Thesis

Comparison of Revision Rates and Epidemiological Data in Total Knee Arthroplasty with the ATTUNE Knee System. An analysis of clinical trials and national arthroplasty registries.

submitted by

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Graz, 01.03.2023

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, 01.03.2023 Anton M. Wagner m.p.

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List of abbreviations

Art. – Articulatio

M. – Musculus

N. – Nervus

A. – Arteria

Lig. – Ligamentum

Ligg. – Ligamenta

MRI – Magnetic resonance imaging

EULAR - The European Alliance of Associations for Rheumatolog

a.p. – anterior posterior

M – men

W – women

FB – fixed Bearing.

MB – mobile bearing

CR – cruciate Retaining

PS – posterior Stabilization

AFTA – anatomical femorotibial angle

JLCA – joint line convergence angle

Et al. – et allii

No. – Number

LCA – Ligamentum cruciatum anterius

LCP – Ligamentum cruciatum posterius

EPRD – The German Arthroplasty Registry

SIRIS – Swiss National Joint Registry

AAOS – American Joint Replacement Registry

AOANJRR – Australien Orthopaedic Association National Joint Replacement Registry

NJR – National Joint Registry England, Wales, Northern Ireland, the Isle of Man, States of Guernsey

SKAR – Swedish Knee Arthroplasty Registry

VAR – Valdoltra Knee Arthroplasty Registry

NZOA – The New Zealand Joint Registry

NOCA – Irish National Orthopedic Registry

NAR – Norwegian Arthroplasty Registry

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Zusammenfassung

Hintergrund: Diese Studie hat das Ziel, Daten von Registern und klinischen Studien über das Attune-Knie-System von DePuy Synthes auszuwerten und zu vergleichen. Ein Schwerpunkt wurde dabei auf epidemiologischen Daten, Revisionsdaten sowie auf Daten von verschiedenen chirurgischen Techniken gesetzt.

Methoden: Alle nationalen Knieregister zwischen 1999 und 2022 sowie alle klinischen Studien zwischen 2012 und 2022 wurden bezügliche dem Attune-Knee-System gesichtet und ausgewertet. Ein besonderes Augenmerk wurde dabei auf die Revisionsdaten, epidemiologische Daten sowie Daten von verschiedenen chirurgischen Techniken und Konstruktionsprinzipe gesetzt. Die chirurgischen Techniken wurden eingeteilt in kreuzbanderhaltende Techniken (CR- cruciate retaining) und kreuzbandresezierende Techniken (PS – posterior-stabilized). Die Konstruktionsprinzipe in Fixed-Bearing (FB) und Mobile Bearing (MB).

Resultate: 10 Register und 4 Studien lieferten nach Anwendung der Inklusionskriterien suffiziente Daten und wurden in die Studie aufgenommen. Das mediane Alter bei der Implantation einer Attune Knieprothese lag bei 66,7 Jahren und der durchschnittliche BMI bei 29,4 kg/m2. Die Patienten/Patientinnen waren zum Zeitpunkt der Implantation zu 60% weiblich und zu 40% männlich. Das Schweizer Register (SIRIS) zeigt die höchsten Revisionsraten für das Attune-Kniesystem im Vergleich zum Deutschen (EPRD), Amerikanischen (AAOS), Australischen (AO-ANJRR) sowie England, Wales und Nordirland Register (NJR). Ein Vergleich des deutschen Registers (EPRD) sowie des Registers von England, Wales und Nordirland (NJR) zeigt, dass das Konstruktionsprinzip mobile bearing bei der Implantation einer Attune-Knieprothese einen Vorteil gegenüber fixed bearing bezogen auf die Revisionsraten in den ersten 5 Jahren nach Implantation hat. Bei der Verwendung des fixed bearing Designs zeigt sich ein Vorteil in den Revisionsraten für die Kombination mit der cruciate retaining Technik gegenüber der posterior stabilisation Technik. Die Daten bezüglich der direkten Vergleiche in den Revisionsraten von cruciate retaining/ posterior stabilization sind heterogen und unterscheiden sich innerhalb der Länder.

Conclusio:

Die Daten bezüglich dem Attune Knee System aus den Studien wurden vorwiegend für die epidemiologischen Auswertungen verwendet und die Daten aus den nationalen Registern für die Revisionsraten Es wurden ähnlich niedrige Revisionsraten in den Registern veröffentlicht. Die epidemiologischen Daten waren bis auf die Geschlechterverteilung ebenfalls ähnlich. Bei der Geschlechterverteilung wurden sehr heterogene Daten veröffentlicht. Ein Differenzieren mehrerer nationalen Register in Konstruktionsprinzipe (FB/MB) und chirurgischen Techniken (CR/PS) wäre in Zukunft wünschenswert, um diese besser vergleichen zu können.

Abstract

Background: The purpose of this study was to evaluate and compare national prosthesis registers and clinical trials data on the DePuy Synthes Attune Knee System. Emphasis was placed on epidemiologic data, revision data, and data from different surgical techniques.

Methods: All national knee registries between 1999 and 2022 and all clinical studies between 2012 and 2022 were reviewed and evaluated regarding the Attune Knee System. A special interest was placed on revision data, epidemiological data, and data from different surgical techniques and design principles. Surgical techniques were divided into cruciate retaining (CR) and posterior stabilized (PS) techniques. The design principles in fixed-bearing (FB) and mobile bearing (MB).

Results: 10 registries and 4 studies provided sufficient data after applying the inclusion criteria and were included in the study. The median age at implantation of an Attune knee prosthesis was 66.7 years and the mean BMI was 29.4 kg/m2. Patients were 60% female and 40% male at the time of implantation. The Swiss registry (SIRIS) shows the highest revision rates for the Attune Knee System compared to the German (EPRD), American (AAOS), Australian (AO-ANJRR), and England, Wales, and Northern Ireland (NJR) registries. A comparison of the German registry (EPRD) and the registry of England, Wales and Northern Ireland (NJR) shows that the mobile bearing design principle has an advantage over fixed bearing in terms of revision rates in the first 5 years after implantation of an Attune knee prosthesis. When using the fixed bearing design, there is an advantage in revision rates for the combination with the cruciate retaining technique over the posterior stabilization technique. The data regarding direct comparisons in revision rates of cruciate retaining/posterior stabilization are heterogeneous and differ within countries.

Conclusion: The data regarding the Attune Knee System from the studies were mainly used for the epidemiological evaluations and the data from the national registries were used for the revision rates. Similar low revision rates were published in the registries. The epidemiologic data were also similar except the sex distribution. For the sex distribution, very heterogeneous data were published. A differentiation of several national registries into

construction principles (FB/MB) and surgical techniques (CR/PS) would be desirable in the future to be able to compare them better.

Introduction

The desire for mobility and sporting activity without pain and restrictions to maintain quality of life has led to many truly outstanding developments in recent decades. One of these is certainly the endoprosthetic treatment of the knee joint. (1)

Endoprosthetic replacement of the knee joint is considered the most performed endoprosthetic procedure after hip replacement. In Austria, data from 2009 to 2015 show a steady increase in total knee arthroplasties. A comparison with worldwide prosthesis registries shows that in Austria on average 202 total knee arthroplasties are implanted per 100,000 inhabitants. This puts Austria among the leaders in terms of nationwide coverage. (3)

The implantation of the total knee endoprosthesis in the final stage of osteoarthritis is one of the most effective surgical procedures with a survival rate of 94% 16 years after surgery. (2) New innovations and milestones in total knee arthroplasty have been constantly achieved with the aim of increasing the efficiency of these as well as patient satisfaction. But there are still many challenges in the future. Recent studies show that up to 20% of patients are dissatisfied after receiving a total knee arthroplasty. (4)

Continuous development has made it possible to use a wide variety of prostheses and surgical methods. National registries and clinical studies provide important data to compare prosthesis types and surgical methods. This paper deals with the Attune Knee from DePuy Synthes and will present and compare epidemiological data, data from surgical techniques as well as revision data.

1 Anatomy and biomechanics of the articulatio genus

In the largest human joint, three bones (femur, tibia and patella) articulate with each other to form two joints. (Articulatio femorotibialis and articulatio femoropatellaris). The lateral and medial femoral condyles (Condylus lateralis et medialis) and the lateral and medial tibial condyles (Condylus medialis et lateralis tibiae) form the femorotibial joint. The facies patellaris of the femur and the patella form the femoropatellar joint. Both joints have a common joint capsule and joint cavity.(1,2)

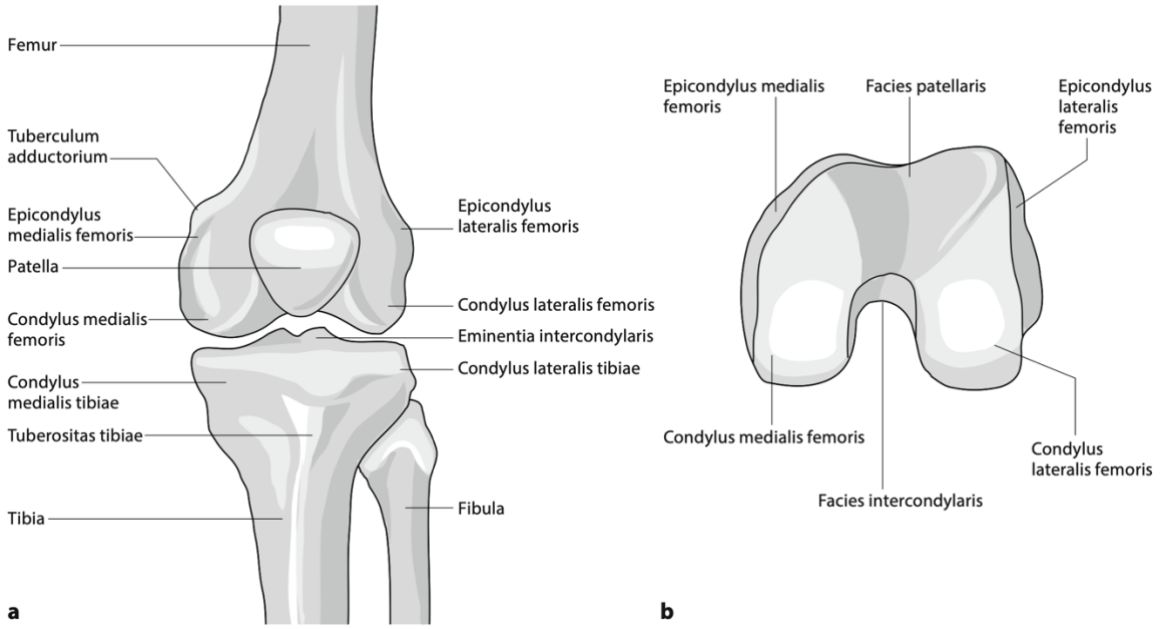

Figure 1: Knee joint a) View from ventral b) View of the femur condyles from distal (3)

1.1 Articulatio Femorotibialis:

The femorotibial joint is functionally seen as a hinge joint (trochoginglymus) with a hinge joint movement (ginglymus) about a transverse axis of rotation and a rotation about the longitudinal axis.(4)

The spirally curved biconvex femoral condyles have an increase in curvature from anterior to posterior. The area of contact between the tibial plateau and the femoral condyles is greatest in the maximum extension position due to convexity. The tibial plateau is inclined backwards about 6 degrees from the horizontal line. The resulting incongruence of the two joint surfaces is compensated by the two menisci.(5)

For flexion and extension in the articulatio femorotibialis, the axis runs almost frontally through the two condyles of the femur. During flexion, the femoral condyles also rotate on the tibial plateau and roll dorsally.(6)

Flexion in the joint is based on two main mechanisms, which are a combination of a rolling and rotating movement. Up to 25 degrees of flexion, the two femoral condyles roll dorsally on the tibial plateau, reaching the dorsal quarter of the tibial plateau. Further movements in the knee joint then trigger local minor forward and backward sliding movements of the femoral condyles. The lateral condyle rolls more and rotates less than the medial condyle. As a consequence, the sagittal displacement of the lateral meniscus is greater than that of the medial meniscus. To allow rotation of the tibia in this joint, both collateral ligaments and capsule must be relaxed. The rotation can be performed by the internal rotators (Musculus semimembranosus, M. semitendinosus, M. sartorius, M. popliteus, M. gracilis) and the external rotators (M. biceps femoris, M. tensor fasciae latae) because the torque of these muscles is highest in the flexion position. During the terminal rotation (final phase of extension), there is an external rotation of the tibia by 5-10 degrees. This is caused by the ligamentum cruciatum anterius, which becomes taut, and the anatomical conditions of the femoral condyles. Due to the terminal rotation, the collateral ligaments receive a high degree of tension and the knee joint is in a stable position. In order to be able to perform flexion from the terminal rotation position, the tibia must be internally rotated again by 5-10 degrees. Depending on the hip joint flexion, active flexion in the femorotibial joint of about 125 degrees is possible with the hip joint extended, and with the hip joint flexed, knee flexion can be increased to 140 degrees. Passively, 160 degrees of flexion can be achieved. Actively, the knee can usually be extended to the neutral position. Passively, the knee can still be hyperextended by 5-10 degrees. Internal rotation of the knee joint is possible up to 10 degrees. External rotation is possible up to 30 degrees. (3,4)

