Thesis

Does a constitutional varus affect the postoperative leg axis after total knee replacement by using the extension-first-technique?

submitted by

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Declaration of Academic Integrity

I hereby confirm that the present diploma thesis is the result of my own independent scholarly work. I also confirm that in all cases where material from the work of others (in books, articles, essays, dissertations, and on the internet) is acknowledged, quotations and paraphrases are clearly indicated. No material other than that cited in the reference list has been used. I have read and understood the Medical University's regulations and procedures concerning plagiarism.

Graz, 13.11.2021 *Carina Zinggl eh.*

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Zusammenfassung

Im Rahmen der Implantation einer Knietotalendoprothese (K-TEP) spielt die Ausrichtung der Beinachse eine wesentliche Rolle. 3 % der Bevölkerung weisen eine Varusstellung der Beinachse von 3° oder mehr auf. Somit ist eine neutrale Ausrichtung der Beinachse nicht für jeden Menschen als physiologisch zu werten. Einige ChirurgInnen favorisieren deshalb bei der K-TEP-Implantation eine 3°-Varus-Ausrichtung.Ziel der Studie war es daher zu evaluieren, ob sich für präoperativ varus-ausgerichtete Beinachsen auch bei einem Nichtbeachten des 3°-Konzeptes und gleichzeitiger Anwendung der Extension-First-Technik postoperativ eine Varusstellung ergibt. Dazu wurden 224 Ganzbeinröntgenaufnahmen (prä- und postoperativ) von 112 zufällig ausgewählten PatientInnen händisch vermessen. Femorale und tibiale Winkel (jeweils lateral, medial und proximal sowie distal), der femorotibiale Winkel, der Hüft-Knie-Sprunggelenk-Winkel und das Abweichen der Mikulicz-Linie vom Mittelpunkt des Kniegelenks wurden gemessen. Die PatientInnen wurden entsprechend ihrer präoperativen Beinachse in drei Gruppen, varus (N = 63), valgus (N = 33) oder orthograd (N = 16), eingeteilt. Nach der Berechnung der Differenzen zwischen prä- und postoperativ für jeden Winkel erfolgte die statistische Auswertung mittels Varianzanalyse (ANOVA) und im Falle signifikanter Unterschiede wurden zusätzliche Post-hoc-t-Tests durchgeführt.

Bei 83 % der PatientInnen (N = 52) mit präoperativer Varusstellung konnte postoperativ eine orthograde Beinachse festgestellt werden. Somit führte das Verwenden der Extension-First-Technik ohne Berücksichtigung des 3-Grad-Konzepts bei einer präoperativen Varusstellung in den meisten Fällen nicht zu einer postoperativen Varusausrichtung. Betrachtet man jedoch die Ergebnisse der Varusgruppe im Vergleich zur Nicht-Varus-Gruppe (valgus und orthograd), konnte bei PatientInnen der Nicht-Varus-Gruppe nur bei 61 % eine postoperativ orthograde Beinachse erreicht werden. Kniegelenke mit präoperativer Valgus-Stellung weisen diese fast zur Hälfte auch postoperativ auf; im Gegensatz zu Kniegelenken mit präoperativer Varus-Stellung. Die Tendenz der vermehrten postoperativen Valgus-Ausrichtung bei präoperativer Valgus-Stellung ist für weitere Untersuchungen interessant, auch um den vorrangig beeinflussenden Faktor (unter anderem Operationstechnik, Messtechnik, Patientengut) hervorzubringen. Insgesamt ist anzumerken, dass die Extension-First-Technik in den meisten Fällen unabhängig vom Phänotyp in einer postoperativen geraden Beinachse resultiert.

Abstract

In the context of Total Knee Arthroplasty (TKA), the alignment of the leg axis is an essential factor. 3 % of the population present a varus alignment of the leg axis of 3° varus or more. As a result, a neutral alignment of the leg axis cannot be considered physiological for everyone. Therefore, some surgeons favour a 3° varus alignment in TKA.

The aim of the study was to evaluate whether a varus position results postoperatively for preoperatively varus-aligned leg axes even if this 3° Concept is not considered and the Extension First Technique is used in TKA. For this purpose, 224 whole-leg radiographs (preoperative and postoperative) of 112 randomly selected patients were measured by hand. Femoral and tibial angles (lateral, medial, proximal, distal), as well as the femorotibial angle, the hip-knee-ankle angle, and the deviation of the Mikulicz Line from the center of the knee joint were measured. Patients were divided into three groups, varus (n=63), valgus (n=33), or orthograde (n=16), according to their preoperative leg axis. After calculating the differences between pre- and postoperative for each angle, statistical analysis was performed using analysis of variance (ANOVA) and, in case of significant differences, additional Post-Hoc t-Tests.

In 83 % (N=52) of the patients with preoperative varus alignment, an orthograde leg axis could be found postoperatively. This indicates that using the Extension First Technique without considering the 3° Concept for preoperative varus aligned knee joints does not lead to a postoperative varus alignment in most cases. However, considering the results of the varus group compared to the non-varus group (valgus and orthograde), a postoperative orthograde leg axis can be achieved in only 61 % (N=30) of patients in the non-varus group. In contrast to knee joints with a preoperative varus position, almost half of the knee joints with preoperative valgus alignment are also valgus aligned postoperatively. The tendency of increased postoperative valgus alignment in preoperatively valgus aligned knee joints is interesting for further investigations, also, in order to reveal the primary influencing factor (among others surgical techniques, measurement techniques, patient population).

Overall, this study showed that the TKA by using the Extension First Technique mostly results in a postoperative orthograde leg axis, regardless of the phenotype.

General part: Knee and Total Knee Replacement

1 Anatomy of the knee

The synovial knee joint is composed of three bones: femur, tibia and patella. They build a pivot-hinge joint, also called trochoginglymus, consisting of two separate joints, the tibiofemoral and the patellofemoral joint (1,2). As for this specialized joint, movements around a transverse and a longitudinal axis are possible (Fig. 1, left side) (2).

1.1 Tibiofemoral joint

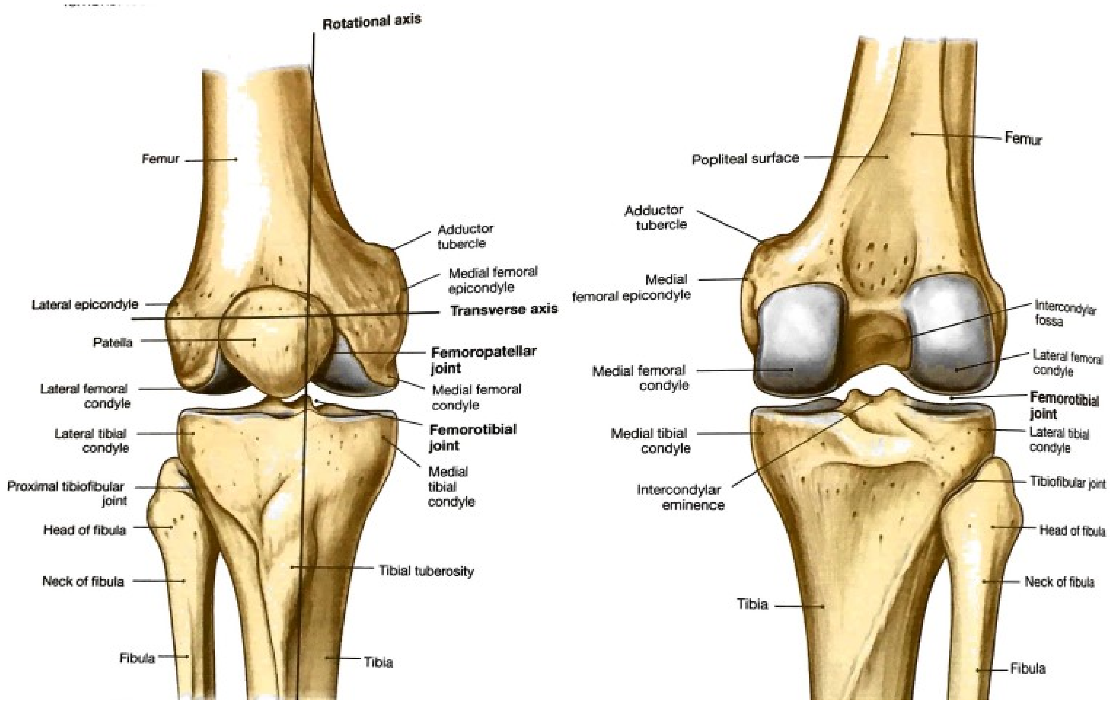


Fig. 1: Knee joint, right side (2).

The articulating surfaces are the proximal tibial surface (also called tibial plateau) and the femoral condyles. The tibial plateau is composed of a medial and lateral articular surface, which corresponds with the femoral condyles. The medial surface is oval, whereas the lateral surface is more circular. Compared to the long axis of the tibial shaft, the head of the tibia slopes posteriorly and the tibial plateau slopes downwards.

The second articulating surface, the femur condyles, is convex and spiral. From sagittal view, the curvature increases posteriorly. The menisci, two fibrocartilage discs between femur and tibia, compensate the irregularity of the articulating surfaces.

1.2 Patellofemoral joint

The articular surface of the patella contacts different areas of the femur condyles. It depends on the flexion or extension of the knee. On flexion, the point of contact between patella and femur is more proximal than in extension (1).

1.3 Superior tibiofemoral joint

Additionally, the tibia and the fibula build the superior tibiofemoral joint, which is also involved in knee movements. The articulating surfaces, varying in size and form, are the lateral tibial condyle and the head of the fibula. The surfaces are covered with hyaline cartilage. Only limited movement is possible.

1.4 Joint capsule

The joint capsule of the knee consists of a fibrous (external) layer and a synovial (internal) membrane (Fig. 2). The fibrous layer is mostly thin. It attaches to the femur above the articulating surface of the condyles and downwards to the edge of the tibial plateau. It also encloses the back of the femur condyles and the intercondylar fossa. The tendon of the popliteus muscle passes through the posterior side of the capsule to attach to the tibia, so there is a gap in the fibrous layer, exactly in the field of the lateral tibial condyle. At the front, the tendon of the quadriceps muscle, the patella and the patellar ligament replace the fibrous capsule.

A synovial membrane surrounds surfaces that are not covered with articular cartilage in the articular cavity. It covers the femoral and tibial condyles, the back side of the patella and the margins of the menisci. On the lateral and medial side, the synovial membrane runs with the fibrous layer. In the center, it deviates from the fibrous capsule. Posteriorly, the synovial membrane comes into the intercondylar region and covers the cruciate ligaments and the infrapatellar fatpad (Fig. 2). So the result of this characteristic process is an infrapatellar synovial fold.

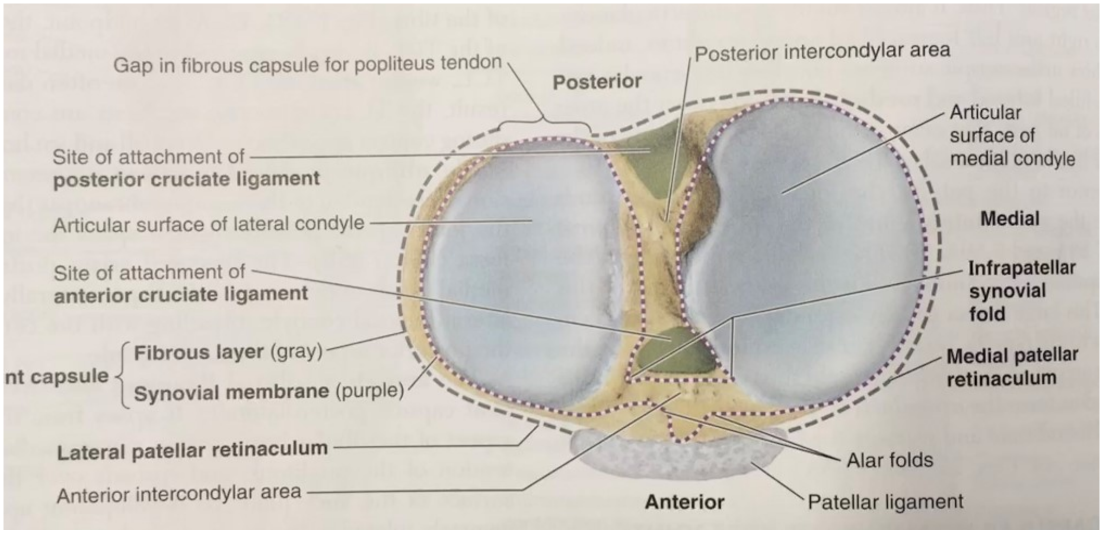


Fig. 2: Superior view of superior articular surface of tibia (3).

1.5 Ligaments

There are many possible classifications for the ligaments in the literature. In Gray's Anatomy, e.g. the Retinacula and collateral ligaments are ranked among soft tissues, the menisci are described in an appropriate chapter (1). Moore uses another classification, the collateral ligaments are "extracapsular ligaments", the menisci and cruciate ligaments are "intra-articular ligaments" (3). In this chapter, the classification of Moore is used.

1.5.1 Extracapsular ligaments

Extracapsular ligaments strengthen the knee capsule and assist in some movements of the knee joint. Especially the tibial and the fibular collateral ligament are important. In extension of the knee they are tight, a stable standing is possible. In flexion, they become loose and allow limited rotation.

Other relevant extracapsular ligaments:

- The oblique popliteal ligament runs posterior from the medial tibial condyle to the lateral femoral condyle (Fig. 3). It is an extension of the semimembranosus tendon and fuses with the posterior aspect of the joint capsule.

