

# Alignment In Total Knee Replacement

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## I. Introduction

This article will discuss alignment in total knee replacement.

Alignment in total knee replacement is a complex issue for many reasons. Firstly, there are preoperative, intraoperative, and postoperative methods of assessment. The assessment is largely image-based, but there are clinical methods that are important and enhance the evaluation.

If robotic assisted total joint replacement is used, the preoperative planning may also involve 3-D modelling and virtual joint replacement with components. The surgery itself often requires nuanced refinement of the preoperative planning by further assessment of the pathology within the joint and the ligament status.

Preoperative imaging provides static measurements of alignment and can provide 3-D models. But this is not a dynamic assessment of the Joint. Some imaging, such as standing long leg alignment x-rays and EOS imaging performed with the patient in the erect posture, provides some physiological axial load. Pre-operative CT scanning is usually done with the patient lying down, so this is a static and unloaded image.

Clinical examination provides vital information. The orthopaedic surgeon can assess the dynamic situation of the joint by evaluating the patient's gait and alignment in standing and walking situations. Examination can assess the stability of the joint particularly the ligament integrity. So the preoperative assessment of the alignment becomes a complex issue that involves both the preoperative imaging and the clinical assessment of the patient.

Preoperative planning for total knee replacement can be a simple process or a highly complex one depending on the surgeon's preferences and available technologies. A simple method is to obtain standard x-rays of the joint and proceed from there. Alignment of the knee replacement will be achieved using operative methods under these circumstances.

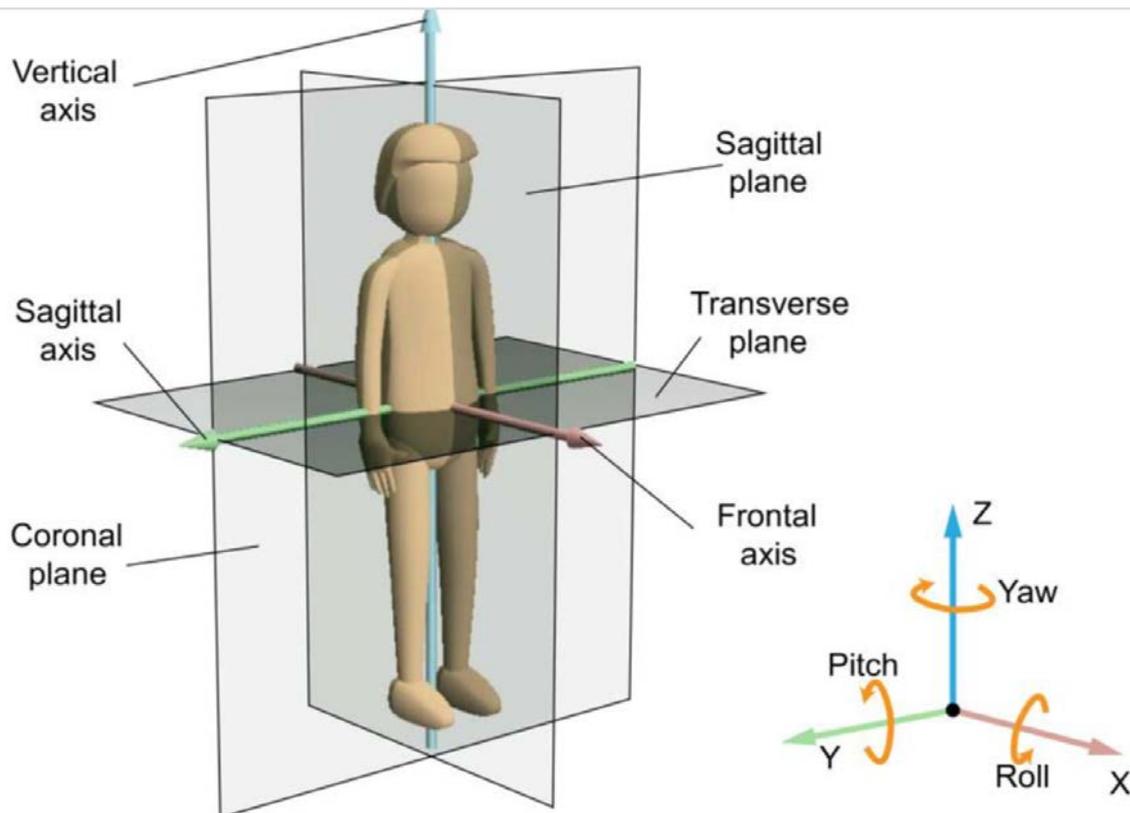
]Preoperative long leg alignment x-rays will allow the assessment of both coronal and sagittal plane alignment under a physiological load of the patient standing on both feet. This gives more information that the surgeon may use during the operative procedure. Preoperative CT scanning of the knee, hip and ankle, will allow a more detailed assessment of the knee joint and the lower limb alignment in coronal, sagittal, and axial planes. CT scans of this type are used for 3-D modelling which in turn allows preliminary virtual placement of total knee replacement components preoperatively.

Postoperative alignment after TKR is usually with a short leg AP and lateral xray performed immediately after surgery or within the first few days. This is standard practice and gives a visual guide to component placement and also to coronal and sagittal alignment but it is not accurate enough to be measured.. Because it is difficult to bend the knee adequately in the first few days after the surgery a skyline or patella femoral view is not usually performed. Therefore patella tracking and component axle alignment cannot be assessed in this early postop period. It has been traditional to obtain further x-ray imaging a few months after surgery and at this time AP standing x-ray, lateral x-ray and skyline x-ray are usually performed. This at least gives some more accurate guide although again it cannot be used for accurate measurement. It has been traditional that detailed postoperative alignment by more accurate methods has only been applied to assess a knee replacement that is problematic or under research conditions.

## II. Defining alignment

In engineering, "6 degrees of freedom" (6DOF) refers to the six independent ways an object can move in three-dimensional space. These include:

- 1. Translational Movements (Linear Displacement):** Movement along the three Cartesian axes:
  - X-axis: Forward and backwards (surge).
  - Y-axis: Left and right (sway).
  - Z-axis: Up and down (heave).
- 2. Rotational Movements (Angular Displacement):** Rotation around the three Cartesian axes:
  - Roll: Rotation around the X-axis.
  - Pitch: Rotation around the Y-axis.
  - Yaw: Rotation around the Z-axis.



Human anatomy planes and basic axes.

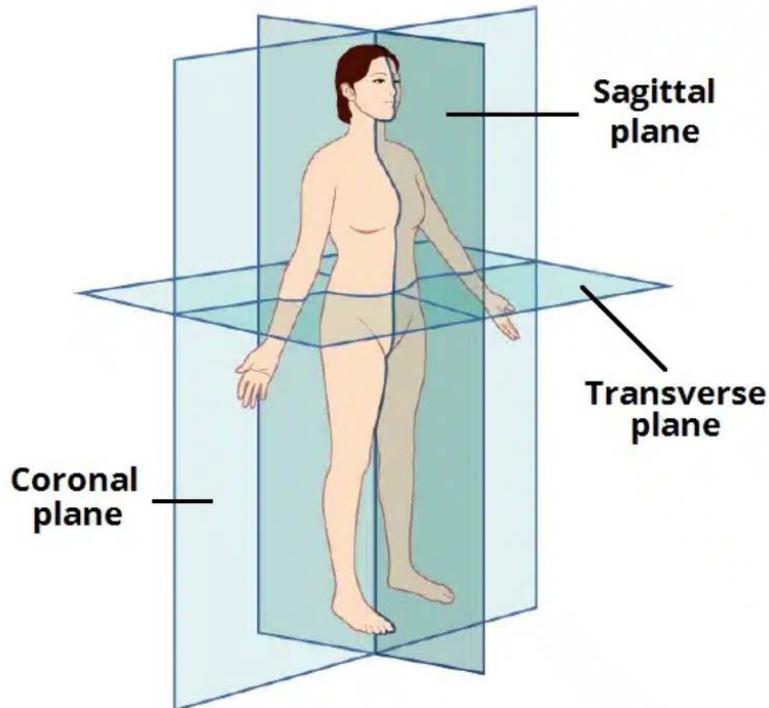
The diagram above illustrates how this universal system of understanding component alignment relates to human anatomy. When knee replacement is inserted, all 6° of freedom are variables, but we use different nomenclature as outlined below.