1.2 Articulatio Femoropatellaris:

As the largest sesamoid bone embedded in the tendon of the quadriceps femoris muscle, the facies articularis of the patella consists of two facets covered with cartilage (medial and lateral facet), which articulate with the facies patellaris of the femur. The two facets form the patella opening angle (facet angle) of 130 degrees on average.(6)

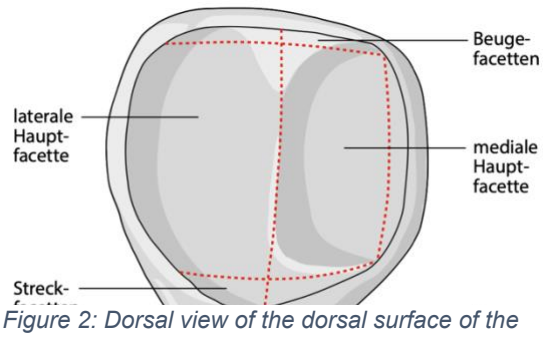

Figure 2: Dorsal view of the dorsal surface of the patella (laterale Hautpfacette = lateral main facet, mediale Hauptfacette = medial main facet, Streckfacette = Strech facet, Beugefacette = Bending facet)(3)

The structure of the patella resembles a flat triangular bone, with the quadriceps muscle inserted at the cranial base and the patella proprium ligament originating at the apex. Seven facet sections are distinguished at the patella. In addition to the medial and lateral facet, several peripheral facets can also be distinguished. Flexion and extension facets, which lie proximal and distal to the two main facets respectively, only come into contact with the femoral condyles during maximum flexion or extension. (3)

The patella serves as a hypomochlion and thereby extends the lever arm by lengthening the distance of the force vector of the quadriceps from the centre of kneerotation A patellectomy results in the torque of the extensors being reduced by about 30%. In flexion, the patella slides in the glide path between the two femoral condyles, covering a distance of 5-7 cm between maximum flexion and extension. In the maximum extension position, there is only a connection to the femur between the distal articular rim, the rest of the patella lies on the suprapatellar recess. In the maximum flexed position, the patella lies in front of the intercondylar area between the two femoral condyles. (3,7)

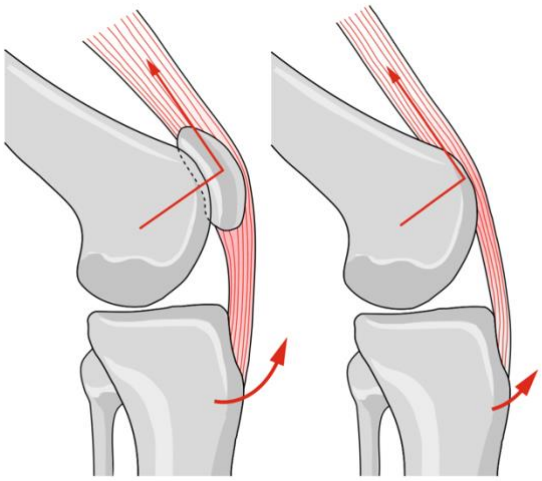

Figure 3: Extension of the lever arm through the patella (3)

1.3 Ligament structures in the knee

1.3.1 Ligamenta cruciata genus

A distinction is made between the Lig. cruciatum anterius and the Lig. cruciatum posterius. The name cruciate ligament comes from the fact that the two ligaments cross like an X. The cruciate ligaments lie between the stratum synoviale and the stratum fibrosum of the joint capsule and are therefore extraarticular but intracapsular. Functionally, the function of the cruciate ligaments is to secure the knee joint in the sagittal, frontal and horizontal planes. They stabilise the knee, especially in a bent position, and prevent hyperextension. A bursa, the bursa intercruciata, can usually be found between the two cruciate ligaments. In addition to the two cruciate ligaments, the anterior meniscofemoral ligament (Humphrey) and the posterior meniscofemoral ligament (Weitbrecht, Wrisberg or Robert) are also part of the central ligament complex. Both attach to the posterior cruciate ligament. (5,8)

1.3.1.1 Lig. cruciatum anterius

The anterior cruciate ligament runs from the condyle femoris lateralis (posteriomedial surface) to the area intercondylaris anterior of the tibia, so that it pulls obliquely from posterior-lateral to anterior-medial. (5)

1.3.1.2 Lig. cruciatum posterius

The posterior cruciate ligament runs from the condyle femoris medialis (anteriomedial surface) to the area intercondylaris posterior of the tibia, so that it pulls obliquely from anterior medial to posterior-lateral. (5)

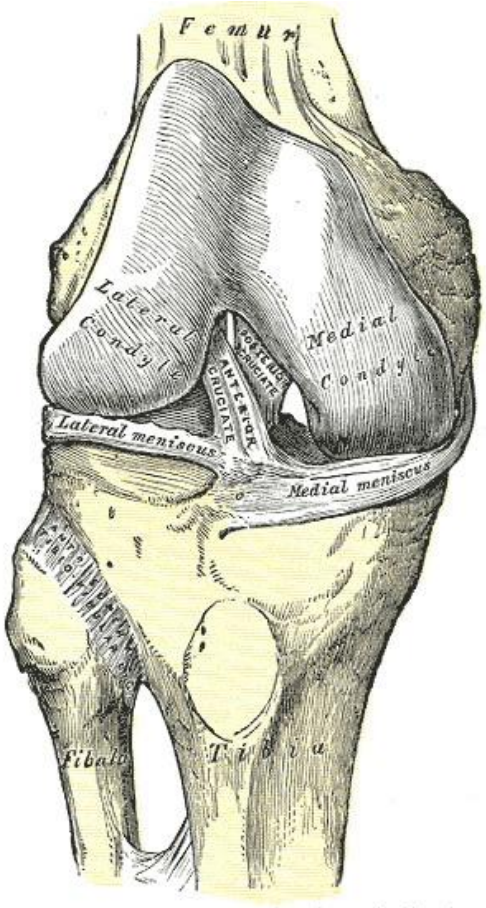

Figure 4: Interior Ligaments of the Right Knee(78)

1.3.2 Ligamentum collaterale tibiale et fibulare

The two collateral ligaments are tense in the extended position and relaxed in the flexed position. This is due to the increased radius of curvature of the femoral condyles in the flexed position. An exception is the posterior part of the tibial collateral ligament, which is shorter than the anterior ligament sections and is fused with the capsule and medial meniscus. Consequently, the range of motion of the medial condyle is limited during flexion compared to the lateral condyle. Due to the relaxation of the collateral ligaments in flexion, an abduction and adduction movement between the tibia and femur is possible to a limited extent. (4)

1.3.2.1 Lig. collaterale tibiale (mediale)

The medial collateral ligament runs from the epicondylus femoris medialis to the facies medialis tibiae. The fibres are divided into an anterior and posterior fibre bundle. The posterior fibre bundle is fused with the joint capsule and meniscus. The posterior fibre bundle can be divided into a superficial and a deep part. The superficial part has parallel fibres and extends towards the tibia. The deep part has mainly short fibres that run from the tibia (meniscotibial ligament) and femur (meniscofemoral ligament) to the base of the meniscus. The anterior fibre bundle has parallel collagenous fibres that only loosely lie on the joint capsule. A bursa (bursa ligamenti collateralis tibialis) is usually found here to ensure the displaceability of both structures. (5)

1.3.2.2 Lig. collaterale fibulare (laterale)

The lateral collateral ligament runs from the epicondylus lateralis femoris to the caput fibulae and stabilises the knee joint, especially in the extended position. The tendon of origin of the popliteus muscle runs under the lateral ligament. This is possible because the lateral collateral ligament has no adhesion to the meniscus or the joint capsule. Due to the lateral femoral epicondyle being displaced anteriorly in the extended position, the ligament runs obliquely from cranioventral to posteriocaudal. (5,8)

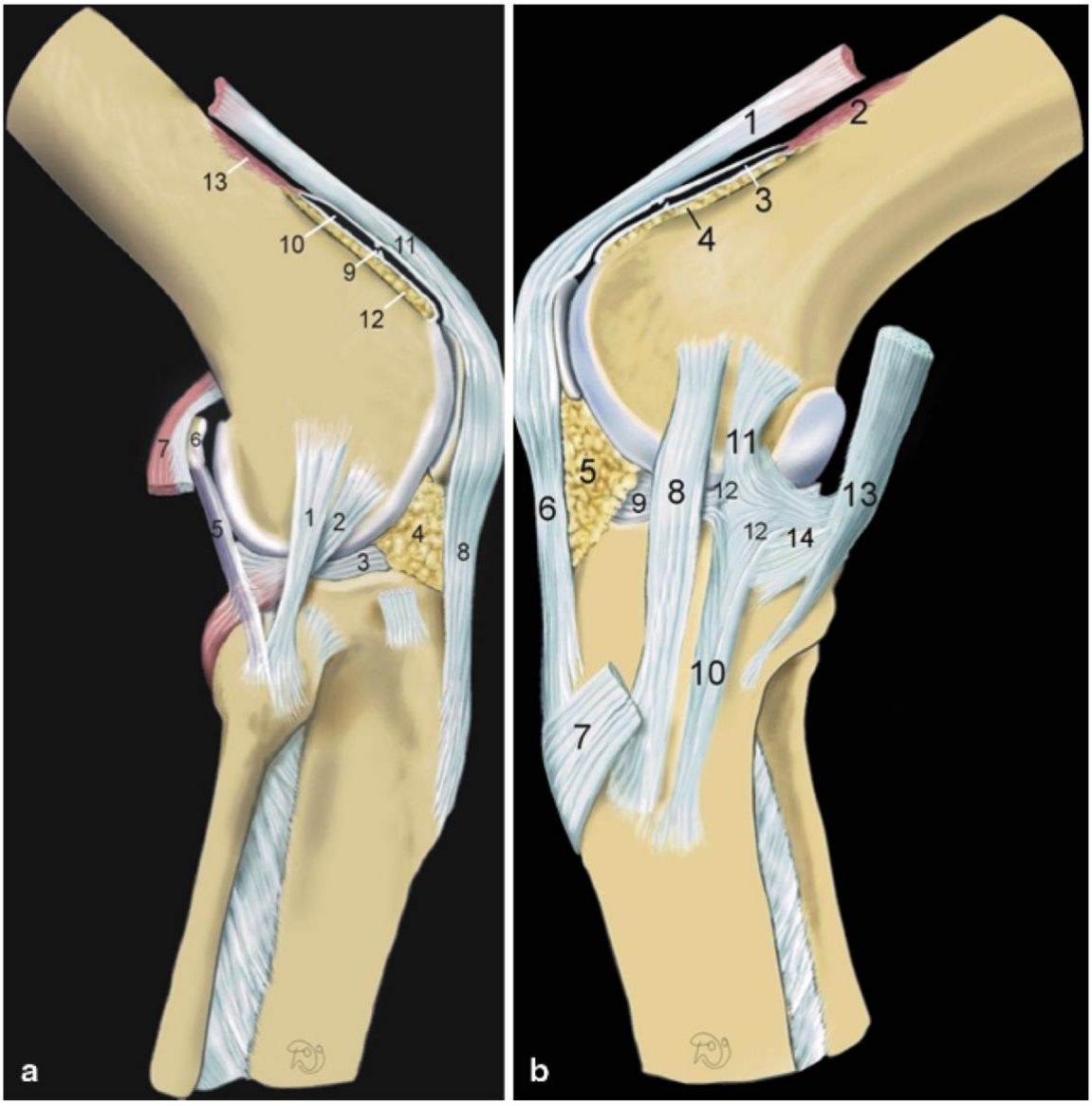

Figure 5: (A) Ligamentous apparatus of the knee joint (8)

A) *Fibular ligamentous apparatus: 1) Collateral fibular ligament 2) Popliteal tendon of origin 3) Lateral meniscus 4) Hoffa fat body 5) Fabellofibular ligament 6) Lateral fabella 7) Lateral polar cap and lateral caput of the gastrocnemius muscle 8) Lig. patellae 9) Plica suprapatellaris 10) Recessus su-prapatellaris 11) Tendon of the quadriceps femoris 12) Fat body 13) M. articularis genus*