- The arcuate popliteal ligament runs from the posterior aspect of the fibula's head to the posterior surface of the knee joint (spreading into the surface) while passing over the popoliteus tendon (Fig. 3).
- The patellar ligament runs from the apex and margins of the patella to the tibial tuberosity (the distal part of the quadriceps tendon) and receives the lateral and medial patellar retinacula (Fig. 4). Retinacula are expansions of the lateral and medial vastus muscle and the surrounding deep fascia.
- The fibular collateral ligament runs from the lateral femoral condyle to the head of the fibula (lateral surface). The popliteus tendon separates the lateral meniscus and the fibular collateral ligament.
- The tibial collateral ligament runs from the medial femoral condyle to the medial condyle of the tibia (medial surface) (Fig. 4). Deep fibers are attached to the medial meniscus. The tibial collateral ligament is weaker and therefore more often damaged than the fibular collateral ligament (like the medial meniscus).

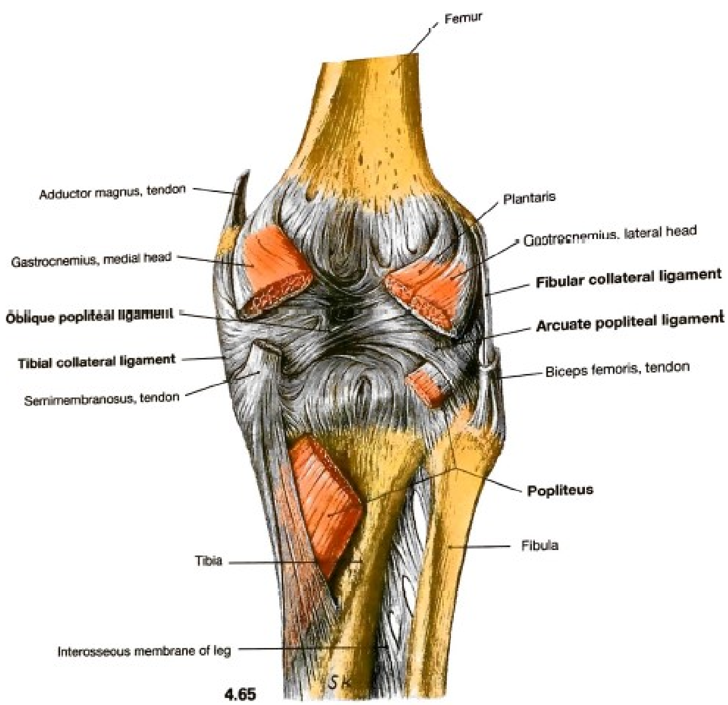


Fig. 3: Knee joint, right side with closed joint capsule (2).

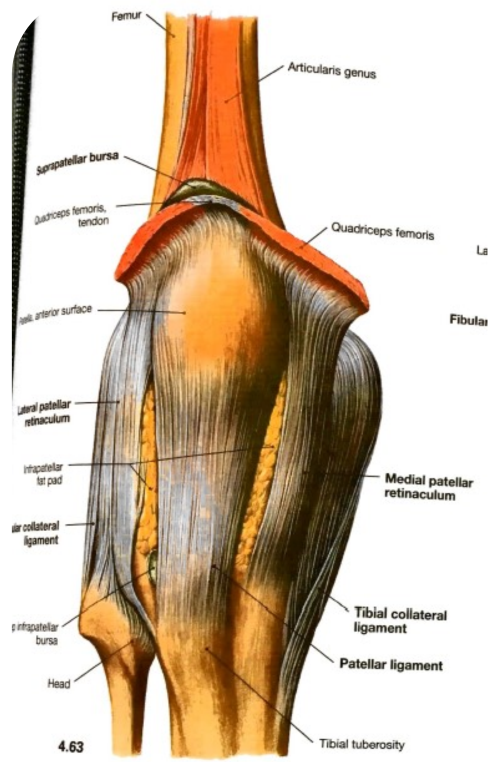


Fig. 4: Knee joint, right side (2).

1.5.2 Intra-articular ligaments

Like mentioned above, Moore, compared to Gray's anatomy, rates the menisci among the intra-articular ligaments in addition to the anterior and posterior cruciate ligaments.

1.5.2.1 Cruciate ligaments

- The anterior cruciate ligament
  - runs from the anterior intercondylar area of the tibia to the medial side and the posterior part of the lateral femoral condyle.
  - Function:
    - A posterior rolling of the femoral condyles during flexion is not possible.
    - The tibia cannot be pulled anteriorly during flexion at a right angle.
- The posterior cruciate ligament

- runs from the posterior intercondylar area of the tibia to the lateral side and anterior part of the medial femoral condyle.
- Function:
    - An anterior rolling of the femoral condyles during extension is not possible.
    - It is stronger than the anterior cruciate ligament.
    - It is a stabilizing factor in downhill walking.

The ligaments cross each other at the center of the knee joint. Because of their oblique orientation, parts of them are always tight (3). Together, the cruciate and collateral ligaments are responsible for impossible rotation of the knee joint during extension. Flexion is necessary for a medial or lateral rotation of the tibia. The different positions of the cruciate ligaments during medial and lateral rotation are illustrated in Fig. 5 and Fig. 6.

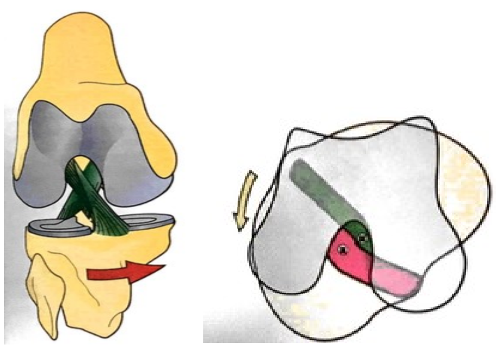


Fig. 5: Medial rotation of the tibia (4).

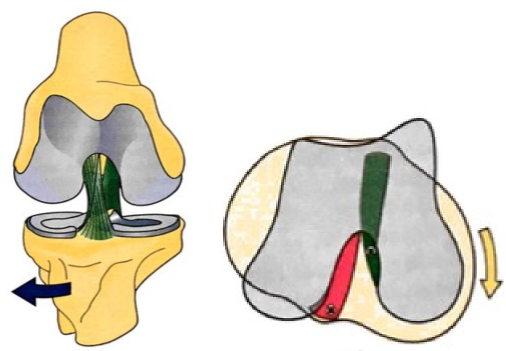


Fig. 6: Lateral rotation of the tibia (4).

The cruciate ligaments wind around each other during internal rotation. During external rotation, the ligaments become loose, there is no inhibition by the cruciate ligaments. Thus, a greater external rotation as opposed to internal rotation is possible (4).

1.5.2.2 **Menisci**

The fibrocartilage menisci are located between the femur and the tibia. The anterior and posterior parts (also called horns) are attached to the anterior and posterior intercondylar area of

the tibia. Additionally, the medial meniscus is attached to the medial collateral ligament, meaning it is less mobile. Compared to the lateral meniscus, there is no additional fixation.
From the cross-sectional area, they look like wedges, because they are thicker at their external margins. Their main task is to balance the different surfaces of the femur and tibia. Furthermore, they are involved in every knee movement ("portable joint sockets") and responsible for a consistent pressure distribution (5).
The horizontal patellar retinaculum links the medial and lateral menisci and the lateral borders of the patella. The transverse ligament of the knee connects both anterior horns (Fig. 7).
The medial meniscus is formed like a "C" or a half moon. Like mentioned above, it is fixed to the medial collateral ligament, more precisely, to the posterior fibers of the collateral ligament. Fibers of the anterior cruciate ligament have also a connection to the anterior horn of the medial meniscus. In Sobottas' Atlas of Human Anatomy, an anterior and posterior meniscotibial ligament is mentioned (Fig. 7). "The medial meniscus […] is anchored via the anterior and posterior meniscotbial ligaments to the respective intercondylar area of the tibia."(2)

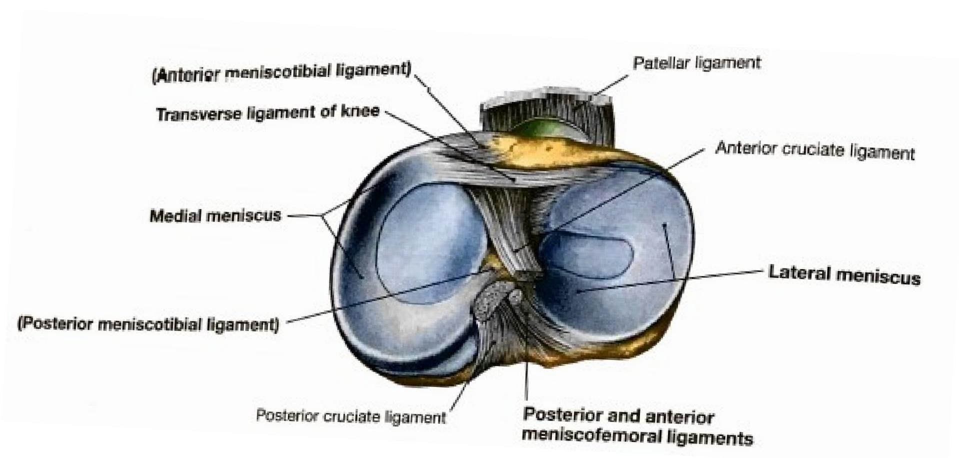


Fig. 7: Menisci of the knee, right side (2).

The lateral meniscus is circular, respectively, it looks like an "O". It has no fixation to the lateral collateral ligament, the tendon of the popliteus muscle separates the two structures and parts of it have a connection to the posterior border of the lateral meniscus (4).
Near the posterior cruciate ligament, two meniscofemoral ligaments can exist. Both meniscofemoral ligaments connect the posterior horn of the lateral meniscus to the medial femoral condyle. The anterior (also called "ligament of humphrey") passes in front of the

posterior cruciate ligament, and the posterior (also called Ligament of Wrisberg) passes behind the posterior cruciate ligament (1,5).

As noted above, the menisici are involved in all knee movements. The meniscopatellar ligaments are responsible for moving forward in extension, the popliteus and semimembranosus muscle for moving backward in flexion. At an internal rotation of the lower leg, the lateral meniscus moves backward and the medial meniscus moves forward. At an external rotation, both mensici act inverse (5).

2 Movement of the knee joint

The main movement of the knee joint is a flexion and an extension around a transverse axis. An active flexion (Fig. 8) is possible up to 140°, a passive flexion (Fig. 9) up to 160°. Passive means that the heel has to touch the buttocks. An extension is possible at 5-10° at most beyond the neutral position. The neutral position stands for a fully extended knee joint, a hyperextension. The rotation of the lower leg is only possible by a flexion of the knee joint. A lateral rotation is possible up to 40°, a medial rotation up to 30°. This movement occurs around a longitudinal axis through the lower leg (4).

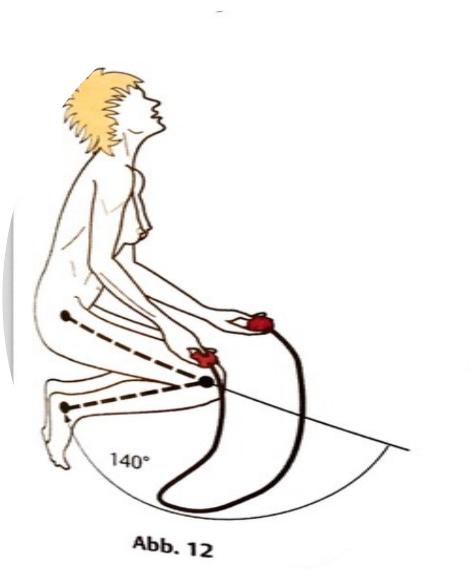


Fig. 8: Active flexion of the knee (4).

Fig. 9: Passive flexion of the knee (4).

2.1 Specialized rotation

In addition, a special rotation of the knee joint, a so called “screw-home mechanism”(3), is possible. It occurs, if the foot is on the ground and the knee is simultaneously fully extended. The medial femoral condyle turns medially and the knee locks. The body’s center of gravity is located behind the transverse axis of the body, so more weight can be beard and the leg muscles can slightly relax. The popliteus muscle is able to unlock the knee. After the muscle has turned the femur laterally (about five degrees), a knee flexion is again possible (3).

2.2 Muscles for movements

Many different muscles are responsible for the movements of the knee joint. Some of them have an assistive character, some are only responsible for special positions.

- Flexion
  - Biceps femoris, Semitendinosus, Semimembranosus (Fig. 10, Fig. 12).
    - Assisting: Gracilis, Sartorius, Popliteus.
    - If the lower leg/foot is fixed: Gastrognemius, Plantaris (Fig. 13).
- Extension
  - Quadriceps femoris (Fig. 11).
    - Assisting: Tensor fasciae latae.

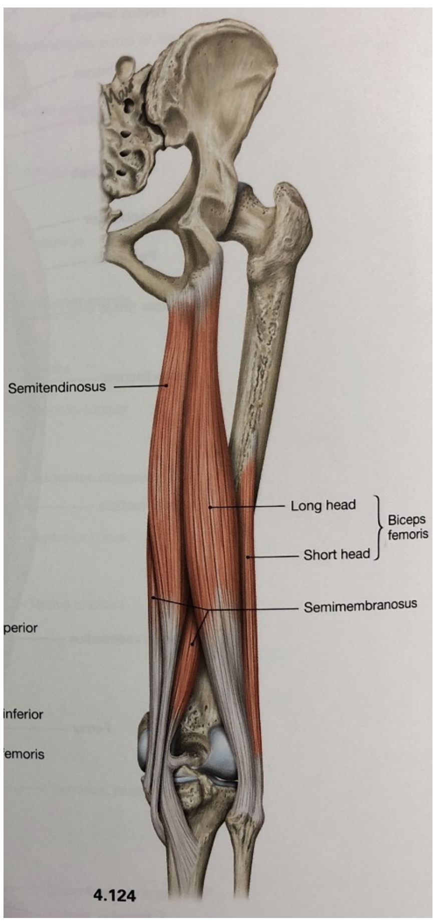


Fig. 10: Dorsal muscles of the thigh, for knee flexion (2).