### 3. Translational Movements (Linear Displacement): Movement along the three Cartesian axes:

- • The X-axis is equivalent to the frontal axis. Translation along this axis has the nomenclature anterior and posterior translation.
- • The Y-axis is equivalent to the sagittal axis. Translation along this axis has the nomenclature medial and lateral translation.
- • The Z-axis is equivalent to the vertical axis. Translation along this axis has the nomenclature superior (cranial) and inferior (caudal) translation.

### 4. Rotational Movements (Angular Displacement): Rotation around the three Cartesian axes:

- Roll is equivalent to rotation around the X-axis. Rotation around the X-axis results in a change of coronal alignment.
- Pitch is equivalent to rotation around the Y-axis. Rotation around the Y-axis results in a change of sagittal alignment.
- Yaw is equivalent to rotation around the Z-axis. Rotation around the Z-axis results in a change of axial/transverse alignment.



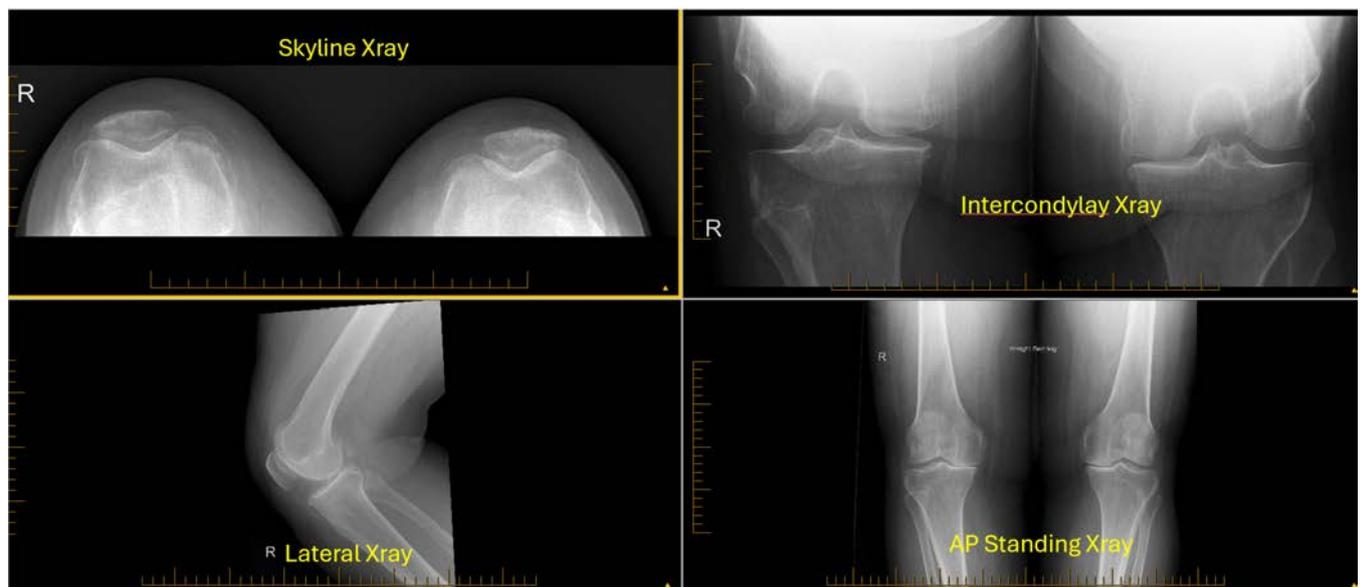
### III. Pre-operative imaging and assessment of alignment

There are numerous options available to the TKR surgeon in regard to the establishment of preoperative alignment. Whilst the following list of options is not exhaustive, it does show the range of options available.

#### 1. Standard Knee x-rays.

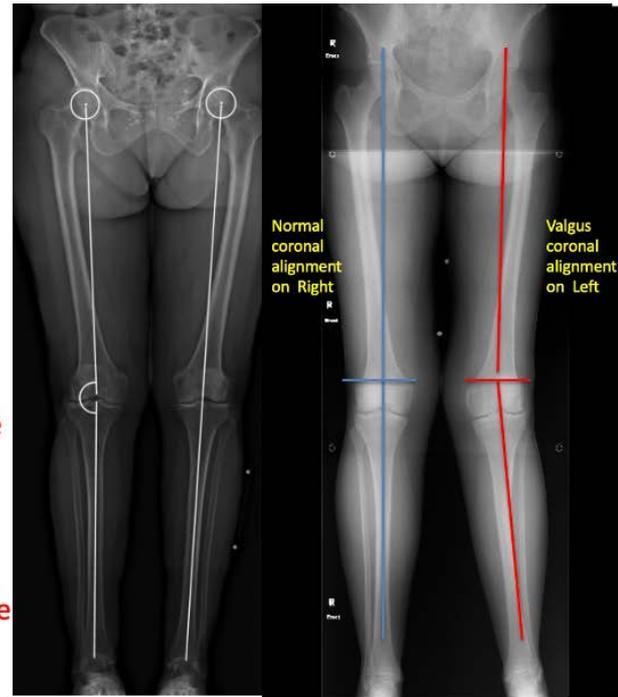
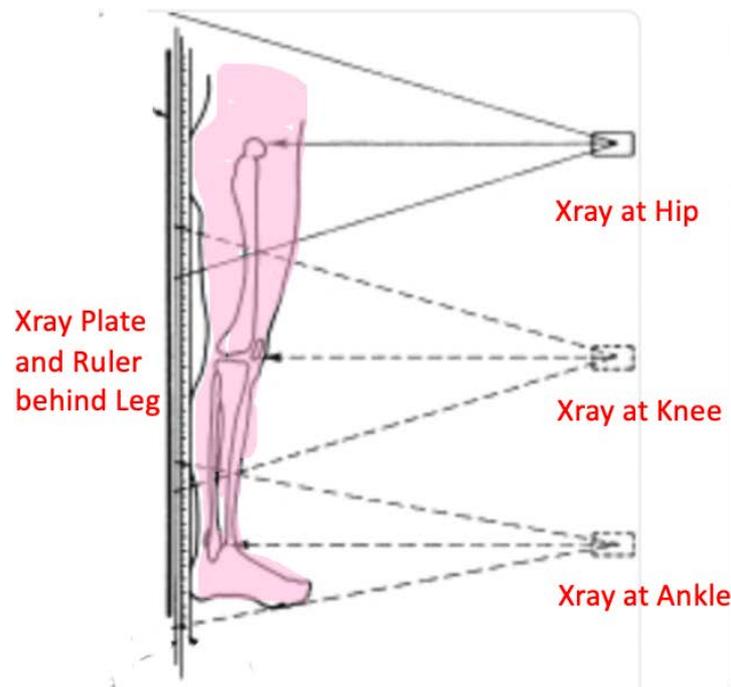
Prior to knee replacement surgery, plain x-rays will be required to look at the pathology (which is most commonly osteoarthritis) and to assess the bone and joint. Typically, the series of x-rays will include a standing AP x-ray, a lateral x-ray, an intercondylar x-ray, and a skyline x-ray. This series gives the orthopaedic surgeon a great deal of information about the joint that is about to be replaced. It shows the bone and the joint. The standing AP x-ray usually shows whether the arthritis is greater on the medial side or the lateral side. It usually

gives a good indication about the coronal plane alignment of the knee. Despite this, they cannot be used to give accurate coronal plane alignment measurements. The lateral x-ray gives a good indication of the sagittal alignment of the native knee joint, both the femur and the tibia, but again cannot be used for accurate measurements. The skyline x-ray gives an overview of how the patella sits and tracks within the track and groove. Patella tilt and patella subluxation and even the congruence angle can be measured on this x-ray. Note, however, that it does not help measure or define any of the important parameters that we need for axial alignment.