Figure 6: (B) Ligamentous apparatus of the knee joint(8)

B) *Tibial ligamentous apparatus: 1) Tendon of the M. Quadtriceps 2) M. articularis genus 3) Recessus su-prapatellaris 4) Fat body 5) Hoffa fat body 6) Lig. Patellae 7) Pes anserinus superficialis 8) Lig. Collaterale tibiale 9) Meniscus medialis 10) Lig. Collaterale mediale posterius 11) Lig. Meniscofemorale 12) Lig. Meniscotibiale 13) M. Semimembranosus 14) Posterior oblique ligament*

Posterior knee ligaments

The posterior ligaments of the knee joint serves to strengthen the dorsal side of the knee and is formed by the following structures:

1.3.2.3 Tendo m. semimembranosi with Pes anserinus profundus

The insertion structure of the semimembranosus muscle is called the pes anserinus profundus and stabilises mainly in the posteriomedial compartment. (8)

1.3.2.4 Lig. popliteum obliquum

The popliteum obliquum ligament pulls away from the lateral femoral condyle in a medial-inferior direction and serves to reinforce the joint capsule. (9)

1.3.2.5 M. popliteus

The popliteal muscle arises from the lateral femoral condyles and inserts into the joint capsule and the posterior surface of the tibia. (9)

1.3.2.6 Lig. Popliteum arcuatum

The popliteum arcuatum ligament has exactly the opposite course of the popliteum obliquum ligament. It pulls away from the medial femoral condyle and bridges the popliteus muscle. (9)

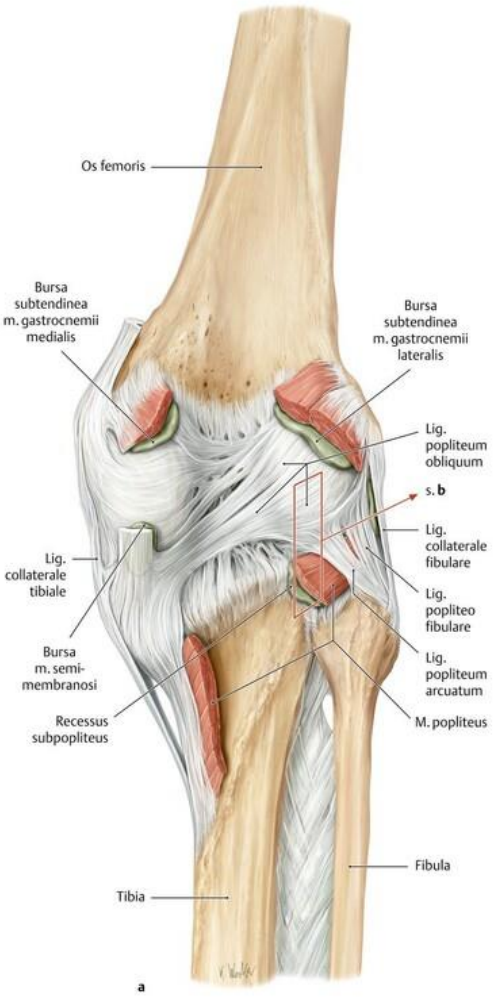

Figure 7: Posterior capsule-ligament apparatus of the knee joint (79)

1.4 Cartilago articularis genus

Articular cartilage consists of 5% chondrocytes, 20-40% collagen and glycoaminoglycans and up to 60% water. The knee joint has the thickest articular cartilage in the human body with an average joint surface of 100cm2. The amount of hyaline articular cartilage is highly variable and usually ranges from 13-32 cm^3. The articular cartilage is most pronounced in the area of the facies articularis of the patella with an average thickness of

2.5 mm. The facies patellaris of the femur has an average thickness of 2.2 mm. In the middle of the femur condyles, which articulate with the tibia in stance, the thickness is 1.6 mm. The facies articularis of the tibia has a thickness of 2.2 mm laterally and 1.7 mm medially on average. (4,10)

The main histological feature of hyaline articular cartilage is that its chondrocytes are often grouped together and surrounded by cartilage matrix (a basophilic, extracellular substance). The main components of the cartilage matrix are collagen fibrils (especially type 2) and proteoglycans. Due to their structure of long-chain proteins in combination with glycosaminoglycan chains, the proteoglycans are able to bind a lot of water and enable the cartilage to distribute forces. In addition to this property, they also have high pressure elasticity and thus act as shock absorbers of the knee joint. The supply of the cartilage cells is ensured by the synovial fluid via diffusion. Articular cartilage is a special form of hyaline cartilage because it does not have a perichondrium, which is why it only has a limited regenerative capacity. (11,12)

The classification of cartilage damage during arthroscopy is usually according to Outerbridge: (1)

Grade	**Property**
1	Cartilage with softening and swelling
2	A partial-thickness defect with fissures on the surface that do not reach subchondral bone or exceed 1.5 cm in diameter
3	Fissuring to the level of subchondral bone in an area with diameter more than 1.5 cm
4	Exposed subchondral bone

Table 1: Classification of cartilage damage according to Outerbridge (1)

1.5 Menisci

The menisci, which are made up of fibrocartilage and C or crescent-shaped, are located in the joint space between the femur and tibia and have a variety of functions. The function of the menisci is to compensate for the incongruence of the joint surfaces, the even distribution of pressure and the restraining effect (limiting the rolling ability of the condyle). In children (1 year), the entire meniscus is still vascularised; in adulthood,

vascularisation is limited to the outermost area (1.5-2 mm). The rest of the meniscus is nourished via diffusion. (5,8)

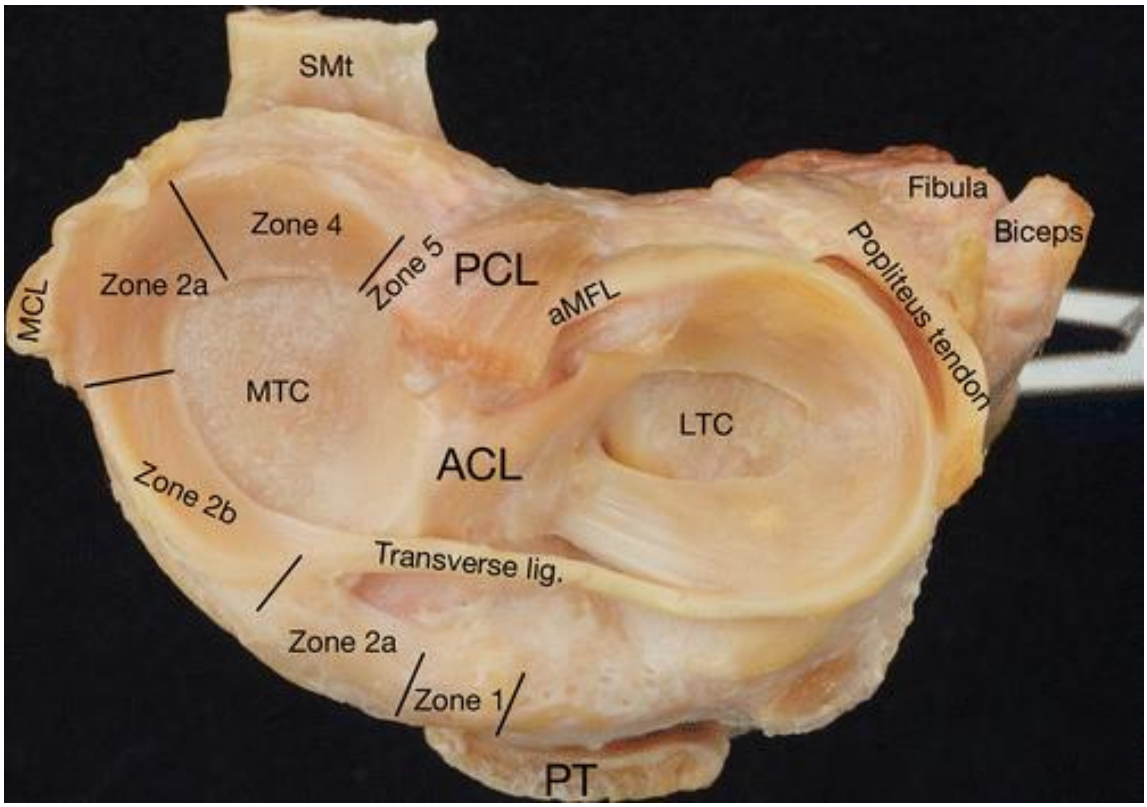

Figure 8: Left knee joint with femur removed (13)
PT - patellar tendon, ACL - anterior cruciate ligament, PCL posterior cruciate ligament, MTC medial tibial condyle, LTC lateral tibial condyle, MCL medial collateral ligament, aMFL anterior meniscofemoral ligament, SMt semimembranosus tendon

Both menisci are made up of a flat underside, which slides on the tibial plateau, and a concave upper side, which hugs the femoral condyles. They are attached via the free ends (anterior horn and posterior horn) in the area intercondylaris of the tibia. The lateral meniscus is circular, and the medial meniscus is sickle shaped. The medial meniscus is also fused with the posterior part of the medial collateral ligament. In the anterior region, the two menisci are usually connected by the transverse genus ligament and the lateral meniscus is usually connected to the anterior and posterior cruciate ligaments (anterior and posterior meniscofemoral ligaments). (4)

1.6 Physiological axes of the knee joint

There are two main axes, the anatomical leg axis and the mechanical leg axis.

1.6.1 Anatomical leg axis

The anatomical axis is formed by the central longitudinal axes (shaft centre) of the tibia and femur. Together these two longitudinal axes form a laterally open angle of 173-175 degrees. (3,14)

This angle of 173-175 degrees is called the femorotibial angle (FTA). A further subdivision of this angle is made by the horizontal line in the knee joint (the knee baseline) into the anatomical lateral distal femoral angle (aLDFA) and the anatomical medial proximal tibial angle (aMPTA). The aLDFA has a physiological angle of 81 degrees +/- 2 degrees and the aMPTA of 87 degrees +/- 3 degrees. The knee base line is the tangent of the femoral condyles. Under physiological conditions, this runs almost parallel to the tibial plateau line. The angle of these two to each other is called the JLCA ("joint line convergence angle"). (11,15)

1.6.2 Mechanical femoral axis

The mechanical femoral axis begins in the centre of the hip joint and ends in the centre of the knee joint. The anatomical femoral axis forms an angle of 5-7 degrees to the mechanical femoral axis. (14)

1.6.3 Mechanical leg axis (Milkulicz line)

The mechanical axis of the leg (weight-bearing line) or also called the Milkulicz line, leads from the centre of the femoral head to the distal tibial joint surface (centre of the upper ankle joint). In extension, the centres of the hip, knee and ankle joints come to lie on a straight line. The mechanical load-bearing axis runs slightly medial (4 +/- 2 mm) in the knee joint. Deviations from this line are called varus or valgus malalignment. Compared to the centre of the knee joint and the centre of the ankle joint, the centres of the hip and ankle joints are slightly further apart, which is why the mechanical leg axis is slightly oblique from craniolateral to mediocaudal by 3 degrees compared to the vertical axis. (3,14,15)