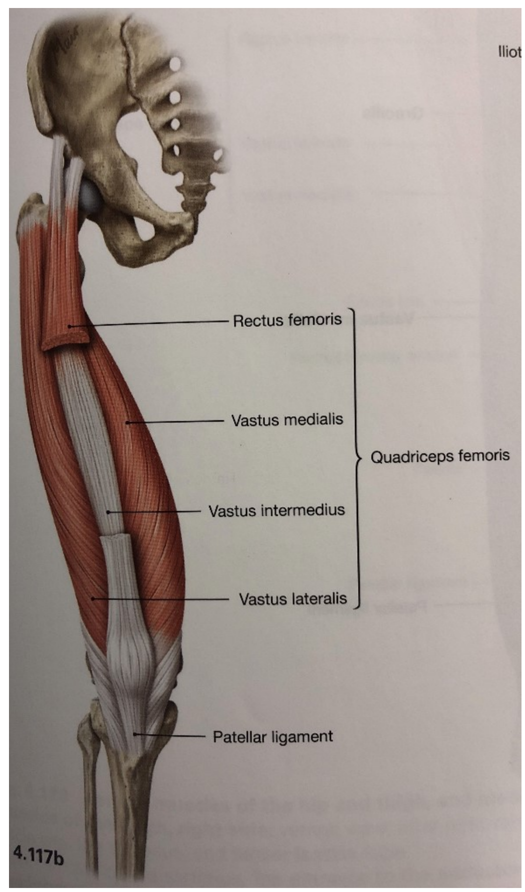


Fig. 11: Ventral muscles of the thigh, for knee extension (2).

- Medial rotation

- When the knee is flexed: Popliteus, Semitendinosus, Semimembranosus (Fig. 12: Muscles for the medial rotation of the knee joint (2).
    - Assisting: Gracilis, Sartorius.
- Lateral rotation
    - When the knee is flexed: Biceps femoris (Fig. 10).

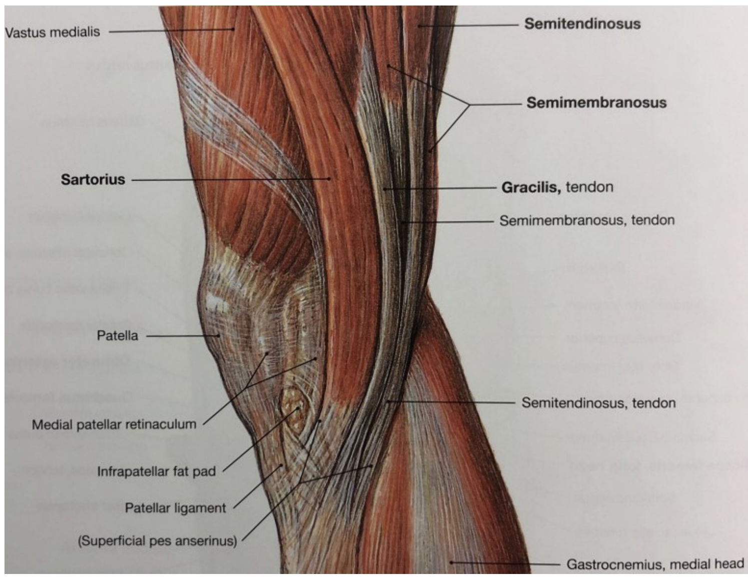


Fig. 12: Muscles for the medial rotation of the knee joint (2).

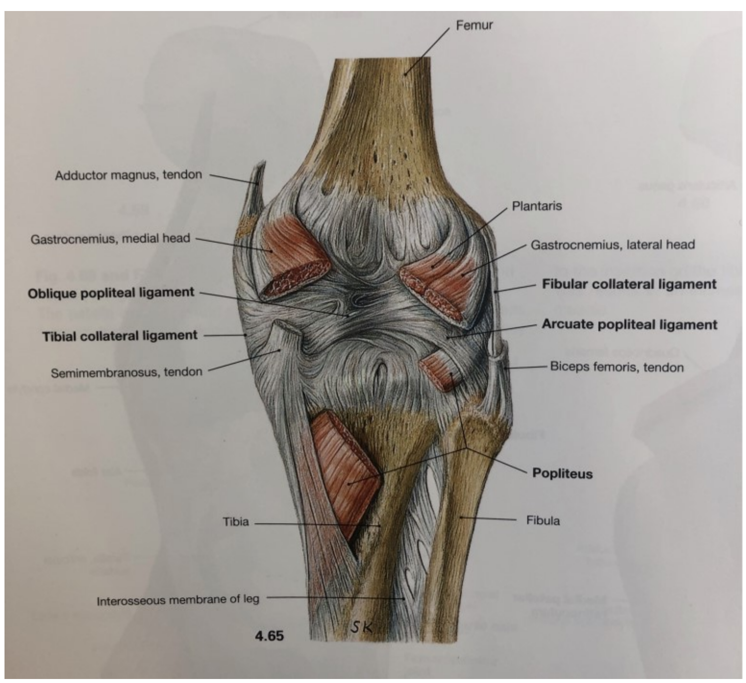


Fig. 13: Muscles and ligaments of the popliteal fossa (2).

3 Physiological axes and joint angles

The physiological axes of the leg change while growing up (e.g. infants have a physiologically genu varum deformity). It is possible to describe anatomical and mechanical axes at the lower limb. Additionally, joint orientation lines are necessary to describe different joint angles.

3.1 Anatomical axes

The main anatomical axes are long axes through the femoral and tibial shaft (Fig. 14). The outcome of the two axes is an external opened angle between thigh and leg. This anatomical femorotibial angle (aFTA) amounts from 173° to 175° (6). In some literature, they define the aFTA as an angle of 174° (2,7).

Waldt gives another definition, which describes an upward acute angle of 6.85° ± 1.4° between the anatomical axes of the femur and the tibia (8). Fang describes an anatomic tibiofemoral angle of 7° to 9° of valgus (9).

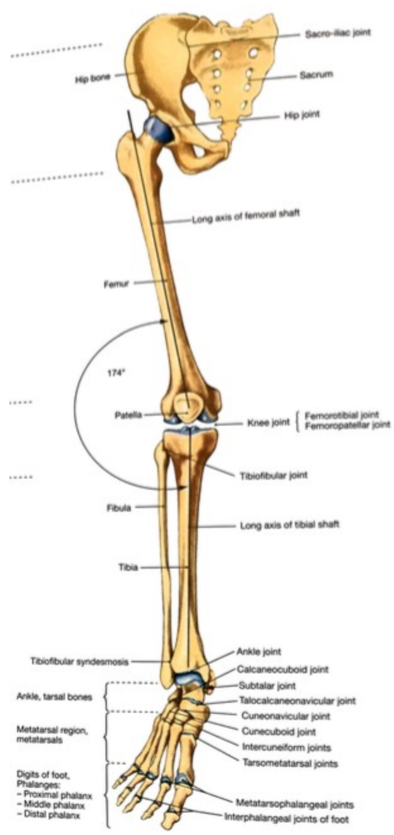


Fig. 14: Anatomical axes of femur and tibia (2).

3.2 Mechanical axes

The mechanical axis of the femur deviates from the center of the femur's head to the center of the knee joint. The anatomical and mechanical axis of the lower leg (tibia) are almost identical (6).

The so called "Mikulicz line" connects the center of the femur's head with the center of the upper ankle joint (Fig. 15). Under physiological conditions, the center of the knee joint is located at 8 ± 7 mm (7, 11) medially of the line. The specification for deviation from the center of the knee joint is called "Mechanical Axis Deviation" (MAD) (5,6,10). However, the values for the physiological MAD are different in literature, for example Wirtz et al. (10) give a range of 4 mm lateral to 4 mm medial for the physiological value of the MAD, Waldt (8) defines a medial deviation of 4 ± 4mm as physiological.

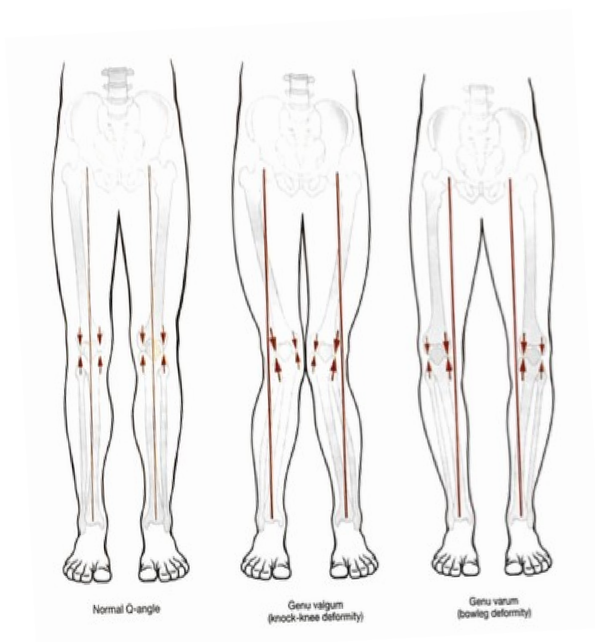


Fig. 15: Mikulicz line:
Orthograde, Genu varum, Genu rectum (2).

An angle between the femoral and the tibial mechanical axis, the mechanical tibiofemoral angle (mTFA) can also be specified (Fig. 16). The information for the values of the mTFA varies in literature, some are presented in Table 1:

Literature and Nomenclature	Physiological values for the angle
Paley(11) - "Tibiofemoral mechanical alignment"	1.3° varus
Bellemans(12) - "HKA=HipKneeAnkle Angle"	between -3° to +3°
Waldt(8)	1.2° varus
Moreland(13)	1.5° varus (right side) 1.1° varus (left side)

Table 1: Comparison of the angle between the mechanical axis of femur and tibia.

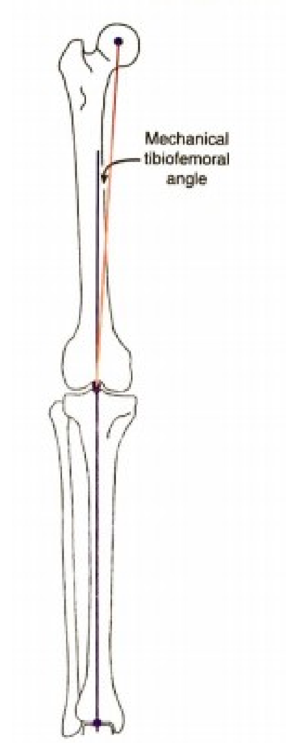


Fig. 16: Mechanical tibiofemoral angle (11).

3.3 Physiological angles between different axes

The axes mentioned above correlate with each other. This makes it possible to specify different angles between anatomical and mechanical axes and between these and the following joint orientation lines (Fig. 17):

- Trochanter head line (a),
- Tangent to femur condyles (b),
- Tangent to tibia plateau (c),
- Tangent to the distal tibia (d).

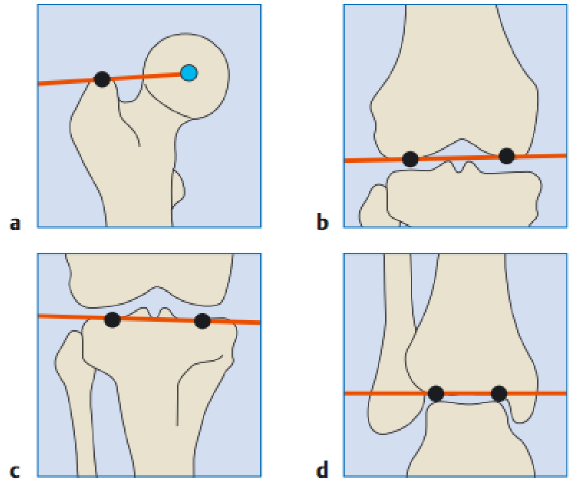


Fig. 17: Joint orientation lines (9).

Between the tangents of femur and tibia, it is possible to define an "Joint Line Convergence Angle" (JLCA). According to Paley's "Principals of Deformity Correction" (11), the two joint orientation lines should be parallel, according to Galla and Lobenhoffer (6), the JLCA should be 0-1°, Hanschen (7) determines 1-2° and Flörkemeier (14) up to 3° convergence to medial for the JLCA.

The values for the angles between the different axes vary from author to author. The names for the angles are abbreviated as follows: The first letter means anatomical (a) or mechanical (m), the next two represent the orientation – lateral (L) or medial (M), proximal (P) or distal (D) (11). Table 2 shows the different angles with the corresponding values:

Physiolog. axis	Joint orientation line (Fig. 17)	Abbrev.	Values
Mechanical femur axis	A	mLPFA	**90°** (85°-95°) (7,11)
Anatomical femur axis		aMPFA	**84°** (80°-89°) (7,11)
Anatomical femur axis	B	aLDFA	**81°** (79°-83°)(5-7,11)
Mechanical femur axis		mLDFA	**88°** (85°-90°) (7,11)
Tibial axis	C	MPTA	**90°** (85°-90°) (7,11)

Tibial axis	D	LDTA	**89°** (86°-92°) (7,11)

Table 2: Joint angles.

Additionally, there exists an anatomical to mechanical femoral angle ("amFA") of approximately 6° (+-1) between the anatomical and mechanical axis of the femur (Fig. 18) (6,10).

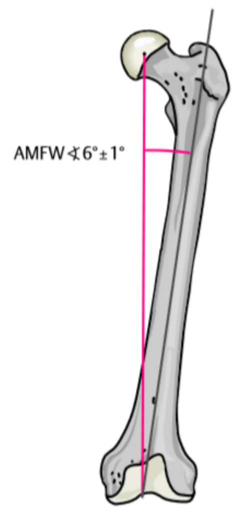


Fig. 18: Anatomical to
mechanical femoral angle (6).