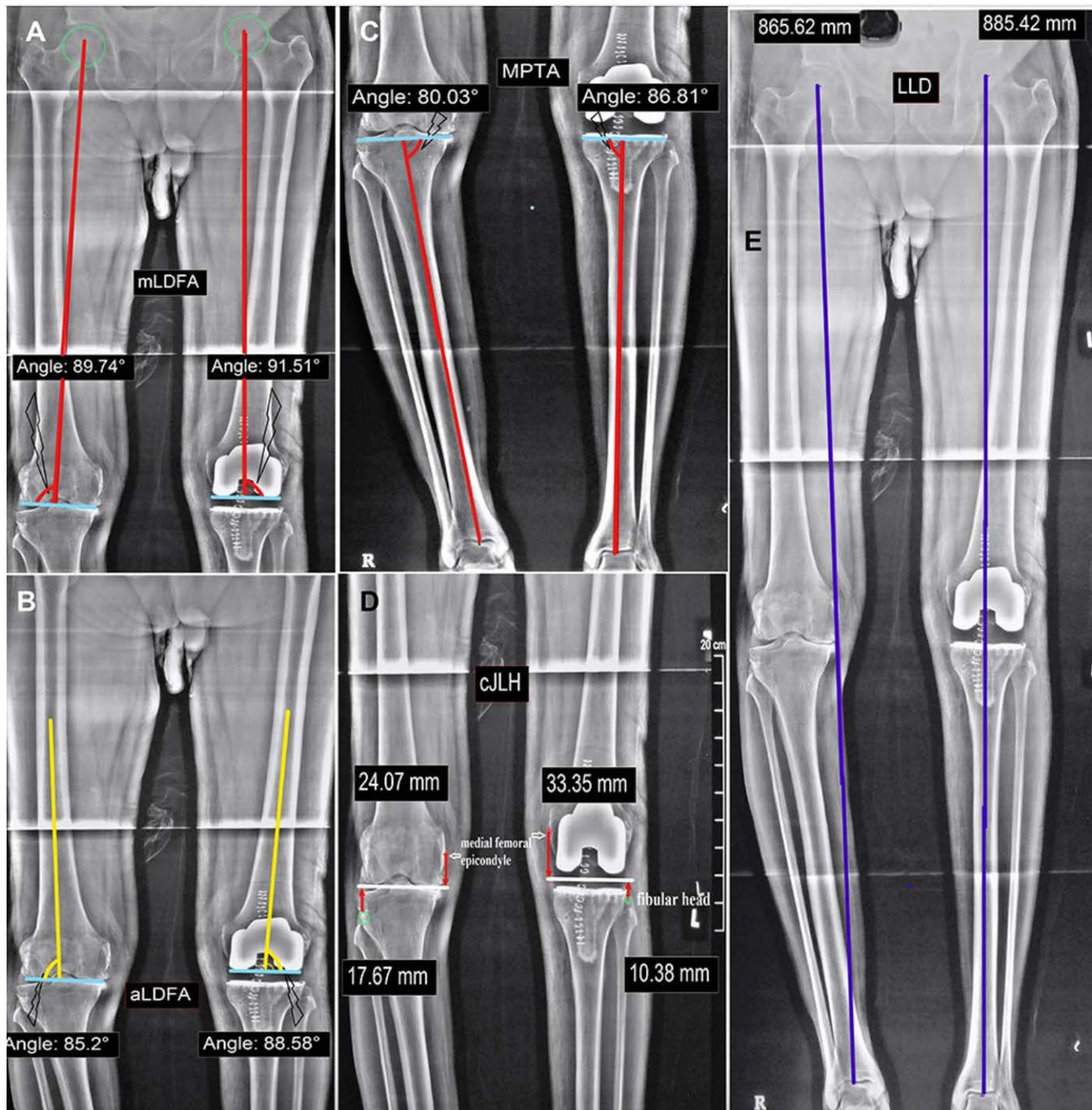
## 2. Long Leg Standing X-rays

This technique uses x-rays taken at the hip, knee, and ankle and digitally stitches them into one long radiograph. It can be done in the AP direction to look at coronal plane alignment and also in the lateral direction to look at sagittal plane alignment.



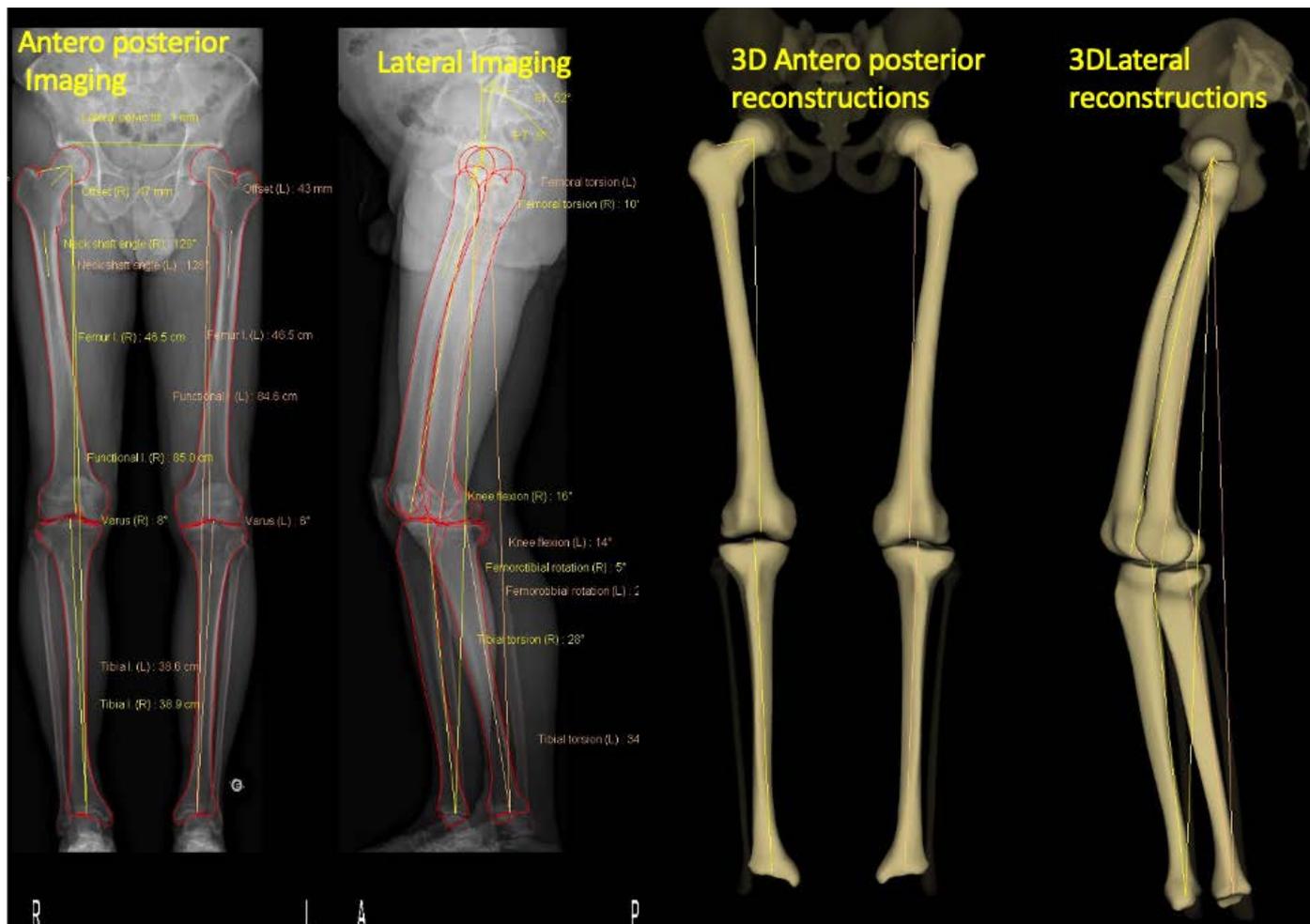
•The long leg AP X-ray shows the coronal plane alignment. A line from the centre of the femoral head to the centre of the ankle joint shows the coronal mechanical axis of the lower limb. A line from the centre of the femoral head to the centre of the knee joint shows the coronal mechanical axis of the femur. A line from the centre of the knee to the centre of the ankle shows the mechanical axis of the tibia. The angle between the mechanical axis of the femur and the distal end of the femur shows an angle called the mL DFA (mechanical lateral distal femoral angle). The angle between the proximal end of the tibia and the mechanical axis of the tibia shows the angle called the MPTA (medial proximal tibial angle). The image below shows the preoperative coronal plane alignment preoperatively on the right knee and postoperatively on the left knee.

The long leg lateral X-ray shows the sagittal plane alignment. A line from the centre of the femoral head to the centre of the knee joint shows the sagittal mechanical axis of the femur. A line from the centre of the knee to the centre of the ankle shows the sagittal mechanical axis of the tibia. The angle between the mechanical axis of the femur and the distal end of the femur shows an angle called the DFFA (distal femoral flexion angle). The angle between the proximal end of the tibia and the mechanical axis of the tibia shows the angle called the PTS (posterior tibial slope).