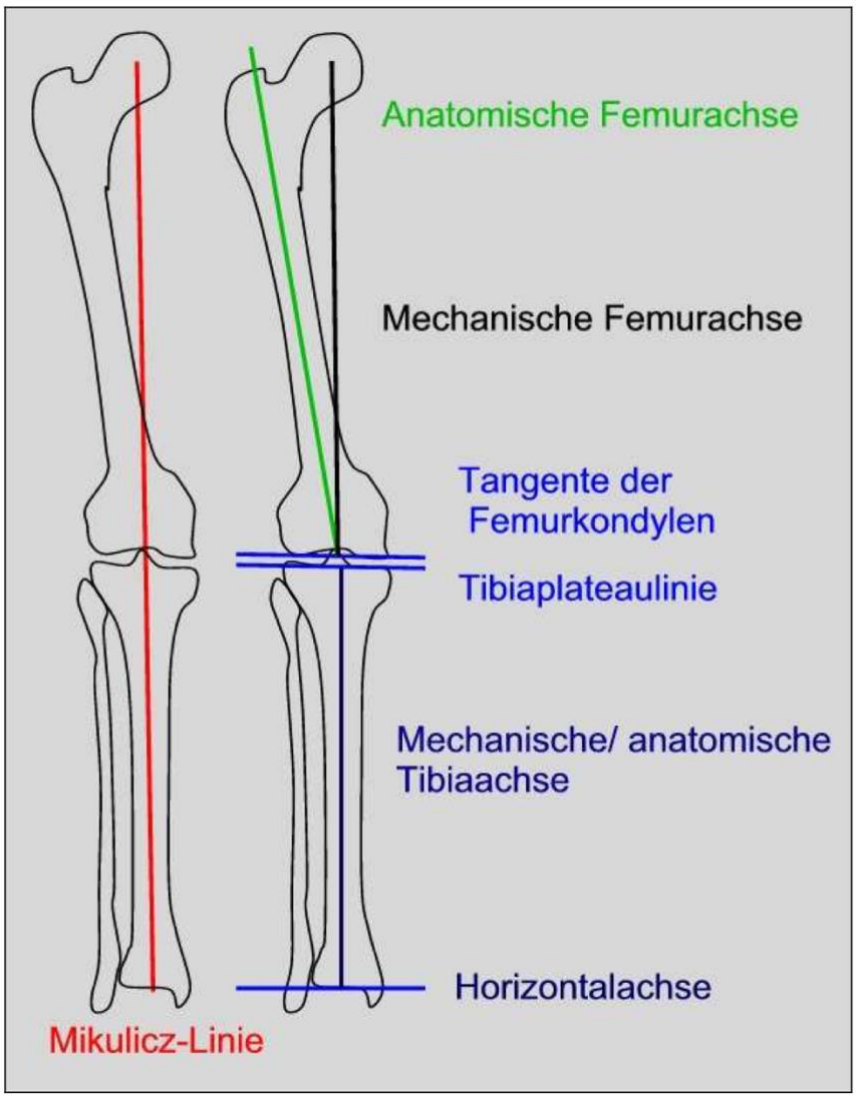

Figure 9: Axes; anatomische Femurachse = anatomical femur axis, mechanische Femurachse = mechanical femur axis, Tangente der Femurcondylen = tangent of the femoral condyles, Tib-iaplateaulinie = tibial plateau line, mechanische/anatomische Tibiaachse = mechanical/anatomical tibial axis, Horizontalachse = horizontal axis(11)

2 Osteoarthritis

Everyone is affected by osteoarthritis from the beginning of the third decade of life due to the ageing process of connective and supporting tissue. From the age of 40, half of the population can already show X-ray morphological degenerative changes in the joint. From the age of 65, almost everyone has a degenerative change in the joints. Osteoarthritis is characterised by the loss of joint cartilage as a result of progressive degeneration due to an imbalance between the load and the load-bearing capacity of the joint. Osteoarthritis can distinguish between primary osteoarthritis (inferiority of the cartilage without a known cause) and secondary osteoarthritis (caused by metabolic disorders, incorrect loading, trauma, inflammation or degenerative causes). This loss of cartilage leads to increased stress on the joints, which leads to a thickening (sclerosis) of the subchondral bone with pseudocyst formation and the formation of osteophytes. Osteophytes are caused by increased new bone formation in the border regions between the joint capsule attachment and the cartilage. They are caused by the tensile and shearing forces at the joint edge as a result of cartilage loss. The loss of cartilage also leads to a narrowing of the joint space, which is visible radiologically. Osteoarthritis mainly affects large joints that are exposed to strong mechanical forces, such as the knee and hip joints. (1,16)

2.1 Pathology of osteoarthritis

Due to complex, multifactorial processes under the influence of genetic as well as environmental factors, osteoarthritis leads to typical micro- and macroscopic changes, which are held responsible for the symptoms. (17)

Arthrosis can be divided morphologically (according to Otte- Söder and Aigner) into 4 stadiums:

- **Stage 1 (Stadium I):** is characterised by superficial cartilage fissures and proteoglycan loss.
- **Stage 2 (Stadium II):** The fact that the cartilage fissures extend to the radial cartilage causes cartilage cells to die. In addition, the foreign body irritation leads to the development of inflammation of the joint mucosa (synovitis), which causes shrinkage of the joint capsule.
- **Stage 3 (Stadium III):** The cracks penetrate even further into the deep cartilage layers. At this stage, larger cartilage surfaces can also break out. These can lie in the joint ("joint mouse").
- **Stage 4 (Stadium IV):** Due to the loss of cartilage, the bony cover plate is exposed. This results in vascular sprouting from the epiphysis and the subchondral bones. The bone plate is thickened due to the load (osteoblast activity) and at the same time, however, there is also osteoclastic degradation of the bone. As synovial fluid enters the bone, pseudocysts are formed, which are first surrounded by newly formed bone and later by fibrous scar tissue. Bone and cartilage metaplasia of the synovium and osteophytes develop in the marginal area of the joint.(16)

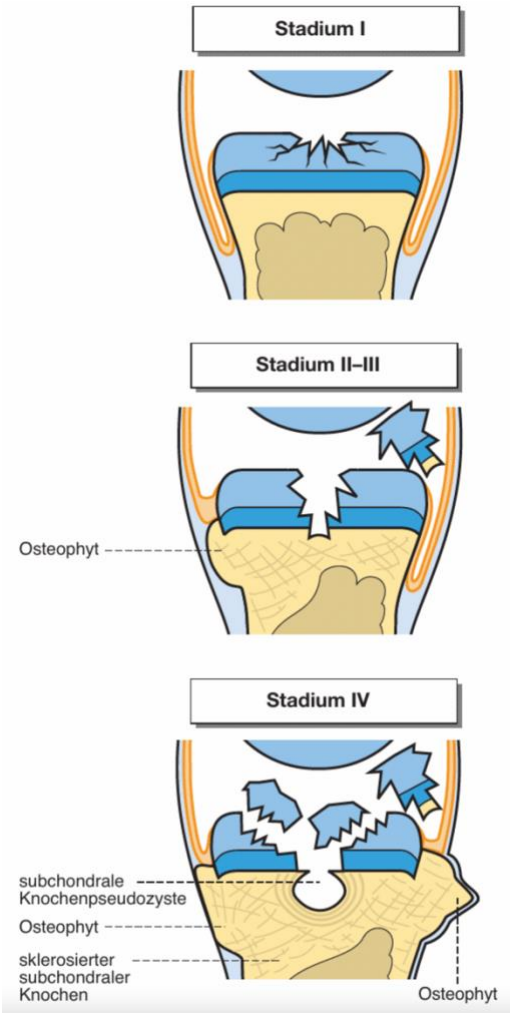

Figure 10: Development of osteoarthritis (16)

2.2 Diagnosis of osteoarthritis:

If a suspected clinical diagnosis is made on the basis of anamnesis and examination findings of the joint, radiological clarification usually follows. The laboratory chemical diagnosis is not indicative, except in the diagnosis of active osteoarthritis. (1,17)

2.2.1 Clinic of osteoarthritis

Osteoarthritis is characterized by painful pressure in the joints, bony thickening ("boney swelling"), restricted function and movement, pain on movement (under heavy load) and "onset pain". The painful onset of a joint movement is referred to a start-up pain. However, the pain subsides when the movement is continued. A morning stiffness of the joint with a duration of a few minutes is also mentioned in the literature. Patients with osteoarthritis may experience so-called inflammatory "activations" in the course of osteoarthritis. These are characterized by the cardinal symptoms of inflammation (pain, redness, swelling, hyperthermia and functional limitation).
As osteoarthritis progresses, crepitations (palpable or audible grinding) may occur as a result of cartilage damage or debris in the joint. As a result of cartilage loss and the direct contact of the two articulating bones, local reactions (bone sclerosis, proliferation, cyst formation and/or collapse of joint surfaces), stiffening of the joint and deformation of the joint may occur. (17)

The osteoarthritis can be classified according to the affected compartment in the knee joint:

- Unicompartmental patellofemoral osteoarthritis
- Unicompartmental femorotibial osteoarthritis
- Bicompartmental femorotibial osteoarthritis
- Tricomparitmentelle, patellofemorotibial osteoarthritis (pangonarthrosis)(8)

2.2.2 Radiological diagnostics

The standard radiological classification for osteoarthritis is that of Kellgren and Lawrence. The most important changes are:

- Osteophytosis
- joint space narrowing

- subchondral sclerosis
- subchondral cysts
- joint erosions (8)

The classification according to Kellgren and Lawrence goes from stage 1 to stage 4 in ascending order of severity.

- stage 1 is a suspected joint space narrowing with possible small osteophytes.
- stage 2 is suspected joint space narrowing, but with definite osteophytes.
- stage 3 is moderate multiple osteophytes with definite joint space narrowing, sclerosis and possible deformities of the bone ends.
- stage 4 is defined as large osteophytes with definite joint space narrowing, severe sclerosis and deformities of the bone ends. (17)

However, the radiographic findings do not go hand in hand with the patient's subjective complaints. (1)

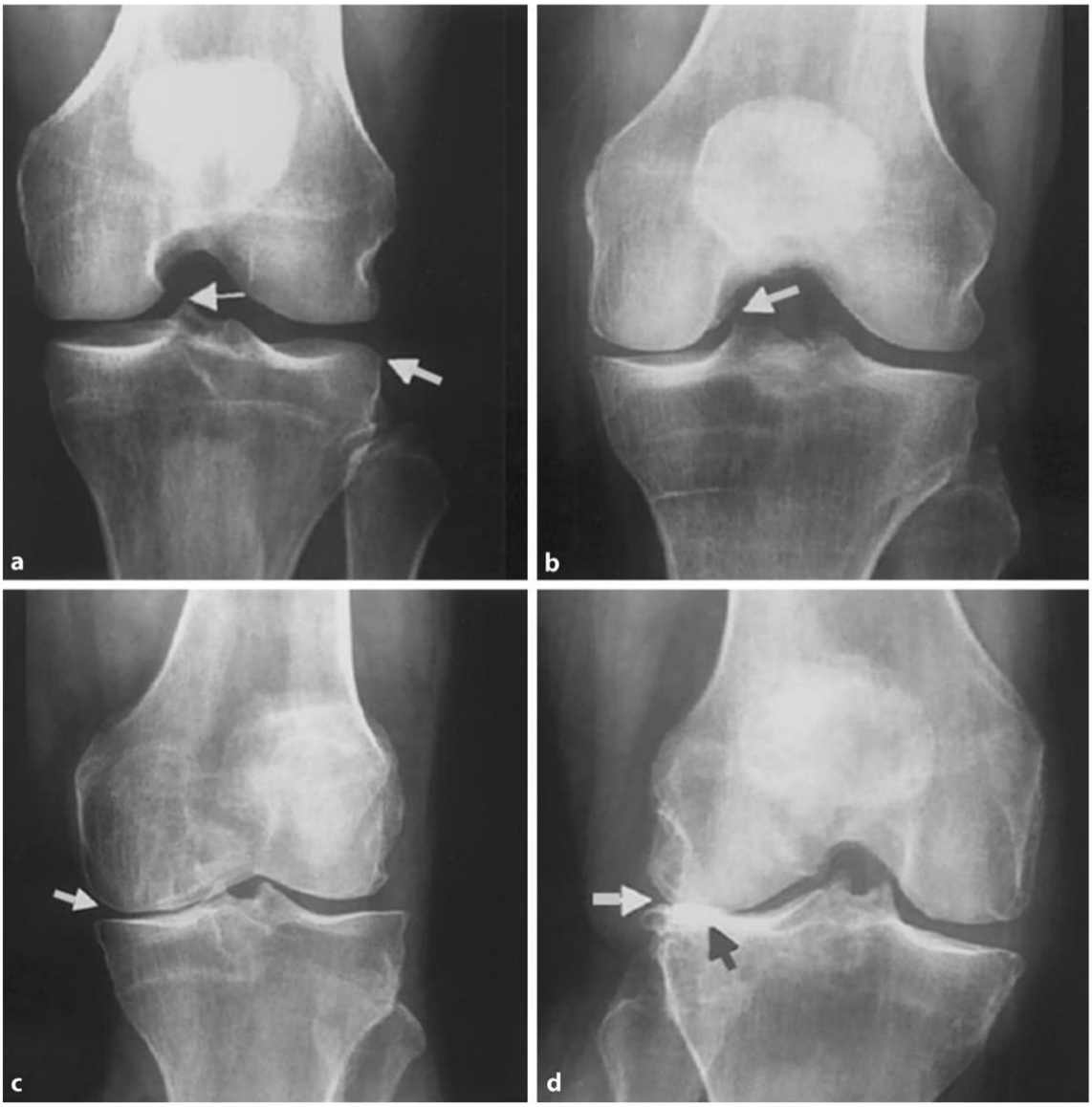

Figure 11: Radiological classification according to Kellgren-Lawrence a) Stage 1 b) Stage 2 c) Stage 3 d) Stage 4 (17)

In addition to the Kellgren-Lawrence classification, the following classification systems are most commonly used for osteoarthritis classification:

- IKDC (International Knee Documentation Committee)
- Jäger-Wirth
- OARSI (Osteoarthritis Research Society International)
- Fairbank (18)

2.2.3 Magnetic resonance imaging (MRI)

In addition to soft tissue structures, other tissue structures can also be precisely imaged with magnetic resonance imaging. These include cartilage, joint-related and subchondral bone, joint fluid, ligaments, joint cavity with or without effusion, muscles, tendons, vessels and nerves. Compared to X-rays, MRI has a rather low significance in diagnostics. It is mainly used to assess cartilage, meniscus and ligament structures and is therefore important in the early detection of arthrosis. A distinction is made in cartilage between cartilage fissures (within the cartilage layer), tears (which extend to the bone) and complete defects. Good validity in the assessment of the cartilage layer is usually only achieved in those regions with a thick cartilage layer (patella, femoral condyles).(18)

2.2.4 Laboratory chemical diagnostics

Laboratory chemical examinations are not of great importance in diagnostics. In activated osteoarthritis, however, it can be helpful to determine the C-reactive protein and the erythrocyte sedimentation rate in the blood. (17)

2.3 Therapy of osteoarthritis:

The therapy of osteoarthritis is difficult due to the very limited regenerative capacity of the joint cartilage. According to the EULAR (European League against Rheumatism), the first priority in treatment is the patient's own lifestyle change. This should be followed by conservative and medicinal measures. Only if these procedures are not successful, surgical procedures follow. (19)

To prevent osteoarthritis, risk factors that play a central role in its pathogenesis should be minimised. Physical inactivity and obesity are such factors and should be taken into account in therapy. Early detection of congenital or acquired deformities, such as axial deformities or joint incongruities, should also be aimed for. (1)

A distinction is made between conservative and surgical forms of therapy:

2.3.1 The conservative therapy of osteoarthritis

Conservative therapy is based on various components.