4 Malalignment of the knee joint

Hereditary or acquired abnormities can cause a deviation from the physiological axes. There is for example a correlation between abnormalities (like genu varum or valgum) and a resultant disproportional distribution of the body weight (5). As a consequence, a degeneration of the menisci or the joint cartilage can appear. This can cause an arthrosis of the knee (2).
Deviations of axes and angles can appear in a sagittal, frontal or transversal plane.

- Transversal plane: external torsion, internal torsion.
- Sagittal plane: Genu recurvatum, Genu procurvatum.
- Frontal plane: Genu varum, Genu valgum (6).

Axes deviations in the frontal plane (Genu varum and Genu valgum) are the most frequently appearing deformities. For malalignment, a significant MAD is required. In case of a medial shift of the Mikulicz line, a Genu varum is present, in case of a lateral shift, a Genu valgum (10). Paley developed a malalignment test to analyze the cause of axis deviation (11). With this test, it is possible to find out whether the cause is femoral or tibial (Fig. 19) (10).

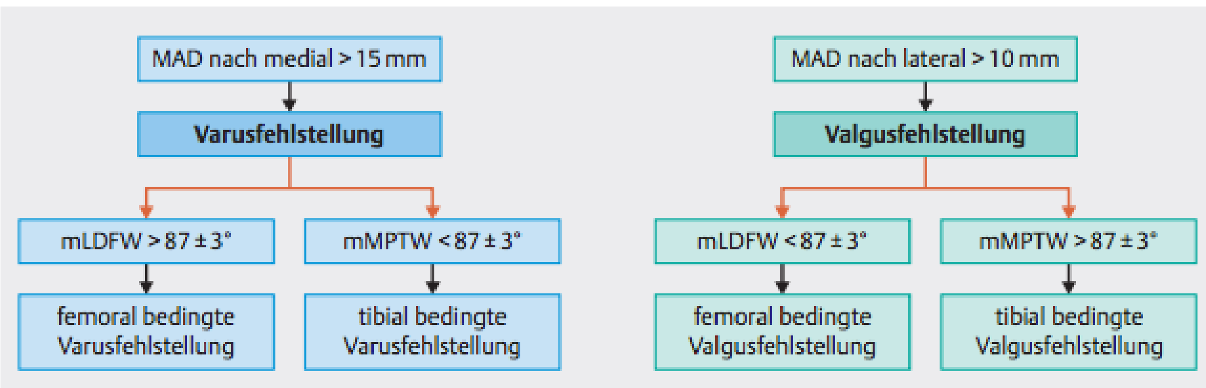


Fig. 19: Malalignment Test according to Paley (14).

Different authors additionally mention changes of the JCLA, aFTA and of the intercondylar or intermalleolar distance, which may cause a malalignment of the knee joint.

4.1 Genu varum

- Anatomical axis deviation
  - aFTA > 173-175° (6,10,14).
  - Acute angle between the anatomical axes of femur and tibia < 0° (8).

- Mechanical axis deviation
  - > 16 mm or > 8 mm medial axis deviation (8).
  - Mikulicz line runs medial to the 4 mm point (more than 15 mm medial is a significant deviation) (6,14)
- Other deviations
  - Increased intercondylar distance (6,14).
  - Laterally opened JLCA (14).

4.2 Genu valgum

- Anatomical axis deviation
  - aFTA < 173-175° (6,10,14).
  - Acute angle between the anatomical axes of femur and tibia > 8.3° (8).
- Mechanical axis deviation
  - > 2 mm or > 0 mm lateral axis deviation (8).
  - Mikulicz line runs lateral to the 4 mm point (more than 10 mm lateral is a significant deviation) (6,10).
- Other deviations
  - Increased intermalleolar distance (6,14).
  - Increased medially opened JLCA (14).

5 Total knee arthroplasty

About one million knee prostheses are implanted worldwide every year. With 90 %, primary gonarthrosis is the most frequent indication for a TKA. Various techniques are used for this intervention and different types of prostheses exist. Which type will be used depends on factors such as the extent of a gonarthrosis and ligament stability. Following, different types of implants exist (5):

- Unicondylar knee prosthesis.
- Bicondylar knee prosthesis
  - with or without replacement of the back surface of the patella.
- Patellofemoral knee prosthesis.
- Partially linked knee prosthesis.
- Linked knee prosthesis (5,15).

The relevant technique for this thesis is the Extension First Technique. As this technique involves the replacement with a bicondylar prosthesis, the procedure is described in more detail as follows.

5.1 Bicondylar knee prosthesis

If all three joint sections (medial and lateral compartment, patellofemoral compartment) and possibly also the anterior cruciate ligament are damaged, a bicondylar knee prosthesis is necessary (5). A surface replacement requires an intact capsule and intact ligaments. If there is a contractual ligament insufficiency, these structures first have to be restored (ligament balancing, see 5.2). If the functionality is further limited, a prosthesis with a higher degree of coupling is necessary (15).

5.1.1 Unconstrained prosthesis

This type of prosthesis is part of the standard therapy. With this, a physiological knee joint function is possible. It enables rolling and gliding and therefore also a normal function of the knee joint. This prosthesis requires undamaged collateral ligaments, the anterior cruciate ligament is not necessary (it is usually removed) (16). The posterior cruciate ligament can either be preserved ("cruciate retaining", CR) or removed ("posterior stabilized", PS). The posterior cruciate ligament will be functionally replaced by a post-cam mechanism. The pivot does not fill the femoral box completely - free rotation is possible. The collateral ligaments have to be undamaged, because there is no varus or valgus stability (17).

In a normal knee joint, the menisci compensate incongruent joint surfaces. In the case of a knee prosthesis, the inlay takes over this function. Depending on the degree of congruence, there are prostheses with congruent (single curve or single radius) or less congruent (multi radius) designs (5).

Knee prostheses are also classified according to the type of the inlay. There are two different types of inlays. In one type, the polyethylene component is firmly fixed on the tibial component ("Fixed Bearing"). At the other type, a movable polyethylene component is placed on the tibial component ("Mobile Bearing"). The second type allows partly sliding and rotation (5,16).

Mobile bearing prostheses are designed to improve kinematics, flexing and reduce a polyethylen abrasion (by increasing the contact area and using a movable polyethylene inlay). Mobile bearing prostheses have not prevailed over fixed bearing prostheses (17) and a superiority over fixed bearing prostheses in long-term studies could not be proven (16).

5.1.2 Semiconstrained prosthesis

Joint stabilization in the frontal and sagittal plane is possible despite functional insufficiency of the ligaments. Design-specific variants of the inlay partially compensate instabilities (for example in the case of insufficient collateral ligaments and the resulting mediolateral instability). In this type of prosthesis, the central pivot and the femoral box are larger than in the PS model. Varus and valgus stability can be ensured (5,16).

5.1.3 Rotational or fixed hinge model

If both cruciate ligaments and both collateral ligaments are missing/damaged or there is isolated higher degree mediolateral instability, a partially coupled prosthesis is no longer sufficient. Axis-guided models are necessary. The coupling mechanism assumes the complete stabilizing function.

- Rotational hinge model: axial rotational movement in the knee joint is still possible.
- Fixed hinge model: fixed femoral and tibial fixation of the coupling mechanism (full hinge prosthesis), no dislocation and rotation possible (5,17).

5.2 Ligament balancing

Ligament balancing is one of the most relevant steps, along with the correct bone incisions, to ensure a satisfactory knee prosthesis (17). The assessment of the medial and lateral ligament tensions in flexion and extension is necessary to achieve a symmetrical, congruent joint gap in these two movements (5,15,17). A step-by-step approach to balancing is necessary. By pulling on the lower leg, the extent of soft tissue release achieved in the flexion and extension position can be determined. Resections that may become necessary can be estimated this way. In the right position and with a correct balancing, the trial spacers, respectively inlays, can be fitted in with the same compression (5). (This is usually done using spacers, trial prostheses or band tensioners (17).)

The popliteus tendon, the posterior cruciate ligament, the integrity of the lateral and medial collateral ligaments, and their ligament insertions are important during release manoeuvre, because they are responsible for the stability of the knee joint (especially ligament structures). The difference in their effect amounts to flexion and extension. Surgical shortening of such structures is not possible. Too short structures will be extended until they have the same ligament tension as the opposite side. A clinical problem can occur, if the ligaments are out of proportion, even if the prosthesis fits optimally. Ligaments, which are too short, can lead to a feeling of tightness with limited movement. Too loose ligaments can lead to instability. The most common reasons for a re-operation are infections, instability and limited mobility.

- Posterior stabilizing factors:
    - Joint capsule,
    - Posterior cruciate ligament.
- Medial stabilizing factors:
    - Joint capsule (dorsal),
    - Semimembranosus muscle,
    - Pes anserinus,
    - Medial collateral ligament (superficial, posterior and anterior proportion).
- Lateral stabilizing factors:
    - Iliotibial tract,
    - Joint capsule (dorsal, lateral),
    - Lateral collateral ligament,

    - Popliteus muscle.

The release technique is the same for the femur first (=measured resection) and the tibia first (=balanced gap) technique, but the release takes place at a different point during the surgery. First, the symmetry of the flexion and extension gap has to be assessed. If both are symmetrical but different in size, the following measures may be necessary:

- Flexion gap and extension gap are too small: usually the tibia resection was too small and
    - a post resection of the tibia is required(5,17).
- Flexion gap is too small: a frequent cause is a too large femoral component.
    - The use of a smaller femoral component is required(17).
    - Release/resection of the posterior cruciate ligament(5).
        - In this case, a prosthesis must be selected that also replaces the posterior cruciate ligament (PS prosthesis).
    - Resection of the tibia (for an increased slope)(5).
- Extension gap is too small: too small resection of the distal femur or a contracture of the posterior structures (flexion contracture).
    - A flexion contracture should be treated before post resection of the femur (posterior release) (17).
    - Release of the posterior capsule(5).

If the flexion and extension gap are asymmetric, a posterior release is necessary (17).

5.2.1 Posterior/medial/lateral release

At first, an existing flexion contracture must be treated gradually before a lateral or medial release can be performed. Jerosch suggests the following order:

- Level 1: resection of dorsal osteophytes.
- Level 2: removing the dorsal joint capsule.
- Level 3: incomplete release of the posterior cruciate ligament at the tibial attachment.
- Level 4: complete resection of the posterior cruciate ligament and selecting a greater type of prosthesis.
- Level 5: resection of the distal femur (max. 4 mm).

After the release of the dorsal structures, a reassessment of the flexion and extension gap is necessary. If it is still asymmetrical, the bone sections should be checked. If the medial or lateral compartments are too tight, a gradual medial or lateral release is necessary (17).

5.3 Surgical approaches to the knee

Several surgical approaches are possible. The standard technique is a medial parapatellar approach, but also a minimal invasive approach can be opted for.

As for the medial and lateral parapatellar approach, the skin is incised from the superior pole of the patella (6 cm proximal(15)) to the upper portion of the tibial tuberosity (2 cm proximal(15)). The underlying structures are then incised, divided (e.g. the tendon of the quadriceps muscle for the medial approach or the iliotibial tract for the lateral approach) or cut through (like the Vastus Medialis Muscle). This way, the joint cavity is opened and it is possible to keep away or evert the patella.

For a minimal invasive approach, it is not necessary to divide the tendon of the quadriceps muscle (in contrast to the approaches mentioned above), meaning the benefit is that the soft tissue structures are better protected (5). Following minimal invasive approaches are found to result in soft tissue protection, less blood loss and less postoperative pain (15):

- Midvastus approach
    - 1-2 mm medial of the patella to the proximal portion of the tibial tuberositas.
    - The approach goes up to the Vastus Medialis Muscle, with this muscle being split.
- Subvastus approach
    - The Vastus Medialis Muscle is not split, the incision is made below the muscle (5,15).

The disadvantage is a more difficult detection of landmarks and resection lines because of a limited overview. Especially in overweight patients or patients with pronounced axis deviation, a minimally invasive approach should not be performed (5).

5.4 General information on surgical techniques

In order to create a durable und well-functioning joint, it is necessary to place the components correctly and to achieve a physiological alignment. There are two standard techniques in TKA, a "femur first" (which is bone-referenced) or a "tibia first" (soft tissue-referenced) approach (15). The difference between the two techniques is the adjustment of the femoral rotation and the determination of the thickness of the femoral bone resection. The orientation of the prosthesis in relation to the axes is the same for both techniques (17).

There are different instruments for femoral and tibial alignment. This is performed either intramedullary or extramedullary. For the tibial alignment both methods are similarly accurate. However, in patients with a BMI over 35, or with a proximal tibial valgus deformity, intramedullary alignment can lead to errors. In addition, the landmarks for the center of the ankle are easier to feel from the outside than, for example, the center of the hip joint. For alignment, the knee must be flexed at 70/110° (for intra- and extramedullary alignment). Currently, extramedullary alignment is most commonly used for the tibia. As for the femur, an intramedullary alignment is standard (it is difficult to feel the hip joint center as a landmark from outside, like mentioned above).

5.4.1 Adjustment of bone cuts, rotation and choice of the correct implant size

Following parameters is important for the adjustment of the **tibial** bone cut:

- <u>Varus/valgus</u>
  - Classic alignment: at 90° to the mechanical tibia axis,
  - or anatomical alignment: corresponding to the joint line that naturally slopes at 3° from lateral to medial.
- <u>Posterior slope</u>
  - Cut surface of the tibia slopes from ventral to dorsal (corresponding to the mechanical tibia axis).
  - Systems currently have a slope between 0° and 7°.
- <u>Rotation</u>: must be set before the bone cut.
- <u>Resection height</u>: the height of the implant with the thinnest inlay must be resected.

After the bone cut, the correct size of implant must be selected and the anterioposterior and mediolateral placement must be observed. The cortex must be covered as much as possible. An implant that is too small could lead to loosening, an overhang could lead to irritation of the capsule, ligaments and muscles.

