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Femoral and tibial malrotation in total knee arthroplasty: Causes and cures

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ABSTRACT

Prosthetic malrotation is an important surgical error that can lead to patellar subluxation, chronic ligamentous instability, and a painful outcome after total knee arthroplasty. Surgical technique must create a near normal anatomical condition that considers bone reconstruction and normal ligament balance. The classic anatomical methods will be historically reviewed assessing reasons for outliers and factors that may cause error. Newer methods will be considered such as computer navigation with ligament tensors, the kinematic method, and patient-specific cutting guides. Computer navigation will eventually rely on intra-operative digital imaging capabilities.

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Prosthetic malrotation is an important surgical error that can lead to patellar subluxation, chronic ligamentous instability, and a painful outcome after total knee arthroplasty. Importantly, Berger et al. [1] demonstrated that a femoral/tibial combined error of 7°–17° internal rotation was associated with patellar subluxation and patellar prosthetic failure [2,3]. Determining the rotation of the femoral and tibial components can be accomplished by direct anatomical landmarks or the use of indirect tensors [4–11]. Appropriate instruments are then used to create the flexion gap. The final goal is an articulation that is comparable to the normal state both in terms of the anatomical position of the resurfacing implants and the carefully adjusted ligamentous condition. These methods are well known but the potential for errors is less acknowledged. A careful description of the known anatomical issues will be made to allow the reader to understand the optimal choices. Additionally, the precision of the surgical techniques will be considered and what the surgeon may expect.

Recent methods have attempted to make surgical implantation more efficient and to create a more natural prosthetic implantation. This could include the use of patient-specific cutting guides and the kinematic method that attempts to restore the natural position of the joint line as opposed to the choice of the limb mechanical axis that reduces the joint line by approximately 3°. The kinematic method chooses an equal cut of the posterior femoral condyles [12,13]. Current computer navigational schemes utilize imageless registration with the combination of reference acquisition and may be combined with ligament tensors. In the future, navigation systems will rely on intra-operative digital imaging acquisition for precision.

Correction of implant rotational errors requires the surgeon to identify the malrotation problem. An axial computed tomography scan of the knee is the best method to study the position of the implants in relation to the anatomical targets. This is supplemented by a careful ligamentous evaluation where the surgeon attempts to identify abnormal gaps that may affect the flexion gap. The final decision for repair is based on a full understanding of the combination of problems [14]. To me, it would be intuitive to address the problem from the front end, and use the CT and the ligament balancing technologies that are currently available, to avoid these problems with improved surgical technique.

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I will define these technologies and project how we may improve current methods with this approach.

1. Femoral anatomical factors

Many years ago, I performed a very simple experiment to determine the relationship of the transepicondylar axis to the kinematics of the knee. A friend and colleague, Rick Komistek PhD, built me a very simple frame that allowed me to place a pin across the transepicondylar axis (Fig. 1). I then used several cadavers to move the leg through the range of motion recording the position of the center of the hip joint compared to the center of the talar dome. The results predicted that the transepicondylar axis performed well as a kinematic center of the total knee reconstruction [10]. As the knee moved into flexion, the longitudinal axis of the tibia remained virtually perpendicular to the TEA. With a cadaver study, the mean mechanical axis was 0.4° of varus in extension and 0.43° of varus at 90° of flexion. In addition, the TEA was virtually in the center of the lower extremity measured from the center of the hip joint to the center of the ankle joint. This study then led to the idea of the "tibial shaft axis" as a method for defining correct femoral rotation [11]. Basically, by aligning the axis of the tibia perpendicular to the TEA, appropriate femoral rotation was accomplished.

Conventional wisdom proved that methods creating a neutral limb axis or "mechanical axis" from the center of the hip joint to the center of the talar dome were more reproducible for conventional surgical instrumentation of the day. However, this maneuver required moving the joint line 3° from the anatomical state placing the tibial surface cut perpendicular to the mechanical axis. While there was a small enclave of surgeons who believed that the anatomical approach of preserving the natural joint line may be a better option, the potential for outliers made this approach somewhat risky for an exaggerated varus deformity that surely led to an early failure. As we will see that anatomical method is attractive from a kinematic point of view and may offer a better option for balancing the ligaments of the knee through the range of motion.