- Risk factor control
- Pain therapy (oral/local)
- Physiotherapy
- Physical therapy
- Orthopaedic measures

For oral pain therapy, paracetamol or metamizole are recommended by international expert committees (EULAR). However, as these drugs are limited due to their side-effect profile and relatively low potency, non-steroidal anti-inflammatory drugs are mostly used in osteoarthritis therapy nowadays. These also have an anti-inflammatory effect, which helps well with an inflammatory component. Percutaneous therapy with hyperaemic ointments (capsaicin, preparations containing pepper or camphor or NSAIDs) can also be used primarily for osteoarthritis of the knee joint. Drugs from the SYSADOA group ("symptomatic slow acting drugs in osteoarthritis") can be applied as well. Known representatives of this group are, for example, glucosamine or chondroitin sulphate. These

substances are physiologically synthesised in the chondrocytes and are supposed to promote cartilage metabolism.(8,19)

Physiotherapy is used to improve or maintain function. The central focus is on the joint-friendly execution of everyday activities and exercise therapies ("range-of-motion-exercise") (17)

A variety of treatment options are available for physical therapy. In addition to thermotherapy, which works by changing the pain threshold and an intraarticular change in temperature, other methods such as electrotherapy are also available. Physical therapy is also recommended in the guidelines for arthrosis therapy. (20)

Cortisone and hyaluronic acid are used for intraarticular infiltration in osteoarthritis. In addition to these two drugs, platelet-rich plasma (PRP) and even stem cells are also used. The infiltration of glucocorticoids has a good effect on joint effusions or accompanying synovitis.(10)

With orthopaedic shoes and shoe fittings, it is possible to cushion the heel strike by means of buffer heels and thus relieve the knee. It is also possible to compensate for a difference in leg length by raising the sole. This is possible up to a difference of 1 cm. In addition to these measures, there are also walking aids such as canes or wheelchairs, which can be used depending on the stage of the arthrosis. The use of a cane support relieves the pressure on the opposite extremity by 30%. (1)

2.3.2 Surgical forms of therapy

The aim of surgical interventions is to improve joint mechanics or joint biology. The different surgical techniques are discussed later in this thesis. (1)

3 History of knee arthroplasty

From a historical perspective, the development of knee prosthetics already began in the 19th century. The German surgeon Theophilus Gluck, a student of Virchow, His and Langenbeck, implanted the first knee prosthesis (a hinged prosthesis) made of ivory in the Kaiser and Kaiserin Friedrich Children's Hospital in Berlin on 20 May 1890 in a knee destroyed by joint tuberculosis. The prosthesis was anchored in the bone with a mixture of rosin and plaster. Frequent complications were infections, insufficient metallurgy and inadequate fixation.(8,21,22)

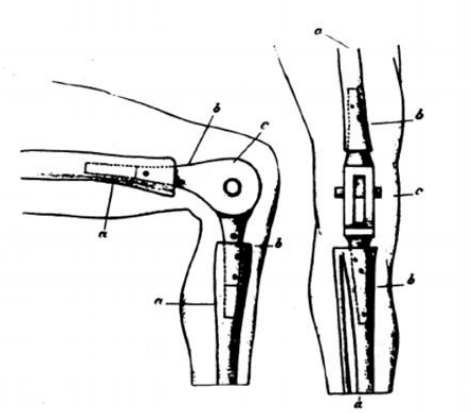

Figure 12: Gluck's ivory prosthesis (22)

Progress was then made in 1951 when Dr Wallidus produced a prosthesis from acrylic and in 1958 from a cobalt-chrome compound. This type of prosthesis was characterised by monoaxial (axis-bearing) hinge prostheses. In addition to the Wallidus prosthesis, the Shiers prosthesis was also frequently used at this time. This type of prosthesis was used until 1970. Due to the high loosening rate and abrasion problems, the use of this type of prosthesis was rather limited.(23–25)

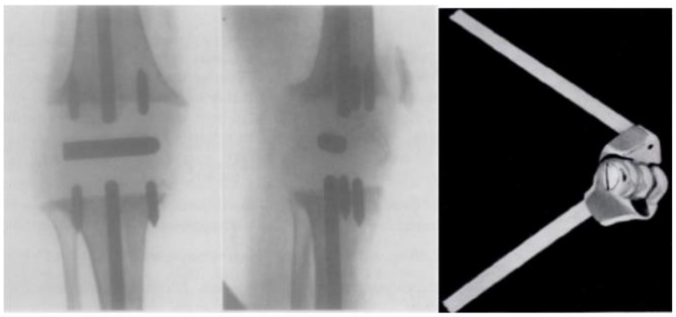

Figure 13: Left (X-ray) Wallidus prosthesis; right: Shiers prosthesis (27,80)

The fixation of these two prostheses was done via a long intramedullary stem. The fixation of the prosthesis by means of a cement was further developed and established by Johann Charnley in the 1960s.(23,26,27)

The disadvantage of all these axis-coupled knee endoprostheses (hinged prostheses) was the bone loss during primary implantation, since a more extensive intramedullary anchoring had to be carried out for optimal force application in the bone, as well as loosening due to non-physiological kinematics and infections. (3,27)

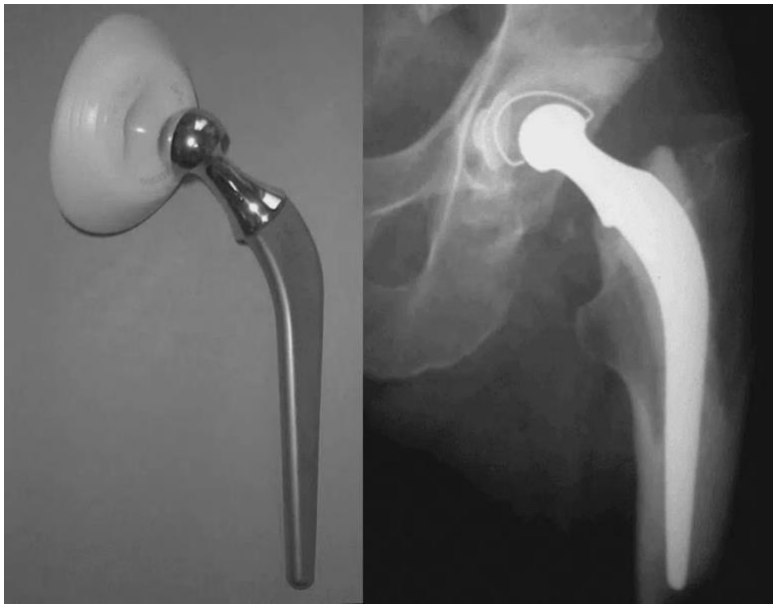

Figure 14: Charnley hip (81)

In contrast to the Wallidus prosthesis, Mazas developed a cemented type of prosthesis, the Guepar endoprosthesis.
In addition to the further development of the cement, it was also the British surgeon John Charnley who developed the laminar air flow (LAF) ventilation system in operating theatres and was thus able to reduce the risk of infection. Instead of the previous metal-metal combinations, he first paired a metal shaft with a Teflon cup, which he then replaced with polyethylene. In addition, he reduced the articulating joint surfaces by making the femoral head smaller. This enabled him to extend the survival time of the hip prostheses he used. The principle postulated at the time, known as "low friction arthroplasty", is still valid today in arthroplasty. (28–31)

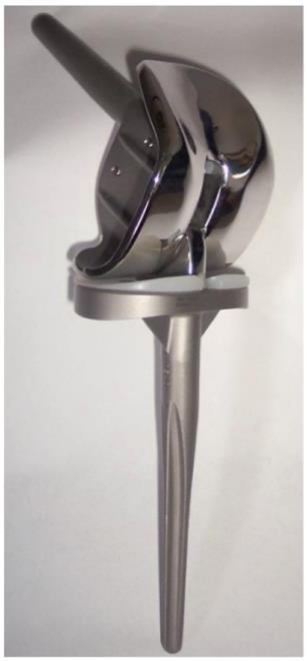

Figure 15: GBS knee prosthesis(8)

From the load-bearing systems (Wallidus, Guepar knee), the non-load-bearing systems (GSB, Blauth prosthesis) developed based on the principle of "low friction arthroplasty". This type is characterised by the larger articulating surface between the metallic femoral part and the tibial plateau made of polyethylene tread. The two best-known prostheses are the GSB prosthesis (Geschwend-Scheier-Bahler), a non-constrained hinge prosthesis with semi-rigidly coupled axes, and the Blauth hinge prosthesis.

The advantages of the Blauth prosthesis are the reinforced anchoring elements and the larger contact surfaces for better force transmission, which now takes place via the prosthetic surface and no longer via the axis, as well as the bone-saving process of implantation. The use of coupled prosthesis systems is still used today, especially in cases of insufficient ligamentous apparatus, rotational misalignments between femur and tibia, bending and extension incongruence. (3,30,32)

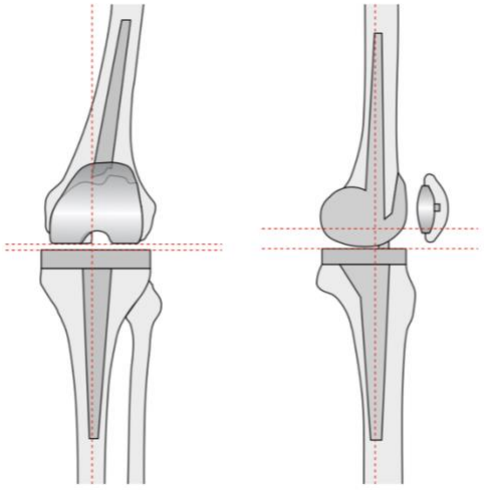

Figure 16: hinged prothesis (3)

The first surface replacement endoprostheses as well as the uncoupled glide bars for the knee joint were developed at the end of the 1970s and the beginning of the 1980s. The understanding of the kinematics of the knee joint led to the development of various models with different philosophies of endoprosthetic fitting. Through continuous further development of the prostheses, it has been possible to imitate more and more natural movements of the knee joint, such as sliding, rolling and rotating. Today, the uncoupled (axis-free) surface replacement is considered the gold standard in knee arthroplasty.(3,21)

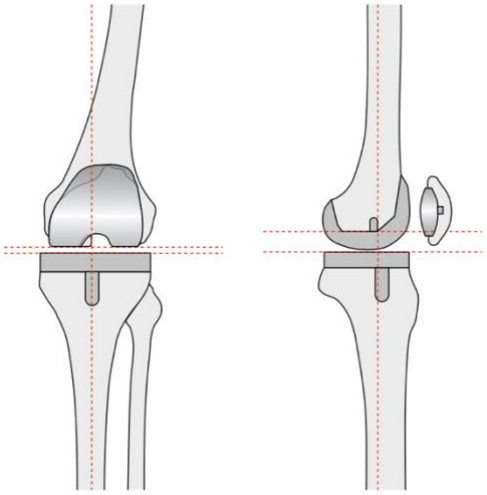

Figure 17. Axis-free guided knee joint endoprosthesis (3)