Following parameters are important for the adjustment of the **femoral** bone cut:

- <u>Varus/valgus</u>
    - Classic alignment: at 90° to the mechanical femur axis,
    - or anatomical alignment: corresponding to the joint line that naturally slopes at 3° from lateral to medial.
    - The angle between anatomical and mechanical femoral axis is measured during preoperative whole leg X-ray.
    - Only then the medullary cavity is reamed and the femoral alignment rod is inserted. The cutting block is then pushed onto the intramedullary rod, making sure to allow femoral rotation.
- <u>Thickness of distal resection</u>
    - Using the Femur First Technique, the thickness of the bone resection is determined by the thickness of the implant, using the Tibia First Technique, it is determined by the height of the flexion gap.
- <u>Flexion/extension</u>
    - Flexion of the distal cut is determined by the intramedullary alignment.

After performing the distal femoral cut, the correct rotation and size has to be selected:

- <u>Selection of sizes (two options for measuring the femoral size):</u>
    - Anterior referencing: anterior resection remains constant, a change in size means only a change in the posterior bone cut.
    - Posterior referencing: posterior resection remains constant, a change in size means only a change in the anterior bone cut.
    - Smaller femur sizes are more common with the Tibia First Method than with the Femur First Method.
- <u>Rotation:</u>
    - Tibia First Technique:

        - Balanced Gap Technique (= functional alignment), the tension of the ligaments in 90° flexion is used.
    - Femur First Technique (uses different landmarks for rotational alignment):
        - Transepicondylar axis (TEA):
            - Connects Medial and Lateral Epicondylus.
        - Anterior-posterior axis (Whiteside's Line):
            - From the lowest point of the trochlea to the highest point in the notch (looking at the joint from the distal side).
        - Posterior Condyle Axis (PCL):
            - Tangent to the posterior condyles.
            - Best representable and palpable.
        - Mechanical tibial axis in 90° flexion (only available during surgery):
            - Tibial resection is performed at 90° (reference to the mechanical tibial axis).
        - If the knee is positioned at 90° before the tibial resection, the long tibial axis can also be used for the rotational adjustment of the femur (this creates a symmetrical bending gap).
        - In contrast to balanced gap, the collateral ligaments are not tensioned, the natural ligament tension is left.
        - A combination of different landmarks is necessary, one single landmark is not sufficient (17).

Jerosch recommends the use of several landmarks. First the PCL should be used and for control the Whiteside’s Line. As a third landmark, the TEA should be palpated and checked by laser marking (17). Kohn mentions the TEA and the Whiteside’s Line as the most reliable landmarks (15).

5.4.2 Femur First Technique

This technique is also named Measured Resection Technique. Bone cuts are performed independently of each other and independently of the ligament tension. The cuts will be performed based on anatomical landmarks (15,17).

The femoral cuts can be made in different order. These variations of the manufacturers are as follows.

- Anterior Cut First (ACF)
  - Rotation is determined at the first femoral cut.
- Distal Cut First (DCF)
  - At first, the distal bone cut is made, followed by the determination of the prosthesis rotation.

5.4.3 Tibia First Technique

The Tibia First Technique is also named Balanced Gap Technique. Within the Tibia First Method, again two methods are differentiated, the Extension Gap First and the Flexion Gap First Technique (Table 3: Comparison between flexion gap first and extension gap first procedure (17). The Flexion Gap First Method is known as the "classical" Tibia First Method.

The difference between the two variants is the timing of the ligament balancing in the sequence and whether the flexion gap is transferred to the extension gap or vice versa.

The bone cuts are performed at 90° flexion in dependence on the tibia and femur and on the ligament tension. The resulting joint gap in flexion determines the extent of the resected bone at the distal femur, the rotation of the femur is not oriented at anatomical landmarks. The following table presents an overview of the main steps of both techniques.

Steps	Procedure of Flexion Gap First	Procedure of Extension Gap First
1.	Tibial bone cut	Tibial bone cut
2.	Ligament balancing	Temporary, distal femoral bone cut for establishing an extension gap with straight leg axis (less bone is removed than the prosthesis is thick)
3.	Adjustment of the femoral rotation (based on ligament tension in flexion)	Ligament balancing with different spacers (of the extension gap)
4.	Posterior femoral cut, to create the final flexion gap	Adjustment of the femoral rotation (based on ligament tension in flexion)

5.	Transferring flexion gap to extension gap Height of the extension gap is dependent on the size of the flexion gap and not on the thickness of the femoral implant	Posterior femoral cut, to create the final flexion gap
6.	Final distal femoral cut	Transferring flexion gap to extension gap Height of the extension gap is dependent on the size of the flexion gap and not on the thickness of the femoral implant
7.	Performing the remaining femoral cuts (with a 4 in 1 cutting block)	Final distal femoral cut
8.	Implantation	Performing the remaining femoral cuts (with a 4 in 1 cutting block)
9.		Implantation

Table 3: Comparison between flexion gap first and extension gap first procedure (17).

Special part: Methods and Results

6 Hypothesis

Bellemans et al. published the concept of Constitutional Varus in 2012. They investigated 250 asymptomatic adult volunteers between 20 and 27 years old and determined that 32 % of the men and 17 % of the woman had constitutional varus knees with an alignment of 3° varus or more. In this study, they considered an HKA angle between minus 3° and plus 3° as normal. The outcome proves that a neutral mechanical alignment is not normal for everyone in the population. This fact should be taken into account with regard to the alignment in TKA.(12)

The hypothesis was that this phenotype persists postoperatively, when using the Extension Gap First Technique in case of a varus alignment.

7 Extension First Technique

Hube et al. published a surgical technique which combines the Femur First (measured resection) and the Tibia First (balanced gap) Method in TKA (18). The so-called Extension First Technique is characterized by the gradual balancing of the extension gap and the flexion gap. This new method is supposed to reduce possible errors in the bone-referenced as well as in the soft tissue-referenced technique. In the study, 267 patients with total knee prosthesis implantation were examined. 92 % of the patients showed a very good function after 6 weeks, only 8 % a satisfactory function. There were no patellofemoral complications.

9 of 267 patients showed a varus or valgus angle of > 3° tibial, 12 of 267 patients showed an angle of > 3° femoral.

7.1 Surgical technique

The surgical procedure is performed in supine position with the knee bent at 80-90°. The surgery begins with a longitudinal incision at the front of the knee. The muscle fibers of the Vastus Medialis Muscle are separated up to 3 centimetres up to the medial proximal patellar pole. The joint is opened with a further incision medial to distal medial of the patella, revealing the joint surfaces. After pushing the patella laterally, the cutting block for the femoral incision is positioned. The femoral cut is made in a perpendicular angle to the femoral axis. The valgus setting is based on the preoperative whole leg X-ray. The rotation is determined later.

The surgical instruments are then aligned at the center of the talus. Starting from the center of the tibial plateau, the transition from the middle to the medial third of the tibial tuberosity is used as a reference. The positioning determines the rotation of the tibial implant in the course of the procedure. After alignment, the saw cut of the tibia follows in correct rotation. The resection height depends on the selected implant (e.g. 10 mm - this would correspond to the central height of a tibial implant and polyethylene).

A spacer is then placed into the extension gap. Arrow bars are used to check the alignment (distal: center of the talus, proximal: center of the femoral head). If the alignment is not correct, it can now be corrected with new cuts.

When correctly aligned, the knee is balanced in extension. If an instability occurs, it must be compensated with a soft-tissue release of the shortened side until the correct balance is achieved.

In the next step, the flexion gap is defined. The balancing is done in flexion. First, the rotation of the femoral component is determined. The rotation depends on the epicondylar axis and the attachment of the collateral ligaments. This step is important for the subsequent stability of the knee and the function of the pulley.

A spacer should check the stability of the knee joint. If the rotation and the extension gap are correctly adjusted, the flexion gap should automatically be at right angles. If it is not, the rotation must be checked again. Next, the size of the femoral component is determined and the femur is prepared for the implant (18).

7.1.1 Advantages of the technique

- There is a fixed target value for balancing the joint (even medial and lateral ligament tension in the traction gap), first the ligament tension is balanced in extension, then the ligament tension in flexion is used to determine the femoral rotation (17).
- Replicable extension gap and flexion gap balancing.
- Combination of the bone and soft tissue referenced surgical technique (18).

7.1.2 Disadvantages of the technique

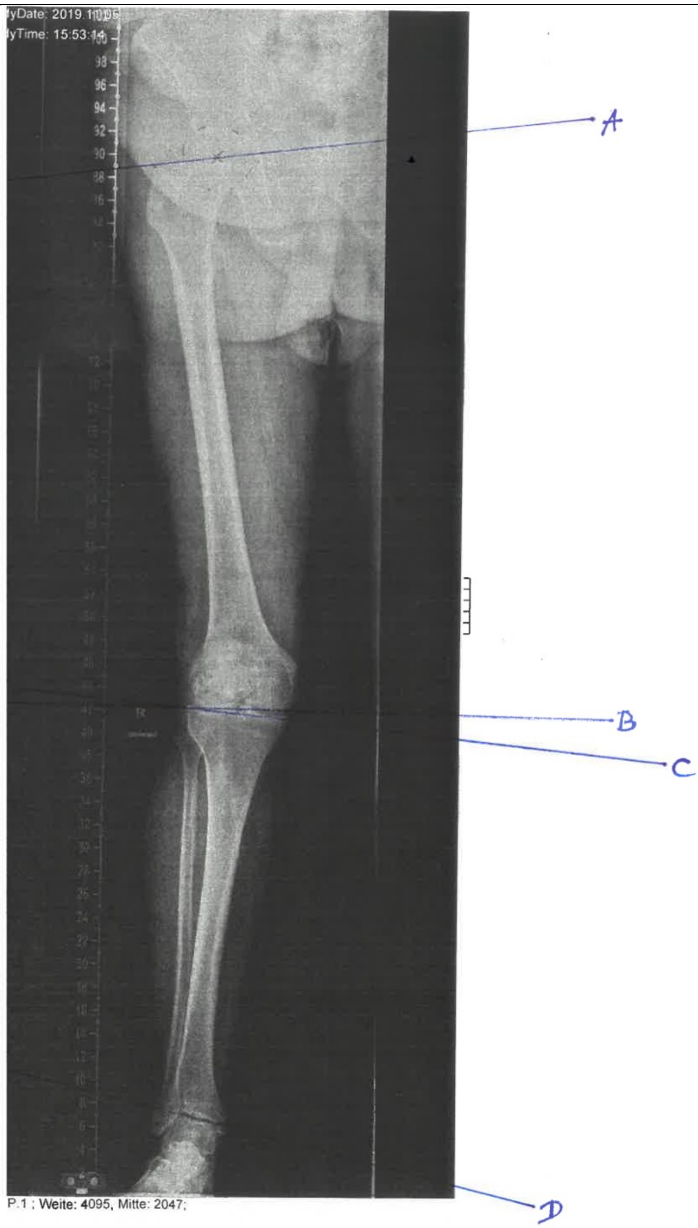
- Mistakes in the tibial cut can be transferred to the femoral alignment.
- A shift of the joint line to cranial and a "mid-flexion" instability can occur (if there is too little tibial resection).
- In case of pathological opening in flexion, there may be errors in the rotation of the femoral component (17).
- Mini-midvastus access: Poor visualization of the joint surfaces in contracted knee joints.
- Demanding surgical technique (18).

8 Study Design

The Ethics Committee of the Medical University of Graz approved the study protocol (30-253 ex 17/18). In this study, a total of 224 whole leg radiographs of 112 patients (pre- and postoperative radiographs) were measured (71 female, 41 male). The average age at the time of surgery was 72 years. The youngest patient was 55 years old, the oldest 88 years. Patients were randomly selected from March 2018 to November 2019. For each of them, the last full leg X-ray before surgery and the first full leg X-ray after surgery was selected. Excluded were X-rays that showed evidence of pre-existing fractures or previous operations.

8.1 Measurements

All patients with a total knee replacement selected for this study underwent surgery with the Extension First Technique. The pre- and postoperative X-ray images were measured by hand with a geo triangle. The measurement was performed in the same way for pre- and postoperative radiographs. The joint lines, joint centers and joint angles were marked and measured according to Paley's definition. All axes were drawn in frontal plane (11). The joint orientation lines were drawn first (Table 4), followed by the anatomical and mechanical axis through the femur, and the middiaphysial line through the tibia (Table 5). The Mikulicz Line was also marked. After the individual axes were drawn, the total joint angles (Table 6, Table 7) and the MAD (Table 7) were measured step by step.

<table>
<tr>
<td>
</td>
<td>A Joint orientation line of the hip:
- line from the tip of the trochanter major to the center of the femoral head.

B Joint orientation line of the knee, distal femur:
- line tangential to the two femoral condyles.
C Joint orientation line of the knee, proximal tibia:
- line across the subchondral line of the tibial plateau.

D Joint orientation line of the ankle:
- line across the subchondral line of the talus.</td>
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Table 4: Plotted joint orientation lines.