### 3. EOS Scanning

EOS is a relatively new technique that has been used in Australia for less than 15 years. It uses very low-dose x-ray scanning. In the lower limb, both anteroposterior and lateral images are produced simultaneously of a patient standing up. The low-dose x-ray beam travels downwards from the pelvis to the feet to create the two images. These images allow accurate coronal and sagittal plane imaging to look at an alignment as well as the various knee angles in a similar fashion to long leg x-rays. From these two images, 3-D models of the lower limbs are reconstructed, which allows more complex images and angular measurements. (see diagram below)



EOS allows accurate coronal plane and sagittal plane alignment to be measured as the imaging is performed in these two planes. It is not particularly useful for axial plane alignment. He can give an indication of femoral neck anteversion, tibial torsion, and femorotibial rotation, which are axial alignment measurements. (see below) It cannot, however, be used for measuring the axial alignment parameters of distal femoral rotation and proximal tibial rotation, including the position of the knee compared to the tibial tubercle and the position of the distal femur compared to the epicondylar axis or the posterior condylar axis. These measurements require CT scanning or MRI scanning, as will be discussed in the next section.

<b>Knee (4)</b>	<b>Right</b>	<b>Left</b>	
Valgus/Varus	<b>Varus 8°</b>	<b>Varus 6°</b>	
Knee flexion/Knee extension	<b>Flexion 16°</b>	<b>Flexion 14°</b>	
HKS	<b>6°</b>	<b>4°</b>	
Femoral mechanical angle	<b>91°</b>	<b>92°</b>	
Tibial mechanical angle	<b>82°</b>	<b>87°</b>	
<b>Torsions (4)</b>	<b>Right</b>	<b>Left</b>	
Femoral torsion	<b>10°</b>	<b>25°</b>	
Tibial torsion	<b>28°</b>	<b>34°</b>	
Femorotibial rotation	<b>5°</b>	<b>2°</b>	

#### 4. CT Scanning

CT scanning remains the gold standard for preoperative and postoperative imaging to look at lower limb alignment in three planes. It is neither dynamic nor weight-bearing. The patient is supine (lying down face up) in the CT scanner. The scan involves the low-dose CT imaging of the entire lower extremities from the pelvis to the feet. Images are therefore created in the transverse/axial plane. From these images, the coronal and surgical plane imaging is reconstructed. This allows the following key measurements:

##### 1. Coronal Plane Measurements (Frontal View)

- **Mechanical Axis Deviation (MAD):** Distance from the centre of the knee to the mechanical axis line (from femoral head to ankle centre).
- **Hip-Knee-Ankle Angle (HKA):** Angle between the mechanical axes of the femur and tibia.
- **Mechanical Axis of Femur and Tibia:** Assessing straightness or varus/valgus deformities.
- **Joint Line Convergence Angle (JLCA):** Measures any tilt in the joint line.
- **Lateral Distal Femoral Angle (LDFA) and Medial Proximal Tibial Angle (MPTA):** Assess bone morphology and joint congruity.

##### 2. Sagittal Plane Measurements (Side View)

- **Posterior Tibial Slope (PTS):** Angle between the tibial plateau and a perpendicular line to the tibial shaft.

- **Femoral Flexion Angle:** To assess the anterior or posterior bowing of the femur.
- **Sagittal Plane Mechanical Axis:** To evaluate flexion deformities.
- **Tibial Shaft Axis:** Assessment for recurvatum deformity.

### 3. Axial (Transverse) Plane Measurements (Rotational Assessment)

- **Femoral Anteversion:** Angle between the femoral neck axis and the posterior condylar line.
- **Distal femoral rotation;** angle between epicondylar axis and femoral posterior condylar axis
- **Tibial Torsion:** Angle between the proximal tibial plateau and the distal malleoli axis.
- **Patellofemoral Alignment:** Sulcus angle, patellar tilt, and congruence angles.
- **Tibial tubercle to trochlea distance.**

## IV. Achieving alignment for TKR component Implantation during Surgery

Performing knee replacement surgery requires intraoperative methods to achieve alignment in all 6° of freedom. There are a number of methods available to achieve this, including the following: 1. Mechanical instrumentation; 2. Computer-navigated knee replacement; 3. Robotic-assisted knee replacement; and 4. Patient-specific instrumentation.

Each method has different systems to achieve alignment in the three different planes. Each system has a method of adjustment whilst performing the surgery.

### 1. Mechanical instrumentation

- This method preceded all the following methods and was used with the original knee replacement systems.
- It utilises mechanical alignment guides in order to achieve bone resection and to achieve desired alignment.
- Whilst pre-operative imaging is helpful for planning, it is not a mandatory requirement for the use of mechanical instrumentation.

### 2. Computer-Navigated Knee Replacement (CNK)

- Utilises intraoperative navigation systems to provide real-time feedback on the alignment and positioning of implants.
- Sensors and trackers are attached to the femur and tibia to guide bone cuts.
- Minimal imaging is required.
- Intraoperative data is often collected using anatomical landmark registration.
- Preoperative imaging is minimal.

### 3. Robotic-Assisted Knee Replacement (RAK)

- Incorporates robotic systems to assist the surgeon in achieving more precise bone cuts and implant positioning.
- Two types of robotic systems:
  - Image-based systems (e.g., Mako by Stryker).
  - Imageless systems (e.g., Navio by Smith & Nephew).
- Image-based Robotic Systems:
  - Require a preoperative CT scan of the entire lower limb for 3D reconstruction.
  - The CT is used to create a patient-specific 3D model for surgical planning.
- Imageless Robotic Systems:
  - Do not require preoperative imaging.
  - The system maps the knee anatomy intraoperatively via surface registration.
- Imageless systems simplify preoperative requirements but rely on intraoperative data collection.

### 4. Patient-Specific Instrumentation (PSI)

- Custom cutting guides are manufactured based on detailed imaging to match the patient's anatomy.
- Aims to improve alignment and reduce operative time.
- Requires either a **CT scan** or **MRI** (depending on the manufacturer).
- CT provides bony anatomy, while MRI offers soft tissue visualisation.
- Imaging is used to create a **3D model** for designing patient-specific guides.
- Preoperative imaging is **mandatory**.
- Imaging modality depends on the implant manufacturer's protocol.
- Provides precise planning but introduces additional costs and preparation time.

## V. Post-operative assessment of Total Knee Replacement (TKR) alignment

Several options are available to the TKR surgeon in regards to the evaluation of postoperative alignment. The options available are similar to imaging methods available for pre-operative alignment and preoperative planning.

### 1. Standard Knee x-rays.

In the immediate postoperative period, most orthopaedic surgeons will obtain knee x-rays following TKR before discharge from the hospital. Usually, a standard-length film AP and lateral x-ray are performed often in the recovery suite immediately following surgery. This is different from the preoperative standard knee x-ray protocol. Firstly, only an AP and natural are performed, and there is no skyline view obtained. This means that the patellofemoral part of the knee replacement and the patellofemoral alignment are not assessed at this time. (see example below; Diagram V.1.i)

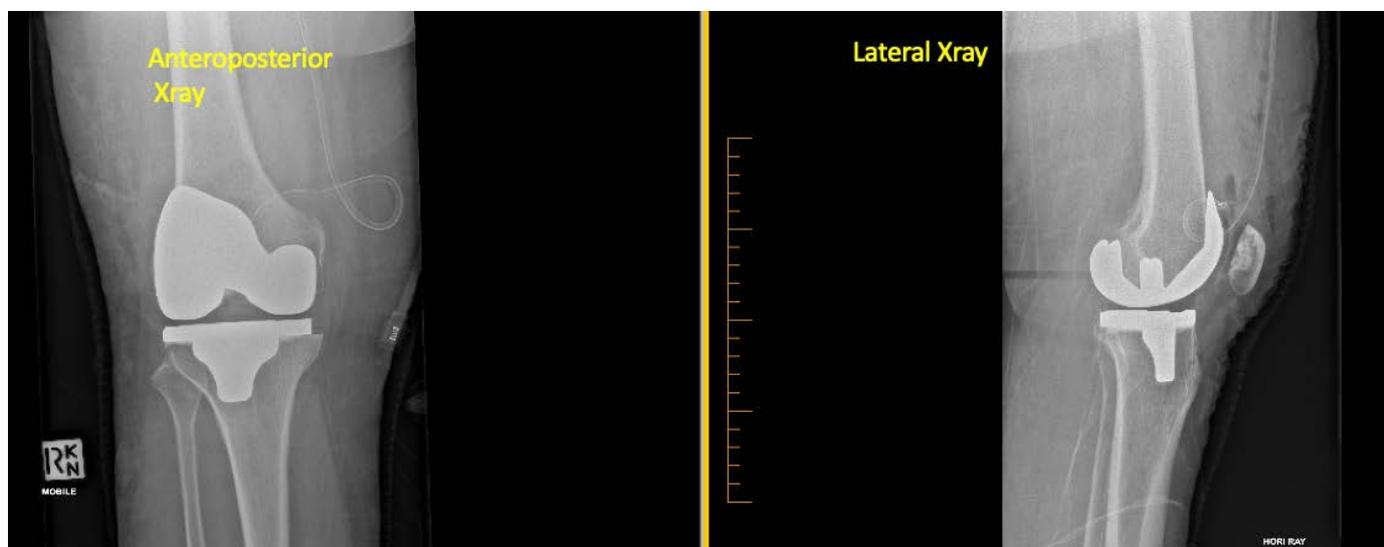


Diagram V.1.i

Routinely orthopaedic surgeons will follow their patients after TKR for a period of time. This may be six months or longer. It is the routine to review the patients with radiographs at these stages. Routine x-rays at this stage usually include AP standing, lateral, and skyline views (see below as an example; Diagram V.1.ii). These are x-rays from the same patient as shown above but performed six months later. Note that the APX rate is now a weight-bearing film