Gunston and Coventry invented the first surface replacement by using two unicondylar prostheses. Although they achieved good results at the beginning, they were not able to fix the components adequately, which led to a high failure rate. They based their design on the configuration of the femoral condyles. The first breakthrough came in 1973 with the total condylar prosthesis, which was introduced by Insall and colleagues and is considered the predecessor of today's modern prostheses. Characteristic of this prosthesis is the increased attention paid to mechanical factors, as opposed to the anatomical factors of the knee, to produce normal kinetics. A short shaft was inserted at the tibial plateau to compensate the asymmetric load bearing. At the beginning, the tibial component was only made of polyethylene and was later provided

with a metal back surface to introduce the forces homogeneously. The articulating tibial surface had a central bar and was raised at the edges so that a perfect contact closure could be achieved through high congruence. This is called the "Round-on-Round" principle (see Fig.17 - ABOVE). This prevented rotational and thrusting movements. Due to the small range of motion of this prosthesis and the tendency of the femur to subluxate ventrally during flexion, the posterior-stabilised prostheses were developed. An example of this is the Insall-Burstein posterior-stabilised prosthesis, which has a central coupling mechanism that shifts the femorotibial contact point posteriorly at approximately 70 degrees of flexion to create a femoral rollback and allow further flexion. Based on the double sled with preservation of the posterior cruciate ligament, with less concavity of the tibial plateau, the Kinematic-Condylar prosthesis was developed. This is based on the "flat-on-flat" design. (see Fig.17 - CENTRE). This philosophy is found in the most used types of prosthesis today. However, the disadvantage of this design is that there is a high point polyethylene load due to the small area contact between the curved femoral component and the flat tibial plateau. To avoid this, the "round-on-flat" principle was developed. The aim is to counteract the increased stresses on the anchorage or the polyethylene that occur when increasing the congruence. For this purpose, prostheses with rotating platforms or meniscus bearings are

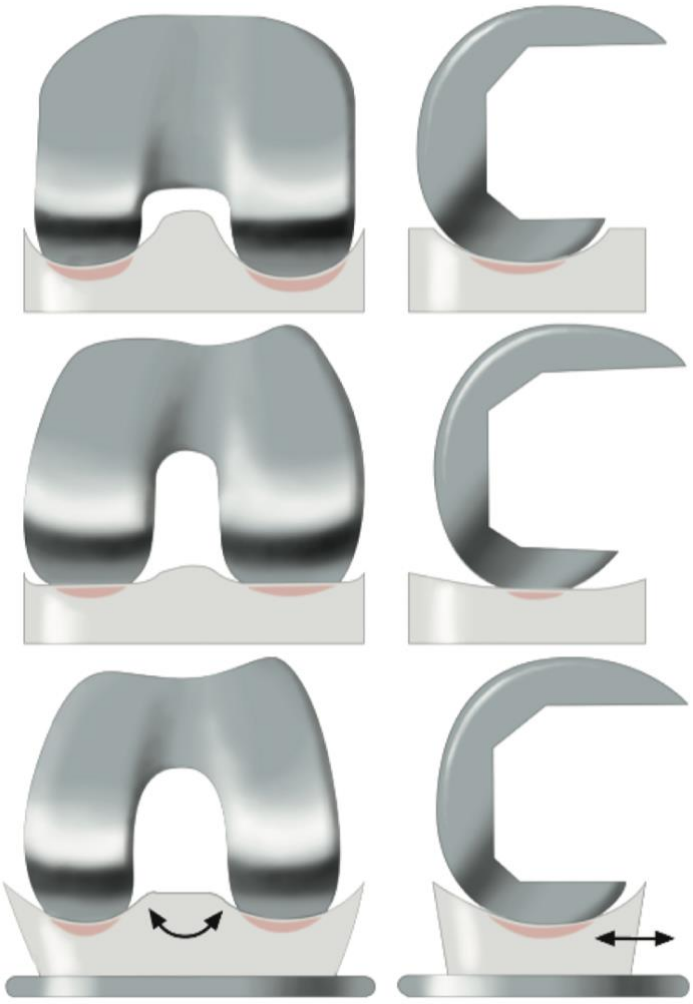

Figure 18: Surface endoprosthesis design: (8)

TOP: "Round-on-round" principle - high form fit with a certain amount of constraint

MIDDLE: "Flat-on-flat" principle - low form fit with small area polyethylene loading

BOTTOM: "Round-on-round with mobile bearing" - high form fit with mobile platform

used. Mobile platforms ensure that rotation and shear forces are also absorbed during roll-slide movements - "round-on-round" principle with mobile bearing (see Fig.7 - BELOW). However, it has not yet been possible to develop a prosthesis that corresponds to the normal kinetics of the knee joint. (8)

4 Types of prosthesis:

Depending on the severity of the arthrosis and the ligament situation, four different classes are distinguished:

1. unicondylar knee prosthesis
2. bicondylar surface replacement prostheses with or without patellar back surface replacement
3. semi-constrained knee prostheses
4. coupled implant systems ("constrained")

In addition to these points, a distinction can also be made between fully cemented knee prostheses (approx. 80%), uncemented knee prostheses (approx. 5%) and hybrid cemented prostheses (15%). Unicondylar and bicondylar knee prostheses are called sled prostheses. In these types of prostheses, femoral and tibial prosthetic components are not coupled. (8,33)

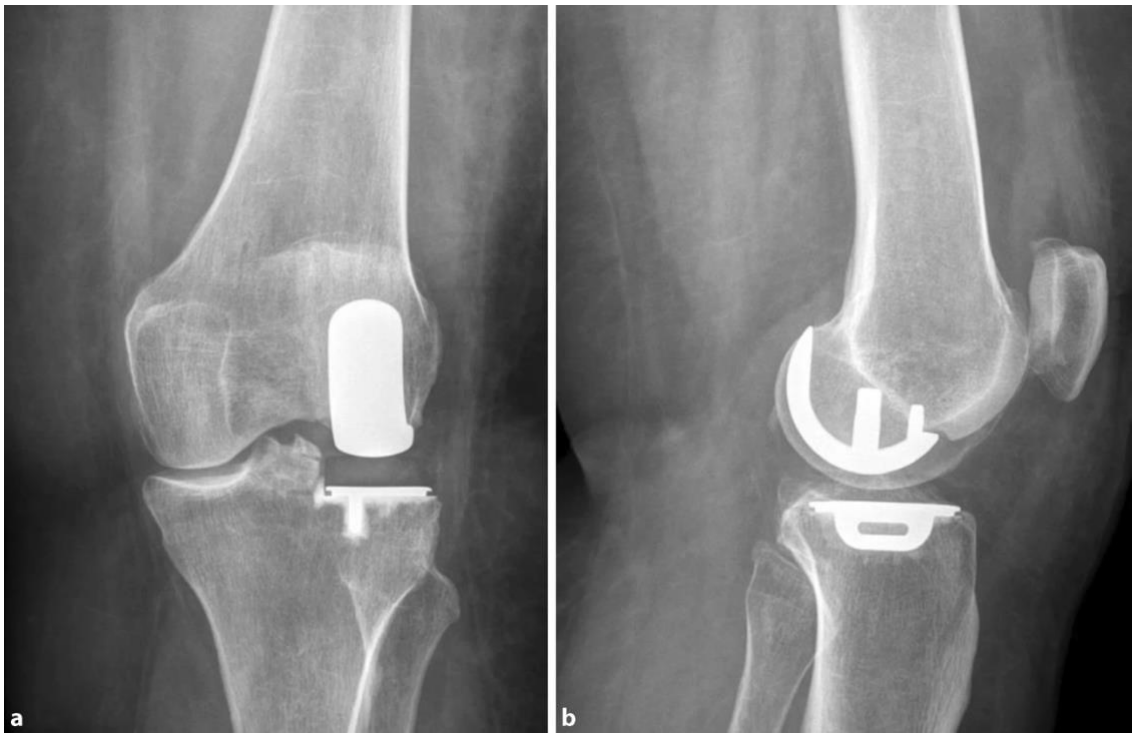

Figure 19: X-ray image in a.-p. (a) and lateral (b) of a lateral unicondylar knee prosthesis with fixed inlay. (35)

4.1 Unicondylar knee prosthesis

In this form of knee prosthesis, only one compartment (medial or lateral) is replaced by the prosthesis. This is the case when only one part of the joint is affected in the context of osteoarthritis (monocompartmental osteoarthritis). The aim of implanting a unicondylar knee prosthesis is to preserve the physiological kinematics, proprioception and stability of the joint by preserving the cruciate ligaments. This type of prosthesis has been increasingly used again in recent years, as publications have shown a similarly good result to the complete surface replacement. The size of the prosthesis can be individually selected so that it can be adapted to the anatomy of the respective knee joint and only the amount of bone is removed that is replaced by the unicondylar knee prosthesis. A distinction is made between fixed and mobile polyethylene inserts, whereby the risk of dislocation should not be ignored. The fully cemented systems are preferred for unicondylar replacements, as sintering of the components and early loosening are observed with the uncemented system. (8,34,35)

4.2 Bicondylar resurfacing prostheses with or without patellar resurfacing

Bicondylar surface replacement prostheses are the most implanted knee prostheses. These knee prostheses only replace the joint surface of the tibia and femur. The guidance of the

joint is still ensured by the capsule-ligament apparatus. The two femoral and tibial components slide on top of each other without a coupling (fixed connection). Therefore, it is important that the capsuloligamentous apparatus is intact in this type of prosthesis (collateral and sagittal ligament stability). If the femoropatellar joint is also affected, the posterior surface of the patella can also be replaced (patellar posterior surface replacement). As already mentioned in the history of knee end prosthetics, three designs are distinguished here: the "round-in-round" principle, the "flat-on-flat" principle and the "round-on-flat" principle . (3,8)

In the case of uncoupled systems, a distinction is also made between posterior stabilised (PS) and cruciate retaining (CR) systems. In the PS procedure, the posterior cruciate ligament is resected. In the CR procedure, the posterior cruciate ligament and the collateral ligament apparatus must be intact. In the PS procedure, an endoprosthesis stabilising in the sagittal plane is used. Indications for the PS procedure are an insufficient posterior cruciate ligament, a higher degree of extension deficit and pronounced dorsal osteophytes that require a dorsal release. (36)

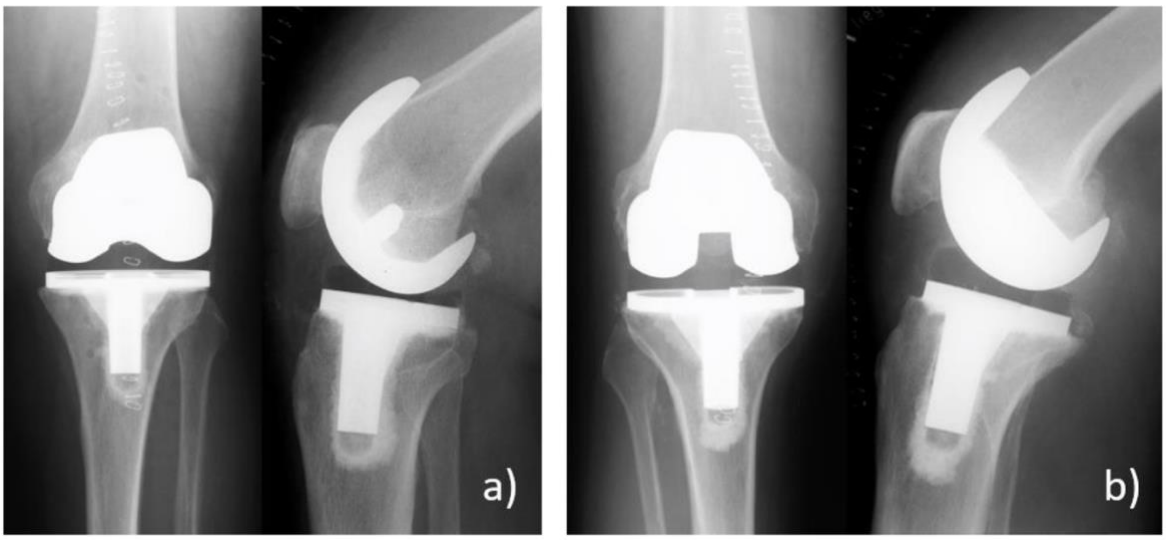

Figure 20: X-ray bicondylar knee prostheses cemented (36)
a. Cruciate retaining (CR) design
b) posterior stabilized (PS) design with inlay pins

There are two different ways of fixing the polyethylene inlays:

1. "mobile bearing
2. "fixed bearing

The mobile-bearing inlays allow the inlay to slide/rotate to a certain extent and thus reduce abrasion. However, the disadvantage of mobile-bearing inlays is that inlay dislocation can occur. (33)