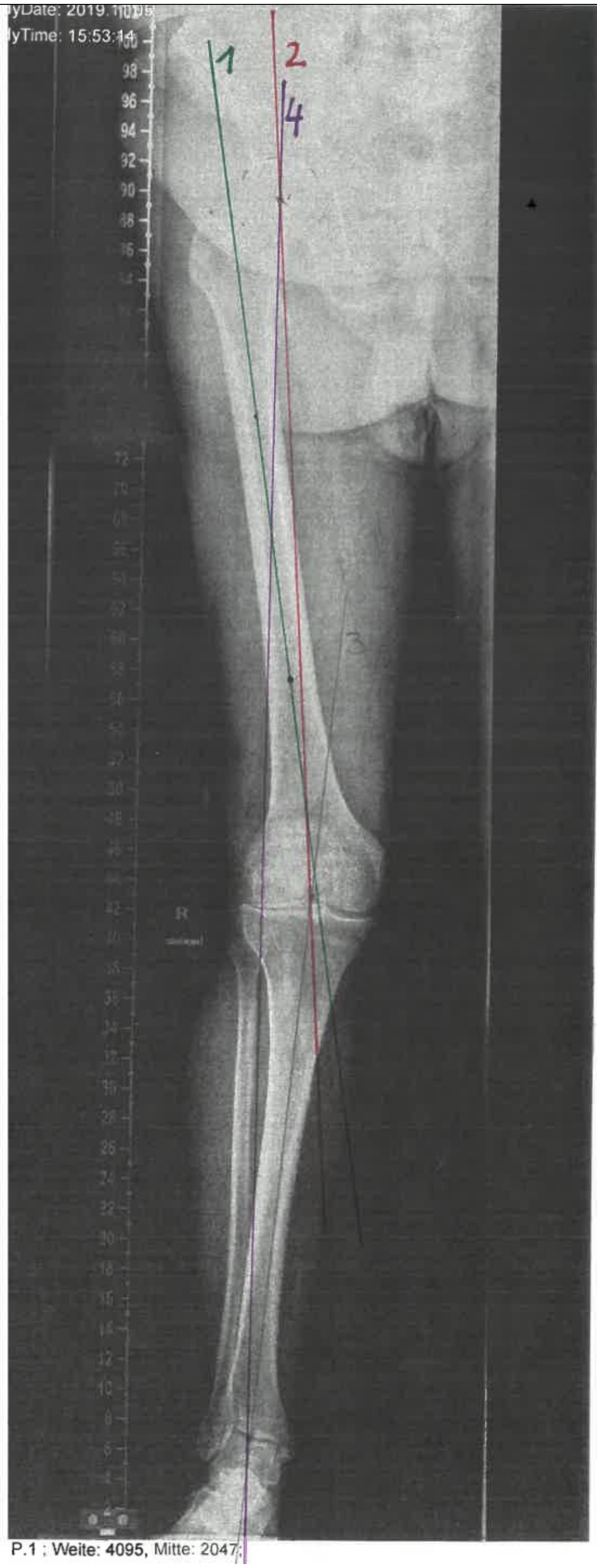
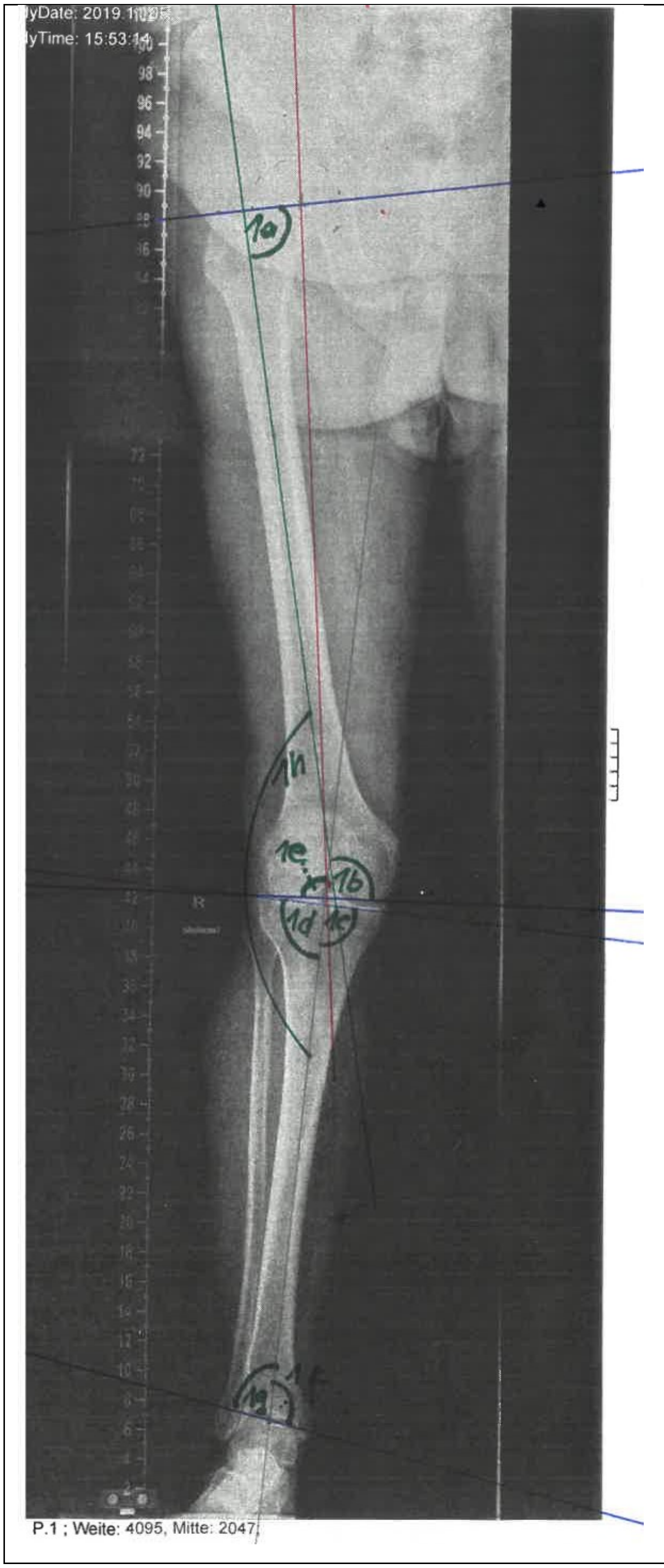
	**1** Anatomical axis of the femur (middiaphysial line). **2** Mechanical axis of the femur (line from the center of the hip and the center of the knee joint). - Center of the hip joint: center of the circular femoral head. - Center of the knee joint: midpoint of the tibial plateau. **3** Mechanical axis of the tibia (line from the center of the knee to the center of the ankle joint)/anatomical axis of the tibia (middiaphysial line). - Center of the ankle joint: mid-width of the talus. - The mechanical axis of the tibia runs slightly medial and parallel to the anatomical line (tibial anatomic-mechanical angle is at 0°, so we use one axis for both). **4** Mikulicz Line (line from the center of the hip joint to the center of the ankle joint).

Table 5: Plotted physiological, anatomical and mechanical axis.



1a aMPFA

1b aMDFA

1c MPTA

1d LPTA

1e aLDFA

1f MDTA

1g LDTA

1h aFTA

Table 6: Plotted anatomical angles.

<table>
<tr>
<td>
</td>
<td>**2a** mMPFA

2b mMDFA

2c mLDFA

x AMA

xx HKA

xxx MAD</td>
</tr>
</table>

Table 7: Plotted mechanical angles, AMA, HKA, MAD.

9 Statistical Analysis

With the collected data (measurements) a descriptive statistic and variance analysis is performed using Microsoft Office Excel and SPSS Statistics.

The pre- and postoperative radiographs are already classified into the orthograde, valgus and varus groups. The criteria for the classification is the HKA, the values for the HKA are listed in Table 8:

Alignment	HKA – Value
Varus	< -3°
Orthograde	-3° - +3°
Valgus	> +3°

Table 8: HKA as criteria for alignment.

At first, differences from pre- to postoperative measurements have been calculated in advance for every angle/value (preoperative minus postoperative). Subsequently, ANOVA is performed to assess the overall difference of change in angles from pre- to postoperative. In case of significant overall-differences, Post-Hoc t-Tests follow to investigate differences in preoperative alignment groups. Differences are given as mean values with standard errors (SE). Post-Hoc t-Tests are performed comparing orthograde vs. valgus, orthograde vs. varus and valgus vs. varus alignment. For each of these comparisons, contrast values are provided, indicating how large the difference in between these two groups is. E.g. for the MPTA, the contrast between the varus and orthograde alignment is 3.8°, with a standard error of 0.6°. On the other hand, the contrast between valgus and orthograde alignment is merely 0.4° (and the standard error 0.8°), indicating no significant difference. A p-value below 0.05 is assumed to be statistically significant.

10 Results

Out of 112 preoperative measurements, 63 are assigned to the varus group (HKA < -3°), 33 to the valgus group (HKA > +3°), and 16 to the orthograde group (HKA -3° ± 3°). Divided into two groups, there are 63 patients in the varus-group and 49 patients in the non-varus-group. The postoperative distribution is as follows:

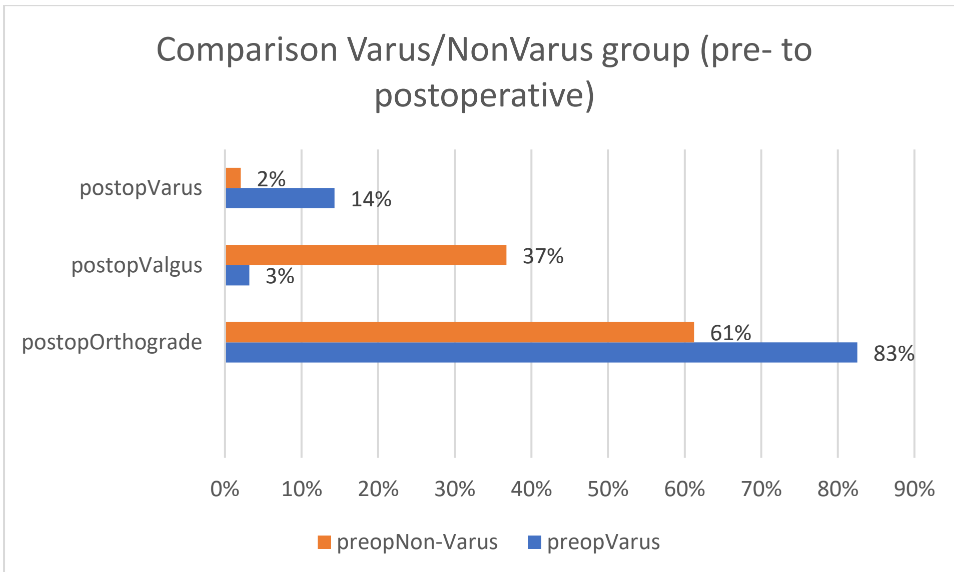


Fig. 20: Comparison varus to non-varus group (pre- to postoperative).

83 % of the patients with preoperative varus alignment become orthograde. This is more frequent than patients with another alignment (61 %: valgus, orthograde). Compared to the varus group (3%), more patients of the non-varus group change to a valgus alignment (37 %). Fig. 21 shows which of the two non-varus alignments is mainly responsible for this:

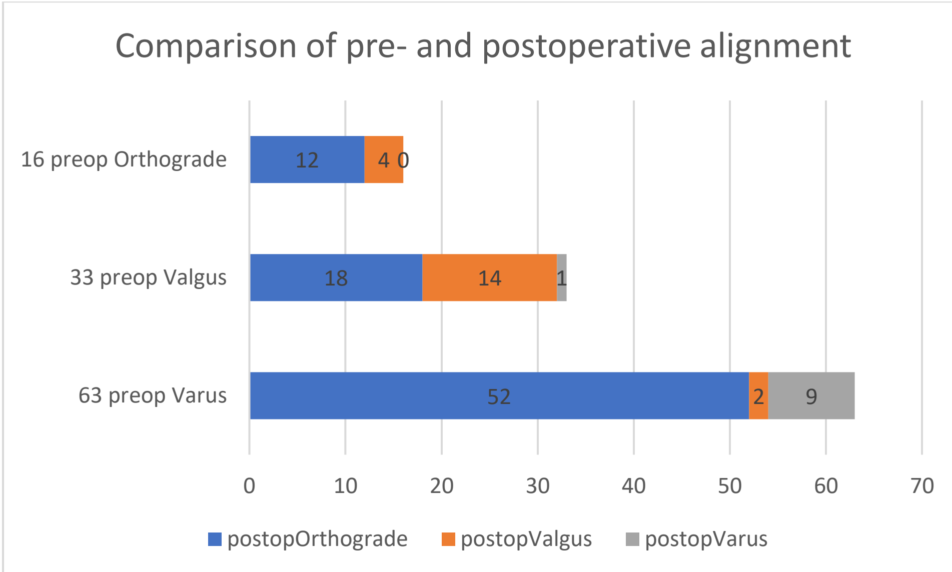


Fig. 21: Comparison of pre- and postoperative alignments.

52 out of 63 patients (83 %) with preoperative varus alignment and 18 out of 33 patients (55 %) with valgus alignment become orthograde. 42 % (16 patients) with preoperative valgus remained with valgus alignment. 12 out of 16 patients with preoperative orthograde alignment remain orthograde after surgery, one third (4 patients) are getting valgus aligned after surgery.

10.1 Results for MAD and aTFA

For the Mean Axis Deviation (MAD), there is a difference of 1.40 mm (SD 2.28 mm) for preoperative orthograde leg axis compared to postoperative, a difference of 6.32 mm (SD 2.40 mm) for preoperative varus, and a difference of 5.86 mm (SD 3.59 mm) for preoperative valgus. So the values for the differences in the varus and valgus group are quite similar (Fig. 22).