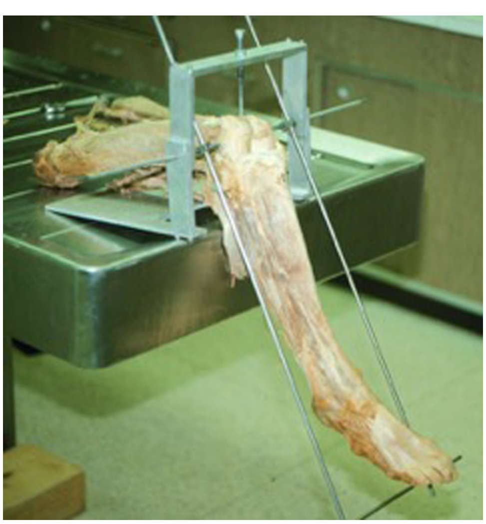

Figure 1 – Test frame to assess the clinical relationship of the transepicondylar axis to the mechanical axis of the knee in extension and flexion. The "tibial shaft axis" remains perpendicular to the TEA through 90° of motion.

To use the transepicondylar axis as a surgical guide, the surgeon must choose a definite point on the medial and lateral epicondyle. This is fairly straight forward on the lateral side if it can be identified but is variable on the medial side. One may pick the most prominent point of the medial epicondyle or the deepest point of the sulcus of the medial epicondyle that represents the "surgical" epicondylar axis [7]. While many studies have evaluated how accurate this could be, the fact remains the reference points are not discreet enough [14–16]. Additionally, there is a significant anatomical variation of the basic landmark. From my viewpoint, this problem was proven when we attempted to perform referencing using computer navigation. The precision was clearly an order of magnitude inferior when compared with the results achieved from mechanical axis alignment using navigation. The explanation is fairly simple and requires considering the errors. Back to the basic transepicondylar frame, the trigonometry of the angles created from the center of the hip joint or the center of the ankle joint are far smaller than the angles created about the transepicondylar axis in flexion simply based on the distance, thus defining the potential precision [9]. To create 1° of error considering the mechanical axis, a point picked in the center of the knee would need to be off by 4 mm. However, an error of the transepicondylar axis to the joint line in flexion could be off by about 1 mm to create a degree of error.

The anterior–posterior axis of Whiteside is similar to the transepicondylar axis in terms of precision, at least from a number of clinical studies [14,15]. However, both the TEA and Whitesides line have persisted and remain common surgical landmarks, and I believe this can be attributed to the fact that they work very well, at least 50–75% of the time. This is because the primary error is manifested only with the flexion gap, which is not as important or noticed with normal ambulation. If one considers that all precision measures function on a bell-shaped curve, where outliers of one to two standard deviations are above the median, only cases where the flexion gap abnormal laxities would exceed 5 mm become problematic.

I have learned with cadaver studies that an interesting relationship can be determined when combining the TEA and the AP axis of the femur. If one compares the two axes and then superimposes the AP axis on the TEA, the point of intersection occurs at the roof of the intercondylar notch (Fig. 2). This then becomes an important reference point to use in computer navigation, and that is the center of the roof of the femoral intercondylar notch is at the center of the knee, but that point also coincides with the TEA (Fig. 3). Additionally, the AP axis can be found to be coincident with the AP axis of the tibia and Akagi's Line, as will be shown below.

The flexion gap must also be considered from the viewpoint of the ligament balance issue. I have resolved the role of the medial and lateral collateral ligaments to be critical for the flexion gap creation and ultimate kinematic performance [16,17]. These structures functionally arise from the medial and lateral epicondyles, and this explains why the mechanical axis method works well. These ligaments are not changed in function by the alteration of the joint line. They must be

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