4.3 semi-constrained prothesis

In the case of insufficient ligamentous apparatus and subsequent instability of the knee joint, it may be necessary to stabilise the joint with a partially coupled knee prosthesis. Stabilisation can be achieved by partially coupling the femur and tibia. This is achieved by a central pin which is supported on an enlarged femoral box and thus stabilises the knee joint in varus and valgus direction. (8,33,36)

The aim is to find the perfect degree of coupling, which should be as high as necessary but as low as possible. The greater the degree of coupling, the greater the loads on the anchors and the prosthesis. (37,38)

Compared to the PS system, the partially coupled systems are also equipped with a femur box, which has a pin with a different shape and height compared to the PS system and therefore rotation in the knee joint is only possible to a lesser extent. (39,40)

Indications for this type of prosthesis are primarily revision operations for ligament instability and the treatment of valgus deformities with an insufficient medial collateral ligament. (8)

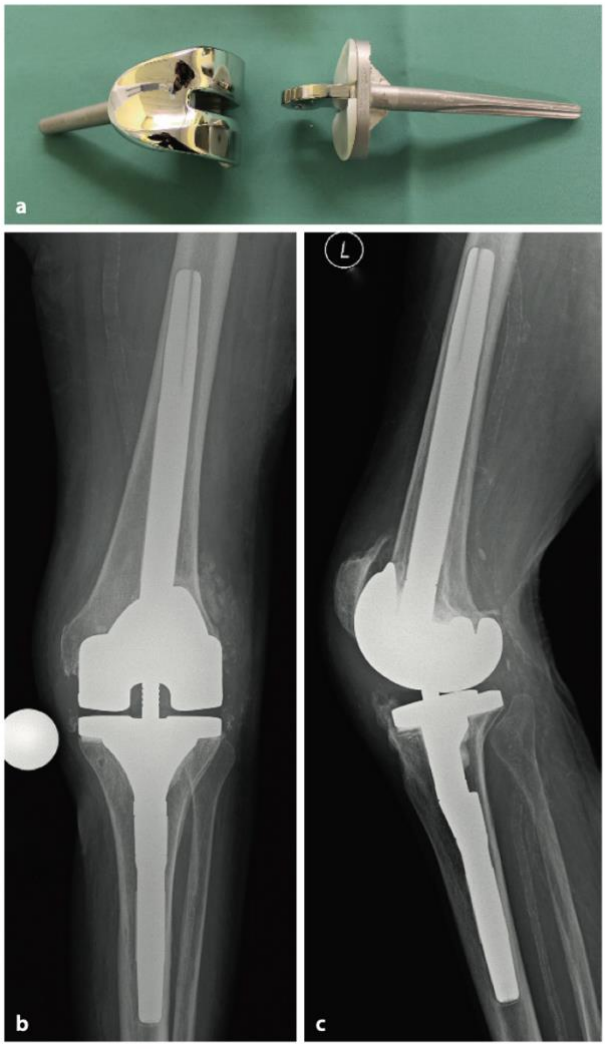

Figure 21: Partially coupled total knee arthroplasty a) Photo; b) and c) X-rays (33)

4.4 Coupled implantation systems ("constrained")

The constrained knee prosthesis is characterised by the fact that the tibial and femoral components of the prosthesis are coupled by a rigid axis. This coupling creates a hinge joint. Indications for this type of prosthesis are severe deformities and unstable joints due to disorders of the ligamentous apparatus as well as mostly knee prostheses due to tumours. This type is used in the revision of knee prostheses. (33,41)

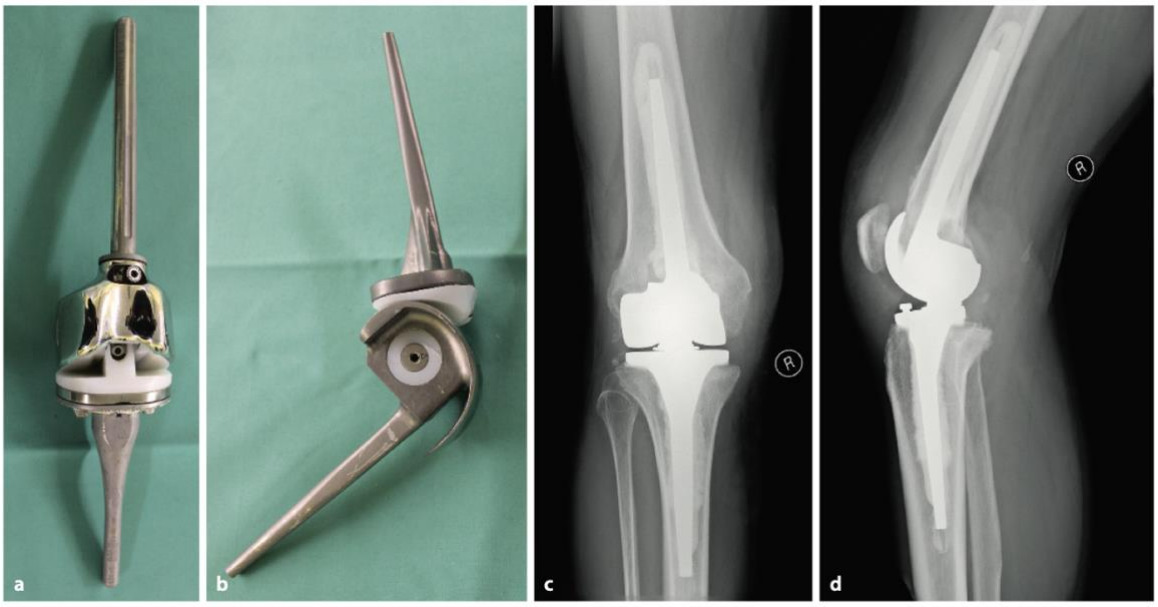

Figure 22: Completely coupled total knee endoprosthesis a) and b) photo; d) and d) X-rays (33)

In German-speaking countries, the most common coupled endoprostheses are the St. George knee, the endorotation knee and the Blauth prosthesis. In addition to these, there are also modular knee prostheses for revision surgery with a tighter coupling (e.g. TC3, MUTARS, ESROM). In contrast to the implantation of surface replacement prostheses, this type of prosthesis does not require consideration of cruciate and collateral ligament stability.(42)

Rotating platforms ("rotating hinges") are also used, which have better kinematics due to the possibility of rotation. This is made possible by securing the coupling mechanism only via the femoral component and inserting a long pin into the tibial component so that rotation in the joint is possible. This technique reduces the load on the implant. (8)

Due to the higher load, it is therefore important that this type of prosthesis is anchored intramedullary with stems. The kinematic disadvantage of this prosthesis is the lack of rolling back of the femur in flexion and an increased contact pressure of the patella. However, coupling reduces friction and abrasion.(37,38)

5 Surgical technique

5.1 Pre-operative planning:

Each prosthesis must be preceded by careful preoperative planning so that any intraoperative problems can be identified and addressed during the operation. Special focus should be placed on the alignment, bone defects and existing soft tissue contractures. For this purpose, an a.p. X-ray of the entire leg, a lateral X-ray of the knee joint and a patellar tangential X-ray should be taken. Malrotations of the distal femur and tibia can often not be detected in the transverse plane on standard radiographs and thus the three-dimensional alignment of the knee joint can often only be inadequately assessed. In this case, a computer tomography can be performed if there is any suspicion. The planning of the approach should also be done preoperatively. (43)

5.2 Surgical approach:

The standard approach for total knee arthroplasty is the median parapatellar approach to the knee joint, which leads from the tibial tuberosity to 2 cm above the superior patellar pole. The medial retinaculum is then visualised subcutaneously and the knee is opened medially parapatellar from the distal tibial tuberosity to the insertion of the medial vastus muscle. The medial vastus muscle is transected parapatellarly and the incision is continued proximally into the tendon of the quadriceps femoris muscle. The incision and the folding away of the patella are intended to avoid damage to the extensor apparatus. The approach offers a good clear view of the knee joint and is therefore used in many situations. It should be mentioned that the approach

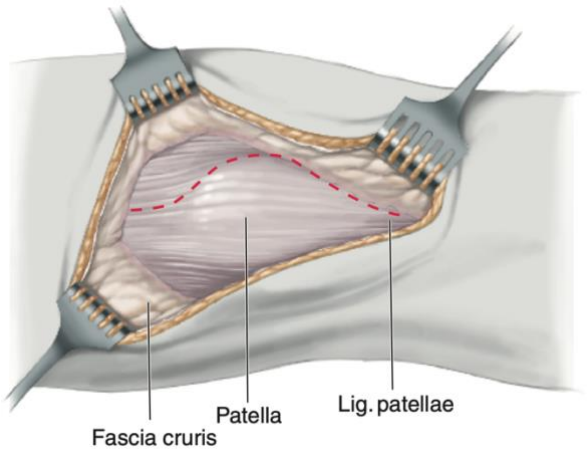

Figure 23: Standard access route for total knee arthroplasty (8)

always depends on the surgeon and the conditions at the joint. In addition to the median approach (standard), there are also minimally invasive approaches to the knee joint such as the midvastus approach or the subvastus approach, which are also used. Common problems associated with the approach are skin necrosis, poor visibility into the joint and therefore suboptimal implantation, tearing of the patella ligament from the tibial tuberosity or severing of the ligament and rupture of the medial ligament.(8,43)

5.3 Surgical technique:

There are two different surgical techniques: the tibia-first technique and the femur-first technique. The choice of method depends on the system used (model) and the associated instrumentation.(8)

5.3.1 Femur-first method:

In the femur-first method, the femur is resected first and then the tibia, which brings a considerable space advantage when resecting the tibia due to the already resected femur. The two bones are prepared independently of each other, which saves bone in contrast to the tibia-first method. The disadvantage of this method is the higher source of errors due to the independent resection of femur and tibia. (8)

5.3.2 Tibia-first method:

The tibia-first method is characterised by starting with the tibial resection and then, building on this, resecting the femur. Since the femur with its condyles is still completely present here, resection of the tibia is more difficult. With this method it is easier to balance the knee joint with the use of spacers or active balance systems. (8)

5.3.3 Procedure of the operation:

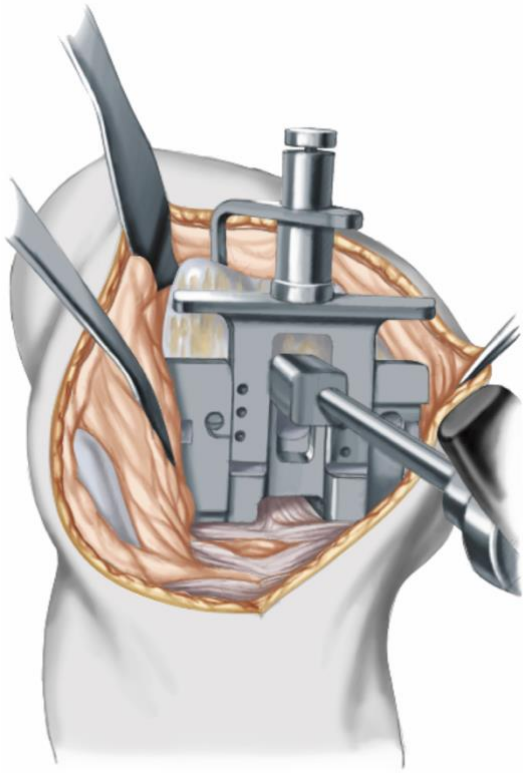

Figure 24: intramedullary femoral alignment (8)

<u>According to the femur-first method.</u>

At the beginning of the operation, hypertrophic parts of the membrana synovialis, Hoffa's fat body, the menisci, the LCA and prominent osteophytes should be removed to allow free access to the joint space.

The femoral medullary cavity is then opened using an intramedullary reamer. A femoral guide is then inserted into the opened femur with the help of an intramedullary alignment rod to determine the femoral section alignment. (8)

Problems with the alignment of the intramedullary axis may occur if the femoral shaft has an abnormal curvature or if a large medullary canal allows insufficient guidance.