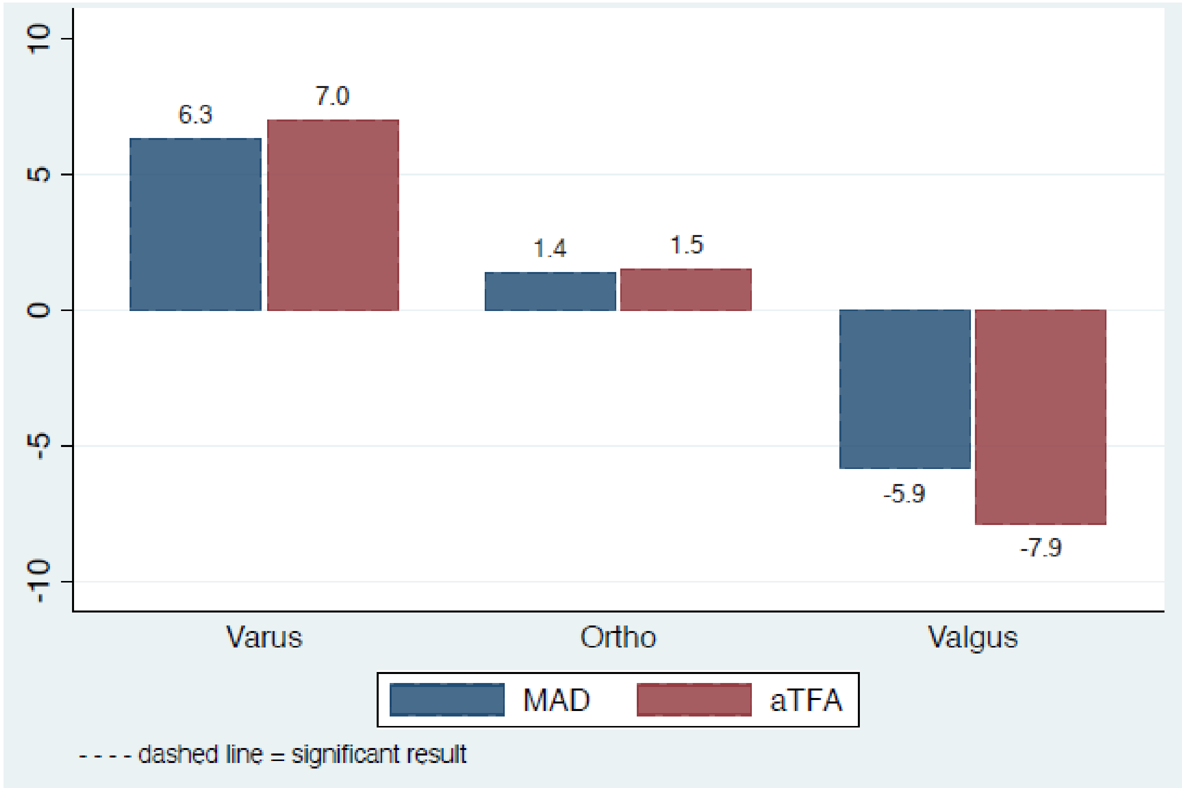


Fig. 22: Results for MAD and aTFA (in °).

The contrast of the mean change in MAD between pre - to postoperative is most evident in valgus vs. varus group with 12.15 mm (SE 0.59 mm, $p < 0.001$), followed by valgus vs. orthograde group with 7.27 mm (SE 0.85 mm, $p < 0.001$). For varus vs. orthograde the difference is 4.91 mm (SE 0.78 mm, $p < 0.001$). There is a highly significant difference overall difference (F (2;109) = 206.41; $p < 0.001$) and a highly significant difference between all groups ($p < 0.005$).

The results for the mean difference between pre- and postoperative values for the Anatomical Tibiofemoral Angle (aTFA) are similar in the varus and valgus group (varus: 7°, SD 4.1°; valgus: 7.9°, SD 4.6°). The mean difference in the ortho group is 1.53° (SD 3.4°). A highly significant difference overall difference (F (2;109) = 136,51; $p < 0.001$) can be determined.

The values of the mean change from pre- to postoperative between the groups is at highest in the valgus vs. varus group (14.9°, SE 0.9°), followed by valgus vs. ortho (9.4°, SE 1.3°). The varus vs. ortho group values result in 5.5°, SE 1.2°. A highly significant difference between all groups ($p < 0.005$) can also be found here.

10.2 Results for femoral angles

	aMPFA	mMPFA
Ortho	-2.8° *(SD 3.9°)*	-1.6° *(SD 6.9°)*
Varus	-0.7° *(SD 3.2°)*	-1.1° *(SD 3.3°)*
Valgus	-0.9° *(SD 4.0°)*	-0.6° *(SD 4.0°)*
Overall difference	*F(2;109)=2.19 p=0.117*	*F(2;109)=0.35 p=0.707*
Contrast varus vs. ortho	2.1° *(SE 1.0°)*	0.5° *(SE 1.2°)*
Contrast valgus vs. ortho	1.9° *(SE 1.1°)*	1.0° *(SE 1.3°)*
Contrast valgus vs. varus	-0.2° *(SE 0.8°)*	0.5° *(SE 0.9°)*
Difference between all groups	*Post- hoc t- test omitted*	*Post- hoc t- test omitted*

Table 9: Results for aMPFA, mMPFA.

There is no significant overall difference in the results for aMPFA (F (2;109) = 2.19 p = 0.117) and mMPFA (F (2;109) = 0.35 p = 0.707), therefore, Post Hoc t-Tests were not performed. Fig. 23 shows that there is no relevant change from pre- to postoperative at either proximal femoral angle, no matter what preoperative alignment existed.

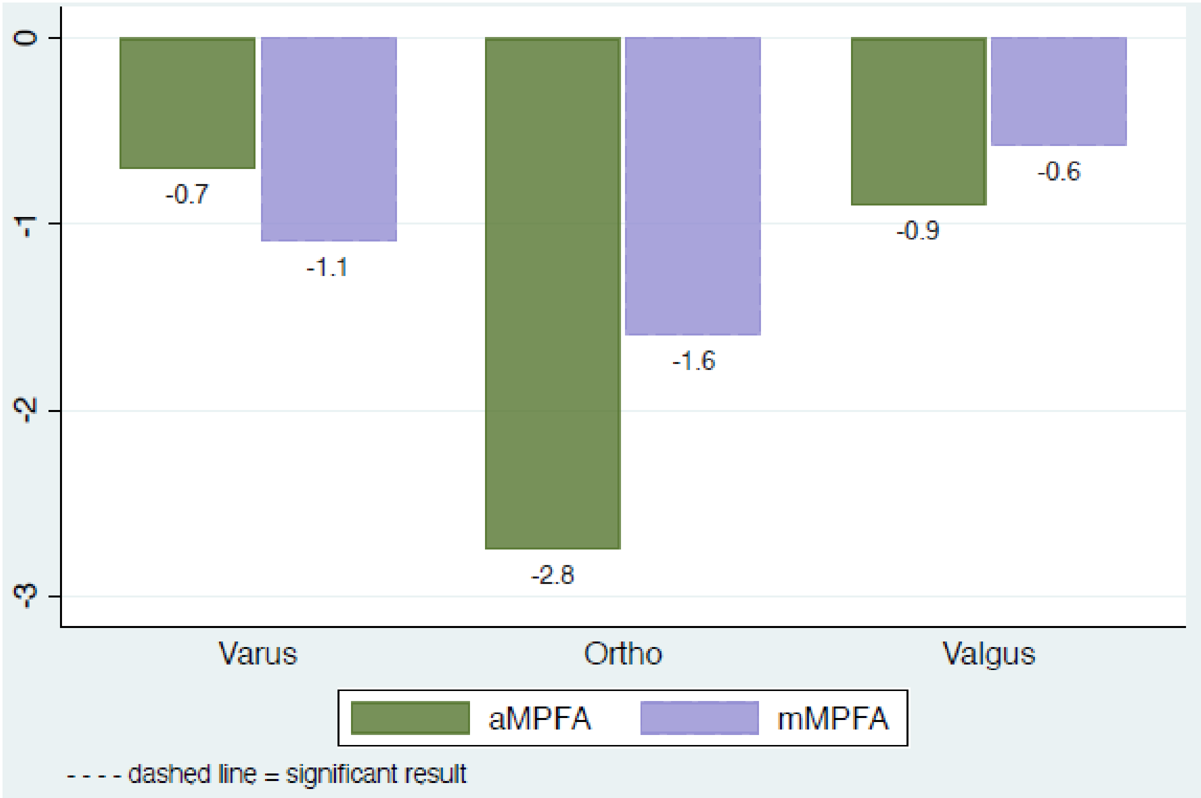


Fig. 23: Difference in anatomical and mechanical proximal femoral angles (in °).

Table 10 shows the results for the distal femoral angles, showing that a highly significant overall difference exists for all 4 angles ($p < 0.001$).

	aMDFA	mMDFA	aLDFA	mLDFA
Ortho	-2.3° *(SD 8.5°)*	1.4° *(SD 4.2°)*	2.3° *(SD 8.5°)*	-1.4° *(SD 4.2°)*
Varus	0.7° *(SD 4.8°)*	0.9° *(SD 2.8°)*	-0.7° *(SD 4.8°)*	-0.9° *(SD 2.8°)*
Valgus	4.3° *(SD 3.5°)*	4.5° *(SD 2.8°)*	-4.3° *(SD 3.5°)*	-4.5° *(SD 2.8°)*
Overall difference	*F(2;109)=9.70 p=0.0001*	*F(2;109)=14.73 p<0.001*	*F(2;109)=9.70 p=0.0001*	*F(2;109)=14.73 p<0.001*
Contrast varus vs. ortho	3.0° (SE 1.4°) p=0.04	-0.5° (SE 0.9°) p=0.59	-3.0° (SE 1.4°) p=0.04	0.5° (SE 0.9°) p=0.59
Contrast valgus vs. ortho	6.6° *(SE 1.6°)* p<0.001	3.0° *(SE 0.9°)* p=0.001	-6.6° *(SE 1.6°)* p<0.001	-3.0° *(SE 0.9°)* p=0.001
Contrast valgus vs. varus	3.6° *(SE 1.1°)* p=0.002	3.5° *(SE 0.7°)* p<0.001	-3.6° *(SE 1.1°)* p=0.002	-3.5° *(SE 0.7°)* p<0.001

Difference between all groups	*Significant difference between all three groups*	*Significant difference for two groups (not for varus vs. ortho)*	*Significant difference between all three groups*	*Significant difference for two groups (not for varus vs. ortho)*

Table 10: Results for the distal femoral angles.

For aMDFA/aLDFA, there is a larger difference between the results for preoperative valgus to preoperative orthograde alignment (6.6°/-6.6°) than for varus vs. orthograde (3.0°/-3.0°) alignment. So after surgery, the aMDFA/aLDFA changes mostly with a preoperative valgus alignment. With preoperative orthograde or varus alignment, the aMDFA/aLDFA also changes significantly, but not as much as with valgus alignment. In addition, the mMDFA/mLDFA also changes significantly with preoperative valgus and preoperative orthograde alignment.

Fig. 24 shows the results of the change in angles from pre- to postoperative in relation to the preoperative alignment. The most significant change of the distal femoral angles exists in case of preoperative valgus, followed by preoperative orthograde alignment.

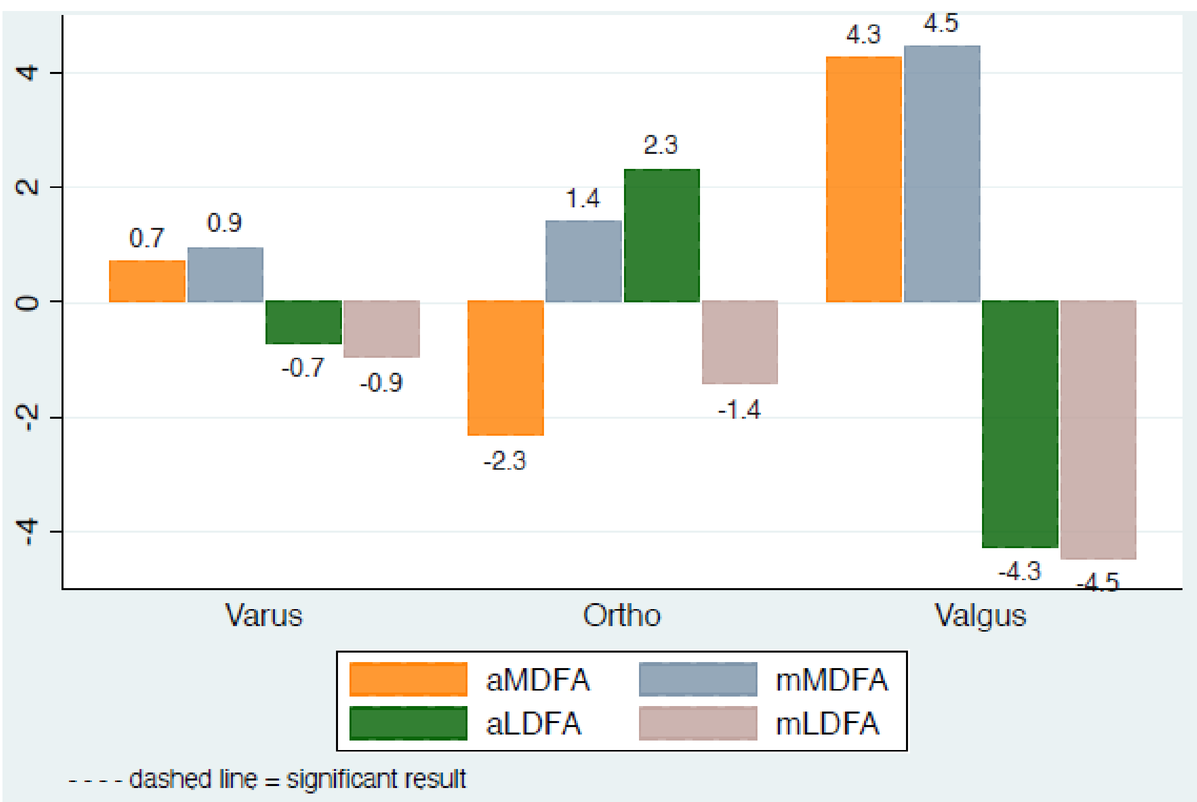


Fig. 24: Difference in anatomical and mechanical distal femoral angles (in °).

