Radiographic Evaluation of Alignment Following Total Knee Arthroplasty – a Systematic Review. Part II

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ABSTRACT

The aim of this second part is to review the existing described methods for measuring postoperative total knee arthroplasty (TKA) alignment in sagittal and axial plane as well as the existing literature regarding the axial plane evaluation with the use of computer tomography. Given that the most frequent mistakes when positioning the total knee arthroplasty components are made in the axial plane, it is necessary to know what are the limits of radiographic evaluation, for which CT scan is the most valuable tool in assessing the rotation of the components.

Keywords: TKA alignment, sagital plane, axial plane, rotational analysis, CT evaluation.

INTRODUCTION

The sagital and axial preoperative and postoperative evaluations of total knee arthroplasty (TKA) are essential steps in improving the surgical outcome. Precise positioning of the patient is crucial for obtaining correct radiological images. In the sagittal plane, the anatomical and mechanical axis of both the femur and tibia, the femoral offset evaluation, patellar height, the joint line height and the patellar tendon angle are important factors for the preoperative planning and also for evaluating the positioning of TKA components. In the axial plane, we can only evaluate the femur. The axial plane evaluation for TKA may be done by using CT scan or MRI. Computer tomography is the most valuable examination in assessing the rotation of the components.

1. Evaluation of the knee in sagital plane (lateral)

1.1 Patient positioning

The precise positioning of the patient is crucial for obtaining the radiological image in sagittal...
plane. This image can be obtained with or without weight bearing of the lower limb. The knee is flexed at 30°, with the patella perpendicular to the cassette and with the lower limb parallel to the radiological table. The contralateral limb is positioned in a slightly posterior rotation, allowing enough lateral space for the affected knee (1). For the lateral weight bearing radiography, the knee is flexed at 30° and the contralateral lower limb is positioned posterior, with the patient in a semi-flexed knee position.

Both images are likely to be obtained after a fluoroscopically guided exploration which certifies the good position of the knee.

After a good positioning of the knee on the sagittal plane, the condyles will appear overlapped. The curve of the femur and tibia must be included in the image as much as possible, obtained with a 24x30 cm image (10x12 inch). The patella must be tangent to the beam to determine the height relative to the joint (1, 2). The fluoroscopically guided examination helps obtaining the femoral condyles overlap for a correct measurement of the position of the components. If fluoroscopy is not available, an external rotation of 3°-5° can be done to try to obtain femoral condyles overlap (3). This image is obtained using a 24x30 cm film (10x12 inch), the beam is on 5° cranial direction, placed at 97 cm (39 inch) from the cassette and centered between the patellar apex and 1 cm distal from the medial condyle.

Paley proposed the use of a 71 or 91 cm cassette with the beam centered knee joint at 305 cm (10 feet) distance from the patient for the lateral weight-bearing image of the lower limb.

Chung et al. created a new technique for obtaining a lateral image of the whole femur in which the femoral head is viewed clearly and both femoral condyles are overlapped. The thigh of the patient is positioned on a 17x17 inch digital detector and the x-ray beam is angled at 15° cranial.

1.2 Axis evaluation

1.2.1 The femoral anatomical and mechanical axis

The sagittal plane radiology in KS evaluation is based on data obtained on lateral short film (14x17 inch). In KS form, the sagittal anatomical angle of the femoral component is named “femoral flexion” (gamma angle). The value of this angle is given by the sagittal anatomical axis of the femur and the sagittal axis of the femoral component.

The sagittal anatomical axis of the femur on the lateral view is obtained uniting the furthest point from the middle of the femoral shaft with a second point placed at 10 cm proximal to the joint line in the middle of the femoral shaft. The sagittal axis of the femoral component is perpendicular to the distal condylar plane of the implant that can be represented by either distal resection of the femur or intercondylar notch of the implant.

The sagittal mechanical axis of the femur is an axis drawn from the center of the femoral head, identified using the Mose circles, and the center of the femoral component on the sagittal plane (4, 5).

There are two possibilities for identifying the sagittal mechanical axis of the femur by the distal points:

- Mechanical axis 1 is a line that goes from the center of the femoral head to a point that is placed 1 cm anterior to the Blumensaat line (a line which goes through the intercondylar notch on the lateral view).
- Mechanical axis 2 is defined as a line that goes from the center of the femoral head to a point identified 65% posterior on a line between the anterior cortex and the most prominent point from the posterior medial condyle.

The sagittal anatomical axis of the femur is obtained by drawing a line through the proximal, middle and distal centers of the femoral shaft on a full lateral lower limb radiography (3, 6). This produces a segmented line which considers the sagittal femoral curve (between 4° and 9°) (7, 8).

