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REVIEW

Postoperative TKA alignment in sagittal and axial plane, a systematic review

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Abstract
The aim of this paper was to review the existing described methods for measuring postoperative TKA alignment in sagittal and axial plane and to review the existing literature regarding the axial plane evaluation with the use of the computer tomography. The most frequent mistakes when positioning the total knee arthroplasty (TKA) components are done in the axial plane, so it is necessary to know what the limits of the radiographic evaluation are and, for this evaluation, the CT scan is the most valuable in assessing the rotation of the components.
Keywords: TKA alignment, sagittal plane, axial plane, rotational analysis, CT evaluation

Introduction

The sagittal and axial preoperative and postoperative evaluations of the total knee arthroplasty 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 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 for evaluating the positioning of the TKA components. In the axial plane, only the femur can be evaluated. The axial plane evaluation for the total knee arthroplasty may be done by using CT scan or MRI. The CT is the most valuable examination in assessing the rotation of the components.

Evaluation of the knee in sagittal plane (lateral)

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 30^0, with the patella perpendicular on the cassette and with the lower limb parallel to the radiological table. The contralateral limb is positioned in a slightly external rotation, allowing enough lateral space for the affected knee [1]. For the lateral weight bearing radiography, the knee is flexed at 30^0; the contralateral lower limb is positioned posterior, the patient being in a semi flexion position of the knee.

Both images are likely obtained after a fluoroscopically exploration that 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 examination helps obtaining the femoral condyles overlap for a correct measurement of the position of the components. If the fluoroscopy is not available, an external rotation of 3^0-5^0 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 5^0 cranial direction, placed at 97 cm (39 inch) from the cassette and centered between 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 [3].

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 [7]. The thigh of the patient is positioned on a 17x17 inch digital detector and the X-ray beam is angled at 15^0 cranial.

Axis evaluation

The femoral anatomical and mechanical axis

The sagittal plane radiology is based on data obtained on lateral short film (14x17 inch). 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 sagittal axis of 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 on the distal condyle plane of the implant that can be represented by the distal resection of the femur or by the 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 2 possibilities to identify 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 whole lateral lower limb radiography [3,6]. This produces a segmented line, which considers the sagittal femoral curve (between 4^0 and 9^0) [7,8].

The distal sagittal anatomical axis of the femur:

- "Distal anterior cortex axis" is defined as a line, which connects two points on the anterior cortex at 5cm and 10cm proximal to the joint line.

- "Distal medullary axis"

A study found an angular difference average of 2^0 (0^0-4^0) between the mechanical axis and the sagittal anatomical axis of the distal femur. Far as 1^0 of anterior femoral curve, the angular deviation between those two axes grows for about $0,5^0$ [7]. The anterior cortical axis has an average value to the mechanical axis of 4^0 (0^0-11^0) [8].

The evaluation of the position in the sagittal plane of the femoral component must consider the anatomy of the distal third of the femur and the neutral position of the femoral component that has the distal condyles perpendicular on the anatomical axis of the distal femur [2].

The sagittal anatomical and mechanical axis of the tibia

Regarding the tibia, the angle called "tibial angle" as well is the equivalent of the so-called "tibial sloping". This angle 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 [3,9-13].

There are 5 anatomical landmarks described for the sagittal anatomical line of the tibia [14]:

- The anterior cortical line of the tibia (acl) is a line, 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 is a line that connects two points of the posterior cortex of the tibia, which are placed on the posterior cortex at 5cm and 15 cm distally from the joint line.
- Fibular shaft axis is a line that connects the distal and proximal parts of the fibular shaft.

The normal tibial sloping is between 5^0 and 11^0 [15,16].

The femoral offset evaluation

The posterior condylar offset (PCO)

Is the maximal thickness of the posterior condyles, projected posteriorly by the posterior cortical tangent of the femoral shaft for the anatomical knee and for the knee prosthesis [17]. There is a great correlation between regaining the PCO and the maximum flexion, the more the PCO decreases after surgery, the more the flexion decreases. For every 2 mm of PCO decreasing, the flexion decreases for about 12.2^0. Regaining the PCO is important in total knee arthroplasty with preserving the posterior cruciate ligament. Soda et al. proposes a new parameter called PCO rate [18]. Arabori et al. found a correlation between PCO and flexion only in cases with total knee arthroplasty with preserved posterior cruciate ligament [19].

The anterior condylar offset (ACO)

Is the maximal thickness of the anterior condyles, projected anterior by the anterior cortical tangent of the femoral shaft for the normal knee and for the knee prosthesis as well [20,21]. After intraoperative measurements in total knee arthroplasty, the standard ACO value represented by the anterior resection of 10.9 mm for a males and 10.1 mm for females [22]. If the ACO increases postoperative, a pressure increasing in patellofemoral articulation may appear with a limitation of postoperative movement [23]. Increasing the ACO goes to an increase of the trochlear groove height in the anterior compartment, the extension arc of the knee increases and in the end, the flexion decreases. After a total knee arthroplasty, Miller et al. discovered an increase of lateral and medial flanges 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 an increase between 2 and 4 mm of the anterior cortex, the flexion decreases by 1.8^0 and 4.4^0, respectively. The modification of the shape of the anterior femur has few consequences on the passive flexion but the clinical implications on the patient's symptoms remain unidentified [24].