and shows by the left and the right knee. A skyline can now be performed because the patient can undertake the required knee band for this x-ray. This is a very important image because it shows the patellofemoral alignment for the first time in the post-operative period.



Diagram V.1.ii

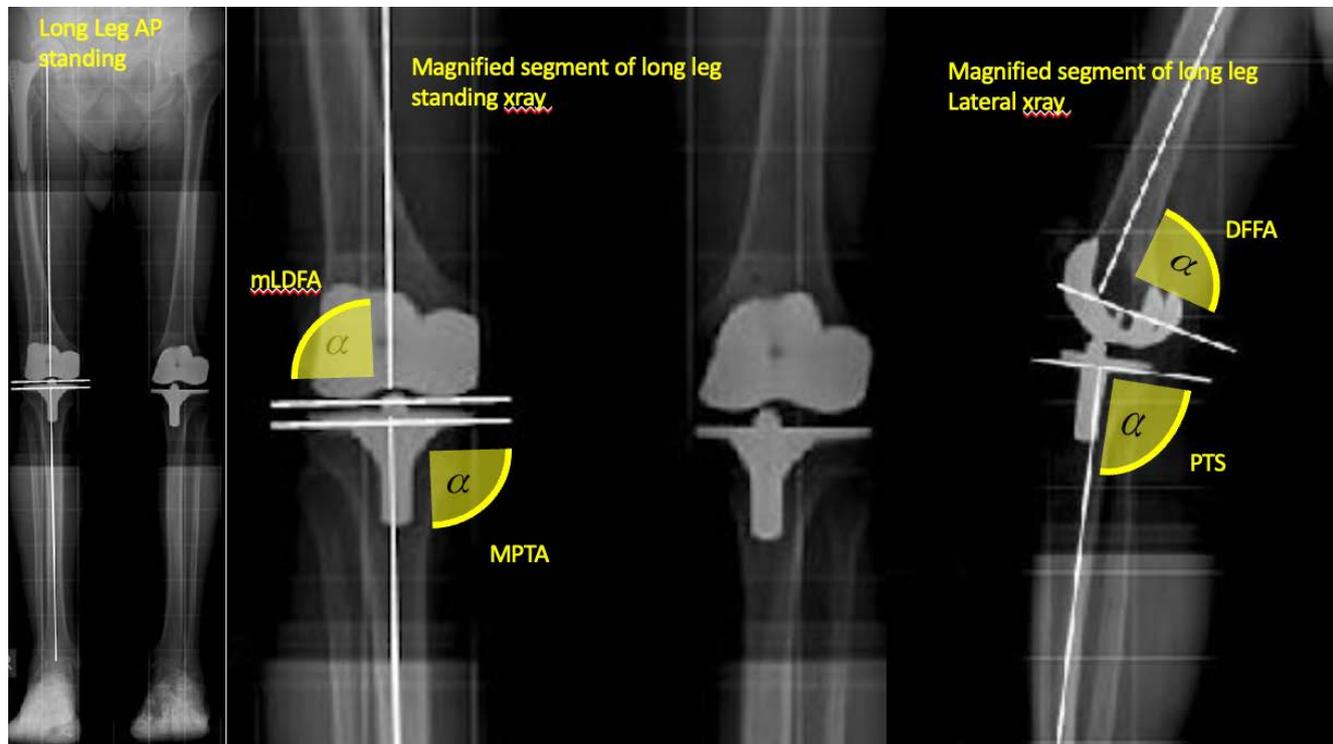
These X-rays do not allow accurate measurement of coronal plane alignment or sagittal plane alignment which require long leg x-rays(see below). They give a good estimate of alignment and component position position, but I'm not accurate enough to use for measurements. The skyline x-ray is extremely useful in the assessment of axial/transverse alignment. If the patella including the patella prosthesis sits accurately in the groove of the femoral prosthesis this is an indicator of, good alignment of the patella. Patella tilt and patella subluxation and even the congruence angle can be measured on this x-ray.

## 2. Long Leg Standing X-rays

The long leg AP X-ray shows the coronal plane alignment of the TKR. A line from the centre of the femoral head to the centre of the ankle joint shows the coronal mechanical axis of the lower limb. A line from the centre of the femoral head to the centre of the femoral component joint shows the coronal mechanical axis of the femur. A line from the centre of the tibial component to the centre of the ankle shows the mechanical axis of the tibia. The angle between the mechanical axis of the femur and the distal end of the femoral component shows the angle called the mLDFA (mechanical lateral distal femoral angle). The angle between the proximal end of the tibial component and the mechanical axis of the tibia shows the angle called the MPTA (medial proximal tibial angle).

The long leg lateral X-ray shows the sagittal plane alignment. A line from the centre of the femoral head to the centre of the femoral component shows the sagittal mechanical axis of the femur. A line from the centre of the tibial component to the centre of the ankle shows the sagittal mechanical axis of the tibia. The angle between the mechanical axis of the femur and

the distal end of the femoral component shows an angle called the DFFA (distal femoral flexion angle). The angle between the proximal end of the tibial component and the mechanical axis of the tibia shows the angle called the PTS (posterior tibial slope). (Some of these angles are demonstrated in the image below; Diagram V.2.i.)



**Diagram V.2.i**

### 3. EOS Scanning

EOS allows the postoperative measurement of the coronal plane and sagittal plane alignment of the tibial and femoral components of the TKR. It is not useful for axial plane alignment or patella alignment. (See the representative images below; Diagram V.3.i.) It cannot be used for measuring the axial alignment parameters of distal femoral rotation and proximal tibial rotation, including the position of the knee compared to the tibial tubercle and the position of the distal femur compared to the epicondylar axis or the posterior condylar axis. These measurements require CT scanning or MRI scanning, as will be discussed in the next section.

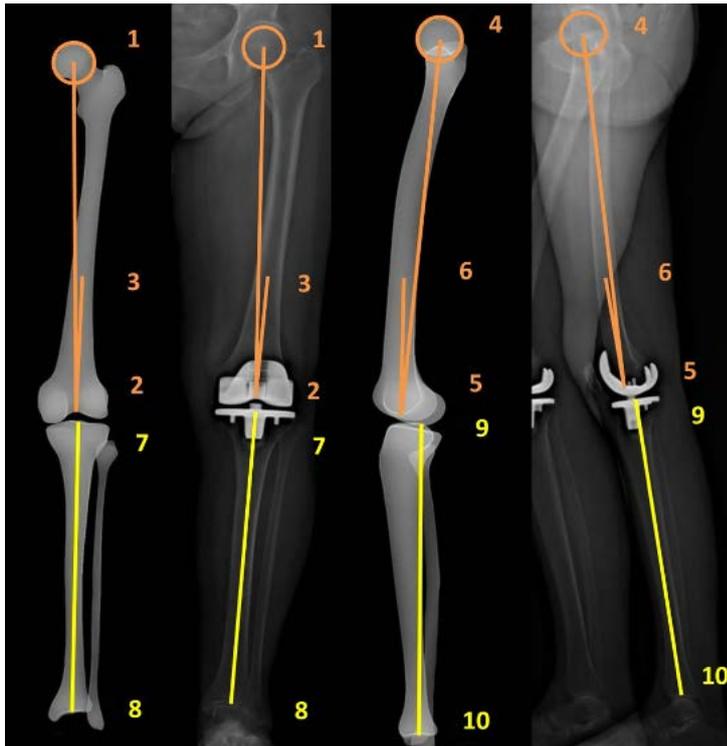


Diagram V.3.i

#### 4. CT Scanning

CT scanning remains the gold standard for post operative imaging. It is certainly the best that most accurate method particularly for measuring axial/ transverse plane alignment

key measurements:

##### 1. Coronal Plane Measurements (Frontal View)

- **Mechanical Axis Deviation (MAD):** Distance from the centre of the knee to the mechanical axis line (from femoral head to ankle centre).
- **Hip-Knee-Ankle Angle (HKA):** Angle between the mechanical axes of the femur and tibia.
- **Mechanical Axis of Femur and Tibia:** Assessing straightness or varus/valgus deformities.
- **Joint Line Convergence Angle (JLCA):** Measures any tilt in the joint line.
- **Lateral Distal Femoral Angle (LDFA)** and
- **Medial Proximal Tibial Angle (MPTA):** .