The distal sagittal anatomical axis of the femur:

- “Distal anterior cortex axis” is defined as a line that connects two points on the anterior cortex at 5cm and 10 cm proximal to the joint line;
- “Distal medullary axis”.

A Korean study found an angular difference average of 2° (0°-4°) between the mechanical axis and the sagittal anatomical axis of the distal femur. Far as 1° of anterior femoral curve, the angular deviation between those two axes grows for about 0.5° (7). The anterior cortical axis has an average value to the mechanical axis of 4° (0°-11°) (8).

The position evaluation in the sagittal plane of the femoral component must consider the anatomy of the distal third of the femur and, according
Radiographic Evaluation of alignment following TKA – a Systematic Review

1.2.2 The sagittal anatomical and mechanical axis of the tibia

Regarding the tibia, the angle also known as “tibial angle” is the equivalent of the so-called “tibial sloping” and, as described in the KS protocol, it is an anatomical angle on that sagittal plane which is formed between a tangent line at the base of the tibial component and a sagittal tibial anatomical line that is formed by connecting the furthest point of the center of the tibial shaft with a point located 10 cm under the knee joint, in the middle of the tibial shaft (3, 9, 10-13).

There are five anatomical landmarks described for the sagittal anatomical line of the tibia (14):

- the anterior cortical line of the tibia (acl), which connects two points on the tibial cortex that are placed proximal and anterior at 5 and 15 cm distally from the joint line;
- the proximal anatomical axis (paa);
- the central anatomical axis (caa);
- the posterior cortical line (pcl) of the proximal tibia, which connects two points of the posterior cortex of the tibia that are placed on the posterior cortex at 5 cm and 15 cm distally from the joint line;
- the fibular shaft axis – a line that connects the distal and proximal parts of the fibular shaft.

The normal tibial sloping is between 5° and 11° (15, 16).

1.3 The femoral offset evaluation

1.3.1 The posterior condylar offset

It is the maximal thickness of the posterior condyles, projected posteriorly by the posterior cortical tangent of the femoral shaft for the anatomical knee and knee prosthesis (17). There is a tight correlation between regaining the posterior condylar offset (PCO) and the maximum flexion – the more PCO decreases after surgery, the more flexion is reduced. For every 2 mm decrease in PCO, flexion is reduced by about 12.2°. Regaining the PCO is important in TKA with preserving the posterior cruciate ligament. Soda et al. propose a new parameter called PCO rate (18). Arabori et al. found a correlation between PCO and flexion only in cases with TKA with preserved posterior cruciate ligament (19).

1.3.2 The anterior condylar offset

It is the maximum thickness of the anterior condyles, projected anterior by the anterior cortical tangent of the femoral shaft for the normal knee but also for the knee prosthesis (20, 21). After intraoperative measurements in TKA, the standard anterior condylar offset (ACO) value represented by the anterior resection was 10.9 mm for males and 10.1 mm for females (22). If ACO increases postoperatively, excessive pressure may appear in the patellofemoral joint, with a limitation of postoperative movement (23). If ACO increases, this can lead to a raise of the trochlear groove height in the anterior compartment; as a result, the extension arc of the knee increases and in the end, flexion decreases. Miller et al. discovered that, after a TKA, the lateral and medial flanges increased by 1.1 ± 2.6 mm and 0.5 ± 2.2 mm, respectively, and the trochlear groove by 0 ± 1.1 mm (24). They calculated that, following an increase of the anterior cortex between 2 and 4 mm, the flexion decreases by 1.8° and 4.4°, respectively. The modification of the shape of the anterior femur has few consequences on passive flexion but the clinical implications on patient’s symptoms remain unidentified (24).

1.4 Patellar height

Of all indexes used for patellar measurement after TKA, just those that are related to the tibia can be used (IS, CD, BP) (25-27). Referring to the femur, it is not possible after arthroplasty (Blumennsatt, Bernageau) (28, 29).

1.4.1 Insall

Salvati Index is the ratio between the length of the patellar tendon, measured on the posterior surface from the distal pole of the patella to the insertion on the tibial tubercle, and the length of the patella measured on the longest diagonal line drawn across the patella. A normal value is 1.02, with a variation of less than 20%. A ratio greater than 1.2 indicates a patella alta, and a ratio lower than 0.8 indicates a patella baja (27).