Patellar height

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

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

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 a 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 bigger than 1.2 indicates patella alta, a; lower ratio indicates patella baja [25].

Caton-Deschamps Index is the ratio between the distance from the inferior margin from 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 patella alta, and an index lower than 0.7 indicates patella baja [26].

The 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 the patellar height in the prosthetic knee [30].

The joint line height

Is defined as a line that passes distally by the femoral condyles. The level of the condylar surfaces depends on 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 total knee arthroplasty, 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 in which 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 coronal plane [32,33].

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

The patellar tendon angle

The value of this angle allows the analysis of 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, which may be quantified [24]. With this angle, a good analysis of the patellofemoral and tibiofemoral kinetics can be made. Major modifications of these angles are due to some abnormalities between tibia and femur. Anterior subluxation of the femur increases the angle value and the posterior subluxation decreases the angle. The patellar tendon angle in a normal knee has an average of 20^0 in extension position. In flexion, the angle decreases in a linear fashion: 0^0 at 80^0 of flexion and 10^0 at 120^0 of flexion [24,34,35].

Axial plane knee evaluation

Patient positioning for patellar views

There are many 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 30⁰, 60⁰, and 90⁰.

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 20⁰. The cassette is holed by the patient at 90⁰ against the beam.

3. Merchant: The patient stays in supination on the radiological table with the knees flexed at 90⁰ and the cassette is placed proximal from the shins. Both knees are exposed simultaneously with the beam directed to the legs, tilted at 30⁰ from the horizontal.

The patellofemoral incidence in axial plane with or without weight bearing

The views described previously 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 respects the entire Merchant incidences 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 head of the patient. 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 45⁰, with the tibia at 15⁰ from the beam. This radiological view shows the patellofemoral maltracking, compared to the standard Merchant's view: the lateral tilt and the 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 the total knee arthroplasty offers additional information over the standard radiography.

Patellofemoral axis evaluation

The patellofemoral alignment, measured according to the KS guide takes into account the following: the thickness of the patella, the width, the tilt, the medio-lateral tracking, and the patellar prosthesis angle to the patellar bone. Those measurements are calculated according to Gomes and Gustilo [40].

1. The preoperative patellar tilt or the unsurfaced patella is formed by a line dragged anterior to the condylar or prosthetic limit in the axial line and a line that connects the ape 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. If the angle 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 through the bone-prosthesis interface.

2. The pre and postoperative thickness of the patella is the vertical distance from the anterior cortex of the patella to the patellar femoral sulcus. A study on cadavers by Scott shows the flexion decreases by 3⁰ for every 2 mm incrementation of the patellar thickness [41].

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

The axial femoral incidence

Besides the patellofemoral evaluation, an axial view offers information referring to the position of the femoral component in axial plane. The femoral component rotation is calculated after the condylar twisted angle (CTA), formed between posterior condylar axis and the clinical epicondylar axis. This angle can be obtained using a CAT scan but using simple radiography as well [42,43]. Preoperative use of such incidence may anticipate the grades of external rotation from the posterior condyles, which the surgeon can use to obtain 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 80⁰ and holed by a support (chair). The X-ray beam is perpendicular on the tibial shaft. The radiology resulted after this positioning is a posterior-lateral view of a flexed knee.

2. Kanekasu view – the patient is positioned on a framework with the lower limbs suspended and the knees flexed at 90⁰. 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].

CT protocol

The axial plane evaluation for total knee arthroplasty may be done by using CT scan or MRI. The CT examination is used most frequently. Berger created a protocol for the evaluation of the transversal (axial) plane rotation [45,46].

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, the CT incidences are done perpendicular on the femoral axis for the femoral scanning and perpendicular on the tibial axis for tibial scanning. The 1.5 mm thickness CT sections are necessary in four locations: through epicondylar axis of the femur, the tibial tubercle, superior edge of the plateau and 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: a line tangent to the posterior condyles, the second line connects the lateral epicondyle prominence with the medial epicondyle sulcus (surgical TEA= transepicondylar axis). The angle formed by those two lines is the posterior condylar angle (PCA). The value of this angle must be as close to 0⁰ as possible. Romero et al. suggests using TEA, which connects the lateral epicondyles with 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 3-4⁰ of external rotation by the PCA [47].

The tibial component rotation

The geometrical center of the proximal tibial and its axial transposition above the tibial tubercle must be determined for the evaluation of the tibial component rotation [48]. After that, the geometrical center of the proximal tibial component and the junction between medial edge and the medial third of the tibial tubercle are connected, resulting the 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 on the surgical transepicondylar 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 with the line, which connects 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. The understanding of rotational assessment of components, combined components position under load, kinematics relationships between components and between bones, will be possible only when the 3D evaluation of the entire lower limb will be made on a routine basis.

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