(some of these are demonstrated in the images below Diagram V.4.1.i.)



Diagram V.4.1.i

## 2. Sagittal Plane Measurements (Side View)

- **Posterior Tibial Slope (PTS):** Angle between the tibial plateau and a perpendicular line to the tibial shaft.
- **Femoral Flexion Angle:** To assess the anterior or posterior bowing of the femur.
- **Sagittal Plane Mechanical Axis:** To evaluate flexion deformities.
- **Tibial Shaft Axis:** Assessment for recurvatum deformity.

(some of these measurements are demonstrated in the images below (Diagram V.4.2.i))

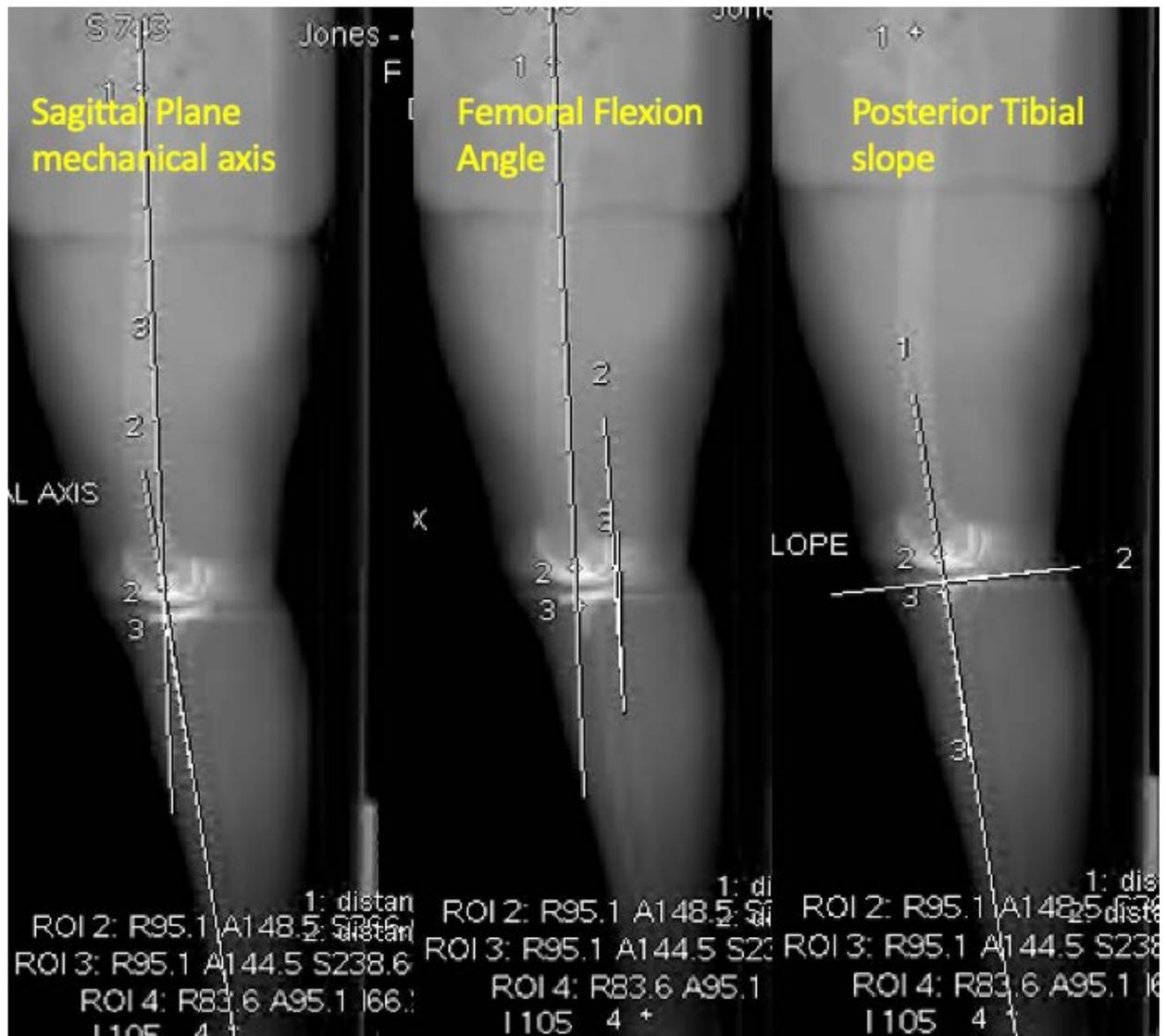
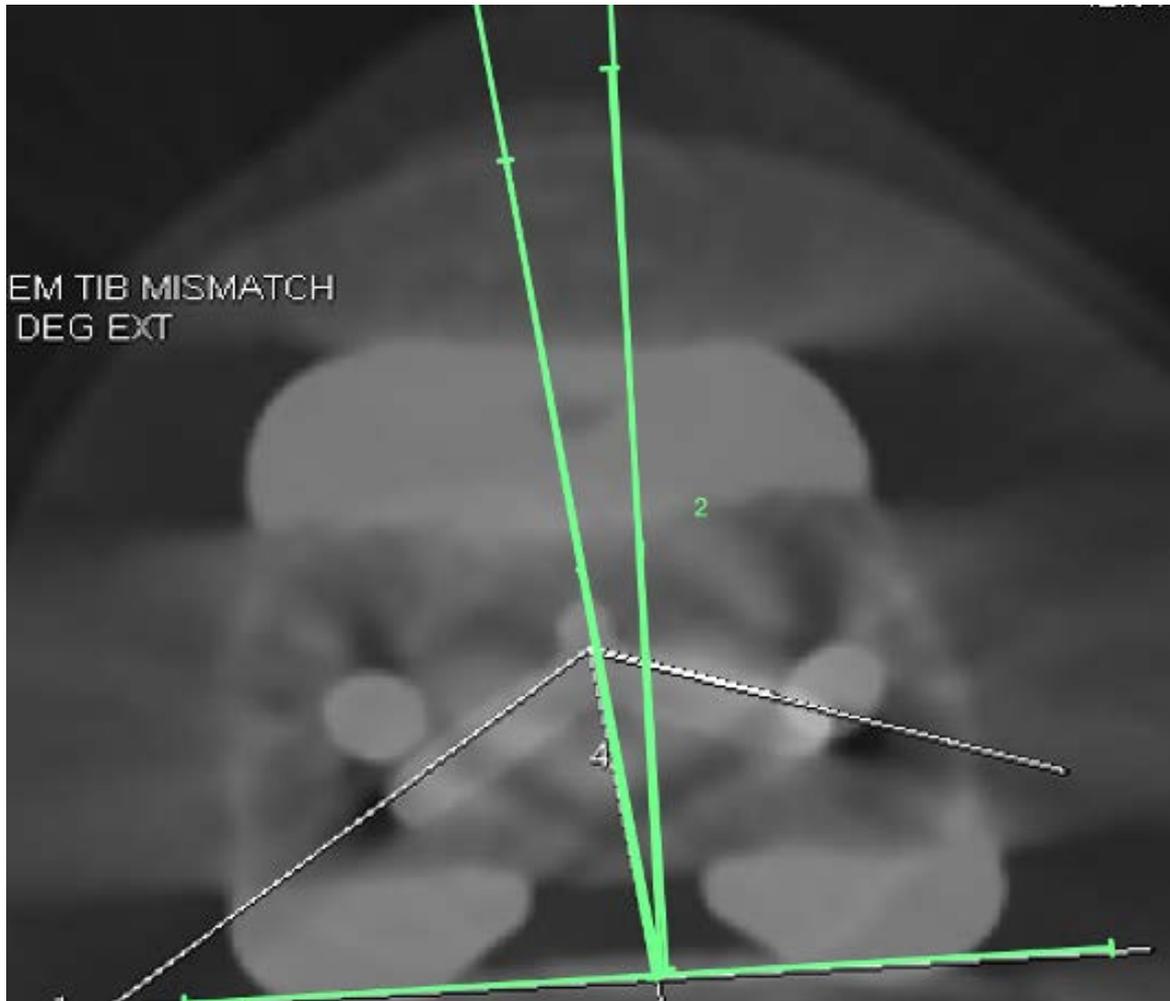