1.4.2 Blackbourne

Peel Index is the ratio between A line, represented by the perpendicular distance from the inferior articular edge of the patella and the joint line, and B line represented by the length of the articular surface of the patella. The normal value...
is 0.8 (0.65-1.38). A ratio greater than 1.2 indicates a patella alta, and under 0.6 suggests a patella baja (25).

1.4.3 Caton

Deschamps Index is the ratio between the distance from the inferior margin of the articular surface of the patella to the superior margin of the tibial plateau (A) and the length of the patellar articular surface (B). The normal value is 1.0 (0.8-1.2). A ratio higher than 1.3 indicates a patella alta, and lower than 0.7 suggests a patella baja (26).

The Insall-Salvati (IS) has some disadvantages: the tibial insertion of the tendon is hard to identify and the length of the patella does not show the length of the articular surface.

The modified Caton index was proposed by Aglietti et al., being considered the most suitable for the measurement of patellar height in the prosthetic knee (30).

1.5 The joint line height

It is defined as a line that passes distally by the femoral condyles. The level of the condylar surfaces depends by the spontaneous flexion of the articulation. The position of the joint line is the distance (average of 2.2 cm) from the proximal edge of the tibial tuberosity to the joint line (10, 18). After TKA, the modification of the joint line position is measured as a difference between the preoperative and postoperative status of the joint line. This value is negative if the joint line is lower and positive if the joint line is higher (31). For the cases when the tibial tubercle is not well defined, the usage of the tip of the peroneal head would be a proper method (8).

Usually, the joint line is found 15.4±5.4 mm above the head of the peroneus in the sagittal plane and 13.9±5.8 mm in the coronal plane (32, 33).

The position of the joint line is a complex tri-dimensional concept and for a correct evaluation it needs a CAT scan.

1.6 The patellar tendon angle

The value of this angle allows us to analyse the knee kinetics in weight bearing position with or without sagittal plane (24). It is an angle represented by the patellar tendon and the tibial axis. There is a correlation between this angle and the flexion angle of the knee that may be quantified (24). With this angle, we can make a good analysis of the patellofemoral and tibiofemoral kinetics. Major modifications of these angles are due to some abnormalities between the tibia and the femur. The angle value is increased by anterior subluxation of the femur and decreased by posterior subluxation. In a normal knee, the patellar tendon angle has an average of 20° in extension position, while in flexion it decreases in a linear fashion: 0° at 80° of flexion and 10° at 120° of flexion (24, 34, 35).

2. Axial plane knee evaluation

2.1 Patient positioning for patellar views

There are a multitude of positions described by different authors (Laurin, Ficat, Merchant) (36-38):

1. Ficat and Hungerford: The patient's knees are flexed at the end of the radiological table. The tube is positioned at the legs of the patient and the cassette on the anterior thigh. In this position, the knee is perpendicular on the beam. It can be made at 30°, 60° and 90°.
2. Laurin: The patient is positioned on the radiological table with the legs close to the edge. The beam is parallel with the anterior aspect of the tibia and the knee is flexed at 20°. The cassette is holed by the patient at 90° against the beam.
3. Merchant’s: The patient stays in supination on the radiological table with the knees flexed at 90° and the cassette is placed proximal from the shins. Both knees are exposed simultaneously with the beam directed to the legs, tilted at 30° from the horizontal.

2.2 The patellofemoral incidence in axial plane with or without weight bearing

The previously described views are done without weight bearing. The outcome of the extensor mechanism to the patellofemoral alignment is not taken into account in this radiological view. An axial weight bearing position that incorporates all Merchant’s incidence parameters is described and approved (39). This is achieved with the patient standing against a wall (in front of the mobile radiological support) at 25.4 m (10 inch) distance to the wall. The beam source is brought to the level of the patient’s head. The 18x43 cm cassette is positioned on the dorsal aspect of the legs, which will stay parallel one
against the other. The knee is flexed 45°, with the tibia at 15° from the beam. This radiological view shows the patellofemoral maltracking, comparing with the standard Merchant’s view: the lateral tilt and subluxation of the substituted patella are reduced significantly, the prevalence of the uncovered patella towards femoral trochlear impingement is significantly increased and the patellar maltracking is much easier to correlate with the clinical symptoms. Using the weight bearing axial view for the evaluation of TKA offers additional information over standard radiography.

2.3 Patellofemoral axis evaluation
The patellofemoral alignment, measured according to the KS guide takes into account the following: the thickness, width, tilt, and mediolateral tracking of the patella as well as the patellar prosthesis angle to the patellar bone. Those measurements are calculated according to Gomes and Gustilo (40).

