter lateral laxity is physiological in many normal knees as described at the current authors Institution (31): this "dynamic lateral stability" has been described in normal as well as in osteoarthritic knee joints. The current authors recommend to reproduce this mild lateral pseudolaxity only in accordance to a surgical technique aiming to reproduce the mechanical axis of the knee: surgeons aiming to reproduce a "kinematic alignment" (32) of the knee might involuntarily increase this desired pseudolaxity to a level of a clinically evident (during normal gait) lateral thrust, which can be detrimental to the stability of the knee itself.

In conclusion, TKA designs characterized by an increased medial conformity are extremely appealing in terms of reproducing the normal knee biomechanics. The dogma of a perfect, symmetric balancing of the knee in extension as well as in flexion might not need to be followed when these modern implants are intraoperatively chosen during primary TKA. Surgeons should customize their surgical technique according to the level of intra-articular conformity of their preferred knee arthroplasty design.

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Footnote

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