Diagram V.4.2.i

### 3. Axial (Transverse) Plane Measurements (Rotational Assessment)

- **Femoral to Tibial Rotational Mismatch;** Angular Difference  $\theta$  between the rotation of the femoral component and the tibial component as referenced by the posterior condylar axis of the femoral component and the posterior margin of the tibial component. (Diagram V.4.3.i)
- **Tibial Component Rotation:** Angle between the tibial component and the tibial tuberosity neck axis and the posterior condylar line. (Diagram V.4.3.ii)
- **Distal femoral rotation:** Angle between Epicondylar Axis and Femoral Posterior Condylar Axis (Diagram V.4.3.iii)
- **Tibial tubercle to trochlea distance.** This is the parallel distance between two lines: the first line is perpendicular to the posterior condyle axis of the femoral component and runs through the centre of the trochlea of the femoral component; and the second line is parallel to the first and runs through the medial third of the

tibial tubercle of the tibia. It gives a measure of the lateralisation of the tibial tubercle relative to the femoral component. (Diagram V4.3. iv)



**Diagram V.4.3.i**

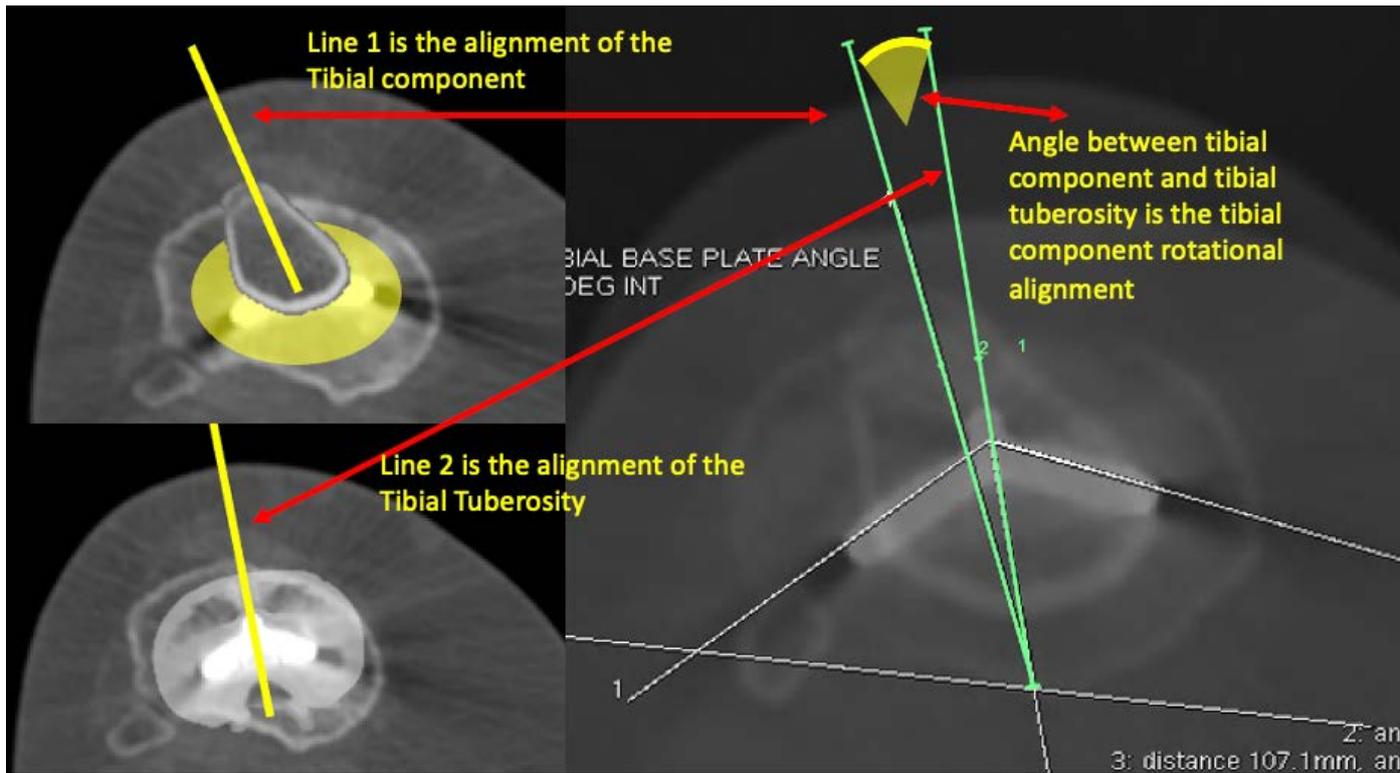
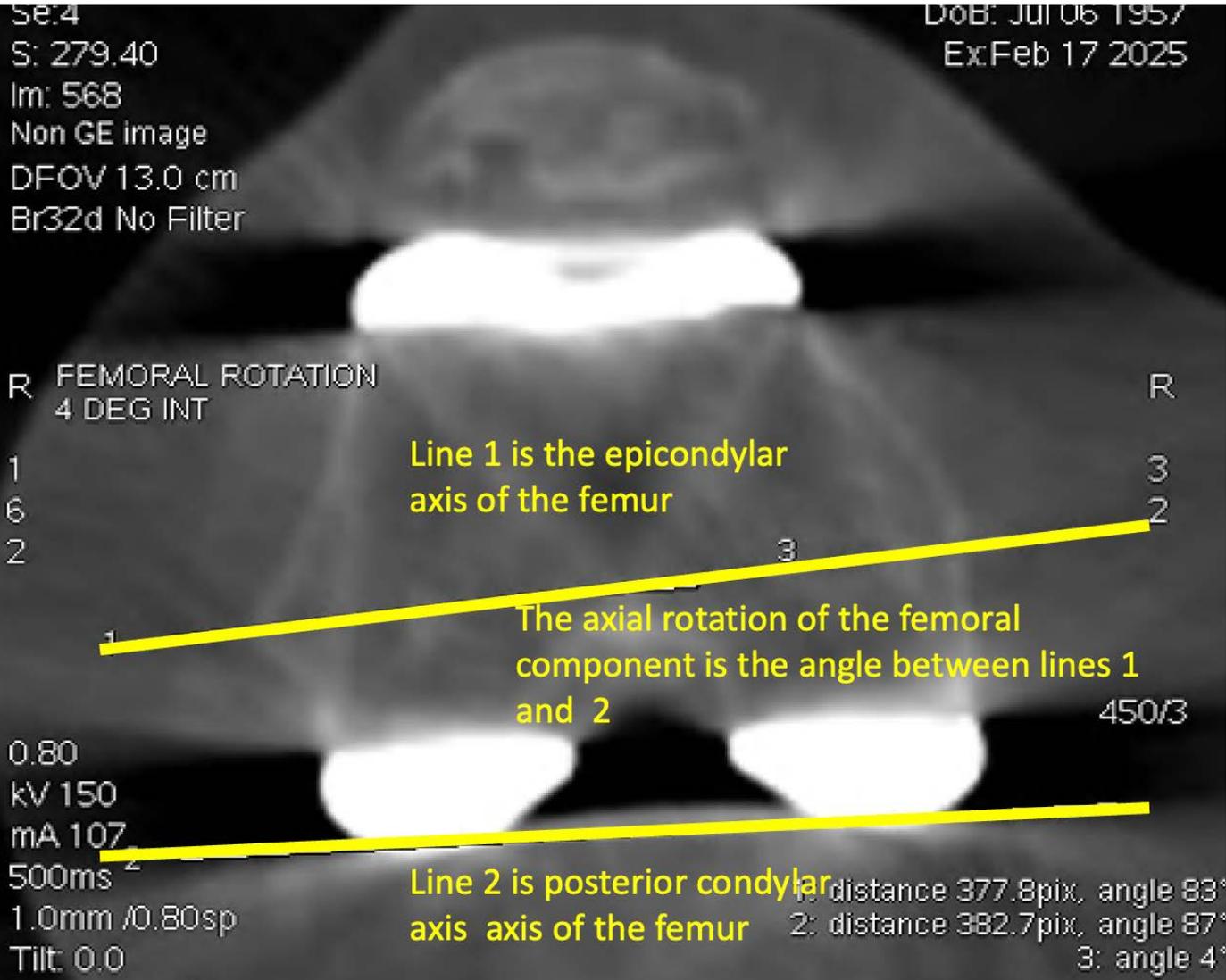
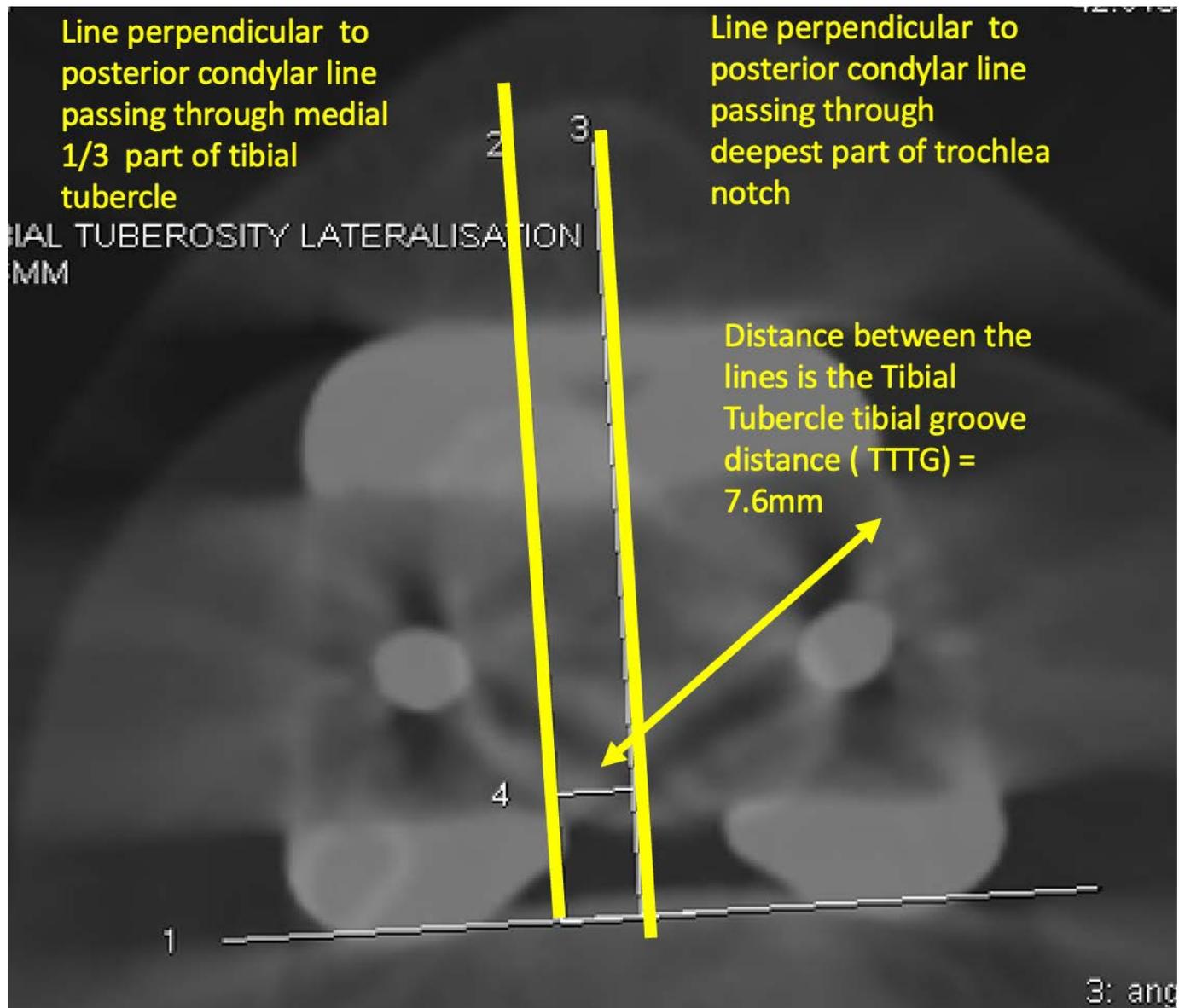