10.3 Results for tibial angles

	MPTA	LPTA	MDTA	LDTA
Ortho	-0.3° *(SD 2.0°)*	0.3° *(SD 2.0°)*	-3.9° *(SD 3.1°)*	3.9° *(SD 3.1°)*
Varus	-3.6° *(SD 2.9°)*	3.6° *(SD 2.9°)*	0.2° *(SD 4.5°)*	-0.2° *(SD 4.5°)*
Valgus	0.1° *(SD 2.8°)*	-0.1° *(SD 2.8°)*	-1.7° *(SD 3.3°)*	1.7° *(SD 3.3°)*
Overall difference	*F(2;109)=24.40 p<0.001*	*F(2;109)=24.40 p<0.001*	*F(2;109)=7.20 p=0.0012*	*F(2;109)=7.20 p=0.0012*
Contrast varus vs. ortho	-3.4° *(SE 0.8°)* p=<0.001	3.4° *(SE 0.8°)* p=<0.001	4.0° *(SE 1.1°)* p<0.001	-4.0° *(SE 1.1°)* p<0.001
Contrast valgus vs. ortho	0.4° *(SE 0.8°)* p=0.7	-0.4° *(SE 0.8°)* p=0.7	2.2° *(SE 1.2°)* p=0.072	-2.2° *(SE 1.2°)* p=0.072
Contrast valgus vs. varus	3.8° *(SE 0.6°)* p<0.001	-3.8° *(SE 0.6°)* P<0.001	-1.8° (*SE 0.9°)* p=0.037	1.8° *(SE 0.9°)* p=0.037
Difference between all groups	*Highly significant difference for two groups (not for valgus vs. ortho)*	*Highly significant difference for two groups (not for valgus vs. ortho)*	*Highly significant/significant difference for two groups (not for valgus vs. ortho)*	*Highly significant/significant difference for two groups (not for valgus vs. ortho)*

Table 11: Results for tibial angles.

For all 4 angles, a highly significant overall difference exists (p<0.001).

For the MPTA/LPTA, the greatest change from pre- to postoperative occurs in preoperative varus alignment (-3.6°/3.6°). This results in a highly significant difference between preoperative varus and orthograde alignment (-3.4°/3.4°, p < 0.001), as well as between valgus and varus alignment (3.8°/-3.8°, p < 0.001). In contrast to MPTA/LPTA, the greatest change from pre- to postoperative for MDTA/LDTA occurs with preoperative orthograde alignment (-3.9°/3.9°). There is a highly significant difference between varus and orthograde alignment (4.0°/-4°, p < 0.001) and a highly significant difference between valgus and varus alignment (-1.8°/1.8°, p = 0.037).

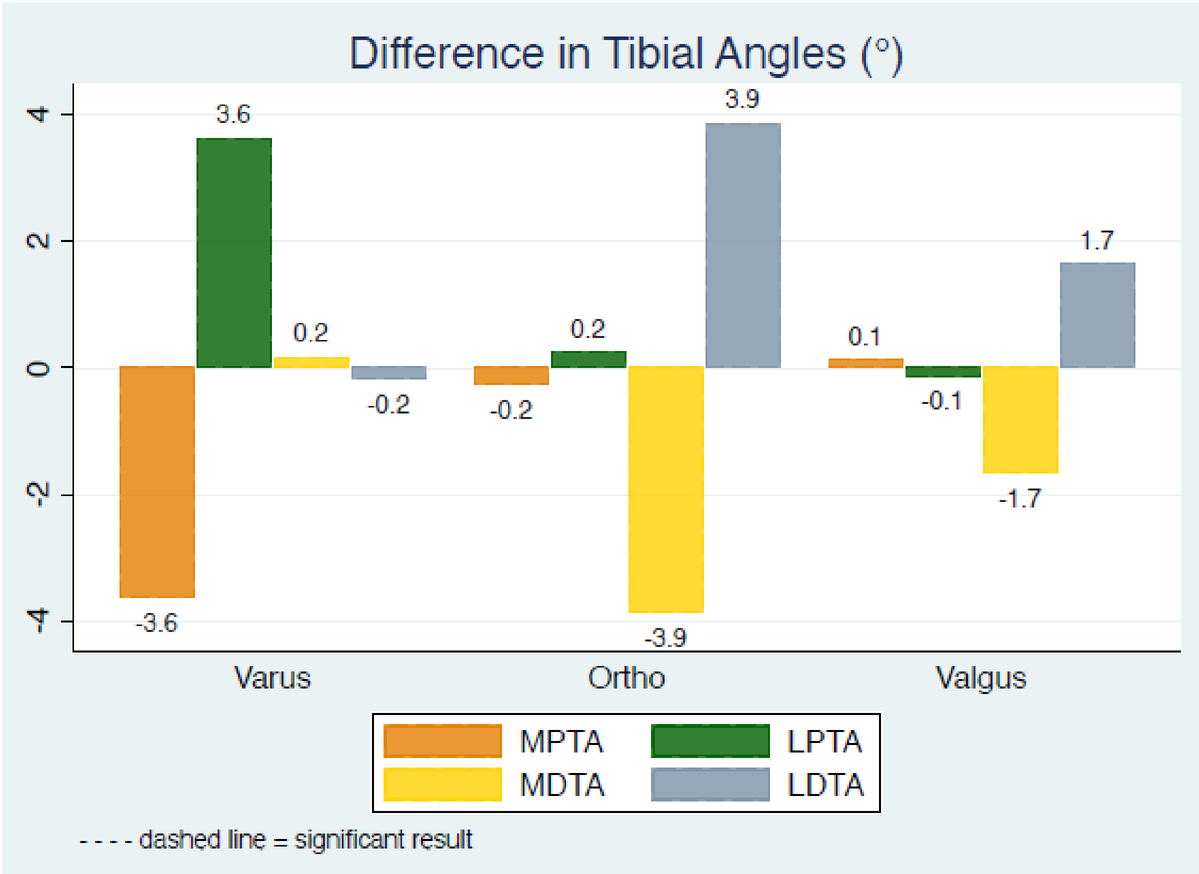


Fig. 25: Difference in tibial angles (in °).

Fig. 25 shows the results for the tibial angles again in a graphical form. In the case of a preoperative varus alignment, the proximal tibial angles change (orange, green). If there is an orthograde alignment before surgery, the distal tibial angles change in particular (yellow, grey). The difference between the preoperative valgus and orthograde alignment is not significant for any tibial angle.

In case of a preoperative varus alignment, mainly the proximal tibial angles change postoperatively. In the case of a preoperative orthograde position, mainly the distal tibial angles change. The difference between the preoperative valgus and orthograde alignment is not significant for any tibial angle.

10.4 Results for AMA

There is no significant overall difference ($F(2;109) = 24.40$; $p < 0.0001$). In case of a preoperative valgus malposition, the angle differs by a mean of 0.1° postoperatively. In case of a preoperative varus alignment, there is a difference of 0.2°, in case of a preoperative orthograde alignment, there is a difference of 0.3°. Obviously, there is not much influence on the AMA with this surgical technique.

11 Discussion

The aim of the study was to evaluate whether there are postoperative genu varus results even if the 3° Concept is not considered. In our case, a varus position does not generally result after surgery. 83 % of patients with preoperative varus aligned knee joints were found to have an orthograde leg axis postoperatively. So, a knee replacement using the Extension First Technique and without using the 3° Concept leads to a postoperative orthograde leg axis in most cases when it comes to prealigned varus knee joints.

Usually, the aim in TKA is to restore a neutral mechanical alignment, but the topic of optimal alignment in TKA has already been controversially discussed in many studies. There are also numerous literature papers that summarize and also compare the different philosophies (19-21). The basic topic of discussion is whether a neutral or varus postoperative alignment is to be preferred.

Many authors are primarily concerned with postoperative orientation with respect to long-term outcomes years after TKA (need of revision surgery, longevity of the knee prosthesis, various clinical scores). Before Bellemans et al. (12) published the Concept of Constitutional Varus in 2011, Fang et al. (9) found in 2009 that postoperative alignment is mainly responsible for failure and revision interventions. They also concluded that well aligned TKA have a better long-term outcome than those in varus or valgus position. Two years later, Bonner et al. (22) found very little relationship between mechanical alignment and revision risk (a trend toward the advantage of neutral alignment did not yield statistical significance).

Parratte et al. (23) also hypothesized that a postoperative neutral alignment would lead to a better long-term outcome in terms of prosthesis longevity. However, the studies did not show an advantage of neutrally aligned TKA in terms of 15-year survival. He also says that postoperative alignment is an unworkable variable to predict longevity.

Both, Bonner and Parratte (22)(23), always referred to the postoperative mechanical leg axis (neutral = between 0° and +-3°).

Magnussen (24) also found equal 10-year survival rates in both groups (residual postoperative varus vs. neutral postoperative alignment). However, he looked at the postoperative alignment of the mechanical leg axis of patients who already had a varus alignment preoperatively. He was

able to show that residual postoperative varus alignment in the case of pre-existing varus alignment does not provide any advantage in terms of prosthesis longevity.
On the other hand, Vanlommel et al. (25) published in 2013, that patients with preoperative varus position do benefit from a postoperative mild-varus position in terms of clinical and functional outcome scores (compared to neutrally corrected knee joints). They also refer in their results to the mechanical leg axis (FTMA or tibiofemoral mechanical alignment(11)), and define "mild varus" as a deviation from 180° by 3°-6° (<177° and >174°).
In addition, Delport et al. (26) were able to determine that the tension of the collateral ligaments remains similar, postoperatively as preoperatively, if the constitutional alignment is left in place. A neutrally corrected alignment leads to "more physiological peri-articular soft tissue strains(26)".
Thus, the two results also fit in part with the results of the study by Bellemans et al., which stated that restoration of neutral alignment should not be attempted in the presence of pre-existing constitutional varus. They used the HKA as a reference in 2011 - this is equivalent to the tibiofemoral mechanical alignment(11) or the FTMA (25).
It can be seen that the postoperative neutral orientation wants to be achieved less strictly in recent years. For example, this is shown by the result of a survey of 300 surgeons from 23 different countries at the Recent Advances in Knee Surgery Meeting 2013 in Prague. While this survey still showed a trend toward neutral postoperative alignment, it does suggest a broader acceptance of postoperative varus alignment in patients with preoperative varus alignment (27).
In a more recent study from 2018, Abdel et al. published results after 20 years of observation in addition to a previous study (15-year follow-up by Parrate et al. 2010 (23)). After the 15-year follow-up, again no significant difference in the longevity of TKA was found between neutrally aligned and not-neutrally aligned knee joints after 20 years (28).

In summary, with the diverse literature, it is noticeable that the studies are mainly concerned with the advantages of postoperative neutral as well as postoperative varus alignment. Valgus alignment and its effects or long-term consequences are less discussed.

Compared with our results from the preoperative varus group, 61 % of the selected non-varus group changed to an orthograde alignment after surgery. Especially in the case of a pre-existing valgus alignment, a valgus alignment occurs after surgery (42 %).

The different joint angles change depending on the preoperative alignment. In general, a preoperative varus position primarily influences the postoperative tibial angles and a preoperative valgus position influences the femoral (distal) angles.
In case of preoperative valgus alignment, the postoperative distal femoral angles change significantly. There is also a significant change in the preoperative orthograde and varus group, but not as much as with preoperative valgus alignment (e.g. the difference for the change of the angles between preoperative valgus and preoperative orthograde to postoperative are 6.6°).
So, for the anatomical distal femoral angles (aMDFA/aLDFA), there is a significant difference between all three groups – in comparison to the mechanical distal femoral angles, where a significant difference was only found between two groups (preoperative valgus and preoperative orthograde alignment).
For the tibial angles, there was mainly a significant change in preoperative varus or orthograde alignment. For the proximal tibial angles (MPTA/LPTA), the greatest change from pre- to postoperative occurs with preoperative varus alignment. For the distal tibial angles (MDTA/LDTA), the greatest change occurs with preoperative orthograde alignment.
The measurements and analysis for MAD and aTFA resulted in highly significant differences between all groups. For both MAD and aTFA, the smallest change from pre- to postoperative occurs with a preoperative orthograde leg axis. This corresponds to the logical consideration that preoperative orthograde aligned leg axes require less correction than deviating leg axes. The differences of the values for MAD for preoperative varus group compared to postoperative (6.32 mm/SD 2.40 mm) and for preoperative valgus group compared to postoperative (5.86 mm/SD 3.59 mm) are quite similar. This similarity between the two groups also apply to aTFA.

For AMA, there is no significant change from pre- to postoperative in any group. Also, the proximal femoral angles (aMPFA/mMPFA) do not seem to be influenced by TKA, respectively the surgical technique.

In summary, valgus aligned knee joints remain more often valgus aligned (barely 50 %) than varus aligned knee joints remain varus aligned (most preoperative varus aligned knee joints become orthograde).

In our case, postoperative valgus alignment occurred in 9 of 63 preoperative varus aligned knee joints. Only 1 out of 33 preoperatively valgus aligned knee joints was varus aligned postoperatively.

The question is whether the reason for these results is due to the surgical technique, the quality or alignment of the preoperative or postoperative whole-leg-radiographs, or the quality of the measurements. Given the obvious tendency toward postoperative valgus alignment (9 out of 63 varus aligned knee joints become valgus postoperatively, 14 out of 33 valgus aligned knee joints remain valgus postoperatively), it can be assumed that the surgical technique is the most determining factor.

However, because we wanted to investigate the effects of constitutional varus in more detail, we included fewer preoperatively valgus aligned knee joints. The tendency toward postoperative valgus alignment when the 3° Concept is not taken into account and the TKA is performed with the Extension First Technique, could be interesting for subsequent studies. Including larger patient groups with preoperative valgus alignment would be necessary – but it should be further investigated to find out the reasons for the increased postoperative valgus position.

12 Conclusion

Not following the 3° Concept does not result in the presumed postoperative varus alignment when performing a total knee replacement with the Extension First Technique in preoperatively varus aligned knee joints.

A preoperative valgus alignment ends up with an orthograde leg axis in most cases but also often persists postoperatively compared to varus phenotypes.

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