1. The preoperative patellar tilt or for the unsurfaced patella is formed by a line dragged anterior to the condylar or prosthetic limit in the axial line and a line which connects the apex of the patellar articular surface with the lateral edge of the lateral facet of the patella. If the angle is positive, this is considered normal, while if it is 0 or negative, the patellar tilt is abnormal. A small or negative angle indicates a subluxation or a dislocation. The patellar tilt after patellar prosthesis is an angle formed by a line that passes anterior to the femoral condyles and a line along the bone/prosthesis interface.

2. The thickness of the patella pre- and postoperatively is the vertical distance from the anterior cortex of the patella to the patellar femoral sulcus. Scott’s study on cadavers showed that the flexion decreased by 3° for every 2 mm incrementation of the patellar thickness (41).

3. The mediolateral position of the patella is the horizontal distance between two vertical lines perpendicular to a line that goes through the femoral condyles. A line is formed by the middle of the patella and another one by the patellar femoral sulcus.

2.4 The axial femoral incidence
Besides patellofemoral evaluation, an axial view offers information on the position of the femoral component in axial plane. The femoral component rotation is calculated after the condylar twisted angle (CTA), angle formed between the posterior condylar axis and the clinical epicondylar axis. This angle can be obtained using either a CAT scan or a simple radiography (42, 43). Preoperative using of such incidence may anticipate the grades of external rotation from the posterior condyles, which the surgeon can use for obtaining a correct positioning, identical with the one obtained using the trans epicondylar axis (TEA).

1. The Takai view – The patient positioning must be in such way that the affected knee is bent at 80° and holed by a support (chair). The x-ray beam is perpendicular to the tibial shaft. The radiology resulted after this positioning is a posterior-lateral view of a flexed knee.

2. Kanekasu view – The patient is position on a framework with the lower limbs suspended and the knees flexed at 90°. The authors of this view have modified the original position, adding a 1.5 kg distraction on the affected leg, being able to evaluate the tibiofemoral space configuration preoperative and postoperative (44).

3. CT protocol
The axial plane evaluation for TKA may be done by using a CT scan (most frequently) or a MRI. Berger created a protocol for evaluation of the transversal (axial) plane rotation (45, 46).

3.1 The Berger protocol
The patient stays in supination, with the examined limb in full extension, so the scanning will go perpendicular on the anatomical axis of the knee. In the lateral, scout view, CT incidences are done perpendicular to the femoral axis for the femoral scanning and perpendicular to the tibial axis for the tibial scanning. The 1.5 mm thickness CT sections are necessary in four locations: through the epicondylar axis of the femur, through the tibial tubercle, through the upper edge of the plateau and through the tibial component.

The femoral component rotation – The optimal level to view both femoral epicondyles is at 30 mm proximal from the joint line (47). Two lines are drawn at this level: one tangent to the posterior condyles and another one connecting...
the lateral epicondyle prominence to the medial epicondyle sulcus (surgical TEA=transcondylar axis). The angle formed by the two lines is the posterior condylar angle (PCA). The value of this angle must be as close as possible 0°. Romero et al. suggest the use of TEA, which connects the lateral epicondyles to the edge of the medial epicondyle, being a much easier landmark to find (47). This axis is helpful to calculate the CTA (condylar twist angle) (the angle between the posterior condylar axis and the clinical transepicondylar axis) that has 3-4° of external rotation by the PCA (47).

The tibial component rotation – For the evaluation of tibial component rotation, it is necessary to determine the geometrical center of the proximal tibial and its axial transposition above the tibial tubercle (48). After that, the geometric center of the proximal tibial component and the junction between the medial edge and the medial third of the tibial tubercle are connected, defining the tibial tubercle orientation. The anteroposterior axis of the tibial component is evaluated on the axial view through the tibial component. The rotation of the tibial component is calculated in relationship with the tibial tubercle orientation and the anteroposterior axis of the tibial component (48).

The Akagi line – The line, which goes from the insertion center of the posterior cruciate ligament towards the medial aspect of the patellar ligament, must be perpendicular to the surgical transcondylar axis of the femur, on the transversal plane CT image (49).

The Insall line – The central anteroposterior axis of the tibial component has to coincide the line, which connect the PCL insertion to the junction between 1/3 medial to 2/3 lateral of the patellar ligament.

**CONCLUSION**

Sagittal and axial roentgenographic analysis for the preoperative planning and after TKA are important steps; however, they have a limit: they are bidimensional. Only when 3D evaluation of the entire lower limb will become feasible on a routine basis, it will be possible to understand rotational assessment of components, combined component position under load, and kinematics relationships between components and between bones.

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**REFERENCES**