Diagram V.4.3.ii



(Diagram V.4.3.iii)



(Diagram V.4.3.iv)

## VI. Direct Measurement of alignment and component position at Revision TKA

In certain settings direct manual measurement can be used to evaluate component position before or during its removal in the setting of revision total knee replacement. It is usually done only as an adjunct to preoperative imaging. An example would be an estimation of the position of the joint line position created by the primary TKR implants relative to the fibula head or the femoral epicondyles.

However, it has been established that during revision cases anatomical landmarks are often distorted by bone loss and the previous surgical interventions and so femoral and tibial landmarks are difficult to power or visualise accurately. Measurements with surgical callipers, guides and rulers can give some linear measurements but cannot precisely measure angular alignments in three dimensions. Assessing rotational alignment by looking at the epicondyles of the femur is particularly unreliable.

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## VII. Glossary of terms

### Comprehensive Glossary of Terms and Abbreviations for Alignment Assessment After Total Knee Replacement (TKR)

#### 1. Coronal Plane Measurements

- **HKA (Hip-Knee-Ankle Angle):** The angle between the mechanical axis of the femur and tibia. Ideal value is **180°**.
- **MAF (Mechanical Axis of the Femur):** The line drawn from the center of the femoral head to the center of the knee.
- **MAT (Mechanical Axis of the Tibia):** The line from the center of the knee to the center of the ankle.
- **mMPTA (Medial Mechanical Proximal Tibial Angle):** The angle formed between the mechanical axis of the tibia and the tibial plateau. Ideal is **87°-90°**.
- **mLDFA (Mechanical Lateral Distal Femoral Angle):** The angle between the femoral mechanical axis and the distal femoral joint line, typically **87°-90°**.
- **aLDFA (Anatomic Lateral Distal Femoral Angle):** The angle between the anatomical axis of the femur and the distal femoral joint line, typically **79°-83°**.
- **JLO (Joint Line Obliquity):** The angle between the horizontal plane and the joint line.

#### 2. Sagittal Plane Measurements

- **PTS (Posterior Tibial Slope):** The posterior inclination angle of the tibial component, typically **3°-7°**.
- **Sagittal Slope:** The angle of the tibial component in the sagittal plane.
- **JLH (Joint Line Height):** The vertical distance from a reference bony landmark to the joint line.

#### 3. Axial Plane Measurements (Rotation)

- **FCR (Femoral Component Rotation):** The angle between the surgical transepicondylar axis and the posterior condylar axis of the femur.
- **TCR (Tibial Component Rotation):** The angle between the posterior border of the tibial component and the tibial tubercle.

#### 4. Patellofemoral Alignment Measurements

- **TT-TG (Tibial Tubercle-Trochlear Groove Distance):** The horizontal distance between the tibial tubercle and the trochlear groove. Ideal is **10-15 mm**.
- **PCA (Patellar Congruence Angle):** Assesses patellar alignment within the trochlea.
- **PTA (Patellar Tilt Angle):** The angle between the anterior condyles and the lateral facet of the patella.
- **IS Ratio (Insall-Salvati Ratio):** Ratio of patellar tendon length to the length of the patella. Normal is **0.8-1.2**.
- **CD Ratio (Caton-Deschamps Ratio):** Ratio of the distance from the inferior pole of the patella to the tibial plateau to the length of the patella. Normal is **0.6-1.3**.

## 6. EOS Imaging and Long-Leg Standing X-ray Abbreviations

- **LLR (Long Leg Radiograph):** Full-length standing radiograph for mechanical axis evaluation.
- **EOS (EOS Imaging System):** 3D, low-dose imaging technique for standing alignment assessment.
- **SFA (Sagittal Femoral Angle):** Measured on EOS images for assessing sagittal alignment.
- **STA (Sagittal Tibial Angle):** Measured on EOS images to assess the tibial sagittal alignment.
- **FMA (Femoral Mechanical Axis):** Measured from EOS to evaluate the femoral alignment.
- **TMA (Tibial Mechanical Axis):** Measured from EOS for tibial alignment.