The intramedullary rod should be chosen accurately, as a rod that is too thin will affect accuracy and a rod that is too thick will increase the risk of fat embolism. If intramedullary alignment is not possible, there is also the option of extramedullary alignment. (43)

The alignment of the medullary rod with femoral alignment guide can be done using three landmarks. (8):

1. The dorsal condylar line
2. The epicondylar line
3. Whiteside line

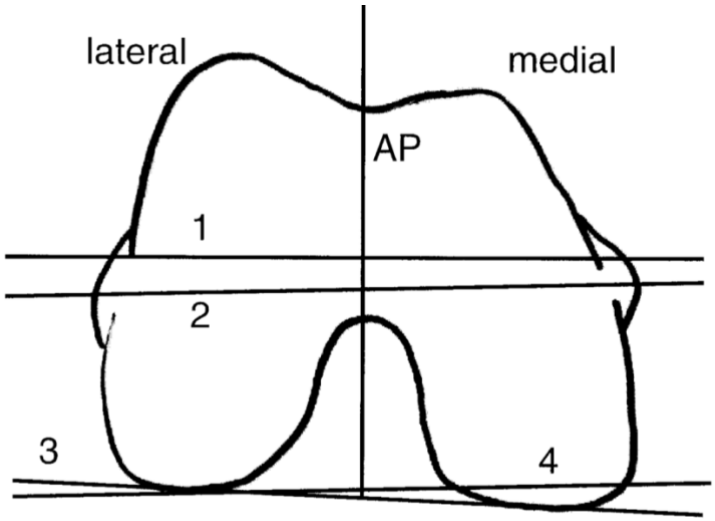

Figure 25: Landmarks of the femur to the femoral alignment void; AP - a.-p. femoral axis, 1st Whiteside line (perpendicular to AP), 2 transepicondylar axis, 3 posterior condylar tangent, 4 posterior condylar tangent + 3 degrees of exter-nal rotation (43)

The femur is now resected through an incision block, which is attached and fixed in place, and the subsequent trial with verification of the correct fit of the prosthesis by means of a trial implant. (8)

The rotational alignment of the femur is particularly important, as important functions of the knee joint are influenced:(43)

- Subluxation or luxation tendencies of the patella in case of internal rotation malposition or insufficient external rotation of the femoral components (too tight tension of the lateral retinaculum)
- Additional loads on the prosthesis parts caused by incorrect rotation can lead to increased wear.
- Asymmetric flexion gap due to faulty rotation with instability in flexion

When aligning the tibia, there are intra- or extramedullary alignment methods. The extramedullary method is often used because the ventral edge of the tibia and the centre of the ankle joint can be easily determined. For intramedullary alignment, the medullary canal of the tibia must be opened. This method of opening the medullary canal is mainly used if the use of a stem is planned or if the anterior edge of the tibia is not sufficiently visible. In extramedullary alignment, the tibial tube is aligned parallel to the tibial anterior edge aiming at the second ray. The resection can be adjusted via sensor systems. (8)

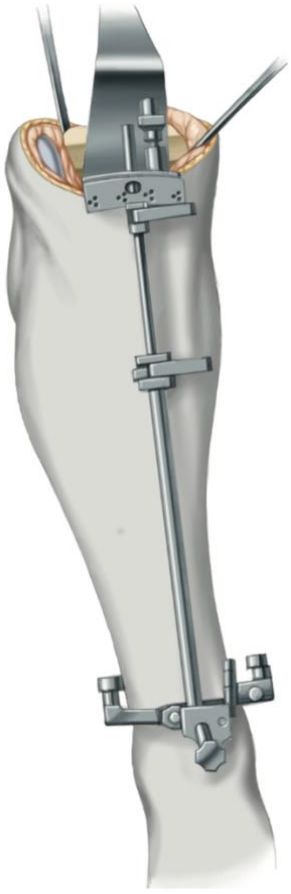

Figure 26: Extramedullary tibial alignment (8)

The tibial resection guide is fixed. An angle in the frontal plane of 90 degrees to the tibial axis is aimed. The resection depth must be determined in addition to the alignment of the saw cut on the tibial plateau and influences both the flexion gap and the extension gap. After the tibial saw cut, the tibial components must be aligned in terms of size, positioning or rotational alignment in the transverse plane, which is important for load transfer and the associated life of the implant. (43)

The aim of the tibial saw cut is to achieve a flexion and extension gap of equal width. The bone drillings, which are important for anchoring, are carried out. The ligamentous apparatus should be stable at maximum flexion and extension (at maximum range of motion). (8)

The last step is to work on the patella to allow it to slide as well as possible. Osteophytes should be removed and adhesions loosened. An incision at the lateral distal patellar pole of the retinaculum can lead to a better gliding by a late-rale loosening. When implanting a patellar back, the thickness of the removed patella must be considered. (8)

If the implant is cemented, the correct cementing technique must also be observed (third generation cementing technique). Before cementing, the implant is prepared with jet lavage

and opened medullary spaces are sealed with bone to prevent the cement from penetrating too far into the medullary space. The cement used is a cooled, vacuum-stirred cement. (8)

5.3.4 Complications

Intraoperative complications include nerve injuries (peroneal nerve), vascular injuries (popliteal artery), periprosthetic fractures, collateral ligament injuries, avulsion of the patellar ligament and posterior cruciate ligament injuries. Perioperative complications include thromboembolism and fat embolism as well as postoperative bleeding. Postoperative complications listed in the literature include aseptic loosening, periprosthetic fractures, wound healing disorders, infections and nerve injuries (due to positioning, bandaging or haematoma). (8)

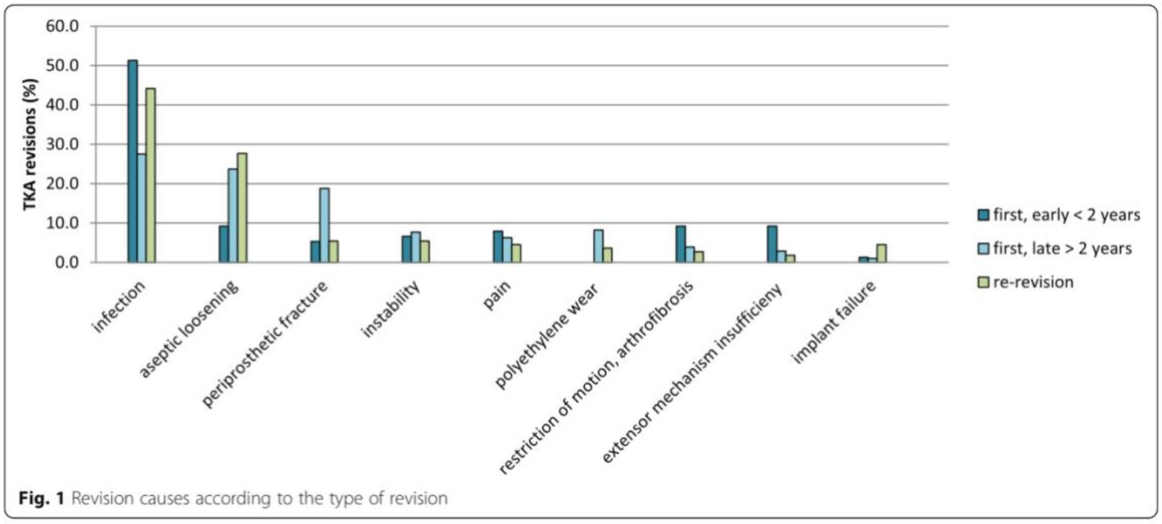

Figure 27: Most frequent causes of revision with classification according to time and re-revision(44)

5.3.4.1 Aseptic loosening

Apart from instability and infections, aseptic loosening is one of the most frequent causes for revision surgery. In addition to infections, this loosening of the prosthesis is also caused by osteolysis due to abrasion (metal and polyethylene). In this case, macrophages phagocytise the abrasion material (BSP polyethylene), which leads to an upregulation of osteoclasts and subsequently to periprosthetic osteolyses. If the periprosthetic loosening and osteolysis are not treated, this can cause a periprosthetic fracture in the area of the bone erosions. The subsequent treatment of such a fracture is costly and has a poor postoperative outcome, which is why early detection of loosening is important. The gold standard in diagnosis is the conventional X-ray. In addition, CT and nuclear medicine examination methods are also available. (45)

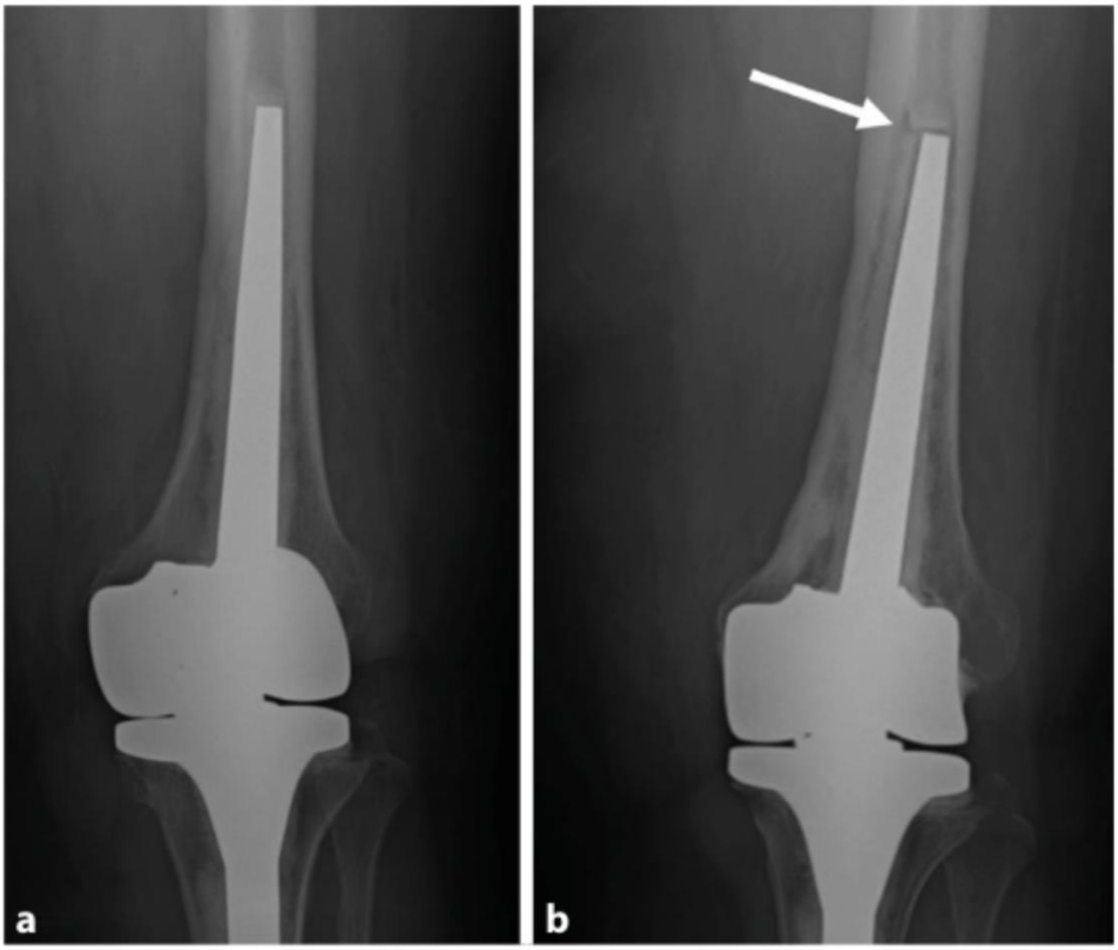

Figure 28: Bicondylar surface replacement: a) No abnormalities b) Lysis seam on the femoral side, which does not completely enclose the prosthesis; in addition, a fracture of the cement mantle at the femoral shaft tip is noticeable (arrow)(45)

5.3.4.2 Periprosthetic infection

Periprosthetic infection is one of the most dangerous complications of total knee replacement and has a catastrophic effect on the quality of life of affected patients. (46)
In primary total knee arthroplasty, periprosthetic infection occurs in 0.5 - 1.9% of cases, in revision procedures in 8-10% of cases. (47)
A distinction is made between early and late infections. The classification is made according to the time of implantation. In the literature, early infections are usually defined as a period of 4-6 weeks after the operation. In the case of an early infection, the prosthesis-preserving procedure is chosen in contrast to prosthesis implantation with one- or two-stage reimplantation, which is preferred in the case of a late infection. Symptoms of an early infection are the classic signs of inflammation (rubor, tumor, dolor, calor, functio laesa). Late infection is often accompanied only by pain. Intraarticular evidence of infection is provided by the detection of germs. In the case of early infection, treatment

includes debridement with inlay replacement and subsequent antibiotic therapy (twice) for 6 weeks. (8)

6 Follow-up treatment

Up to 20% of patients are dissatisfied after total knee arthroplasty, mainly due to pain and reduced function. (48)

The outcome after total knee arthroplasty depends significantly on the type of postoperative rehabilitation. Rehabilitation programmes with an early post-operative walking phase are very effective, with shorter post-operative hospital stays and less use of painkillers. (49)

In 2001, the WHO introduced the concept of the International Classification of Functioning, Disability and Health (ICF). The aim of this concept is to obtain a holistic view of the patient and his/her problems.: (50)

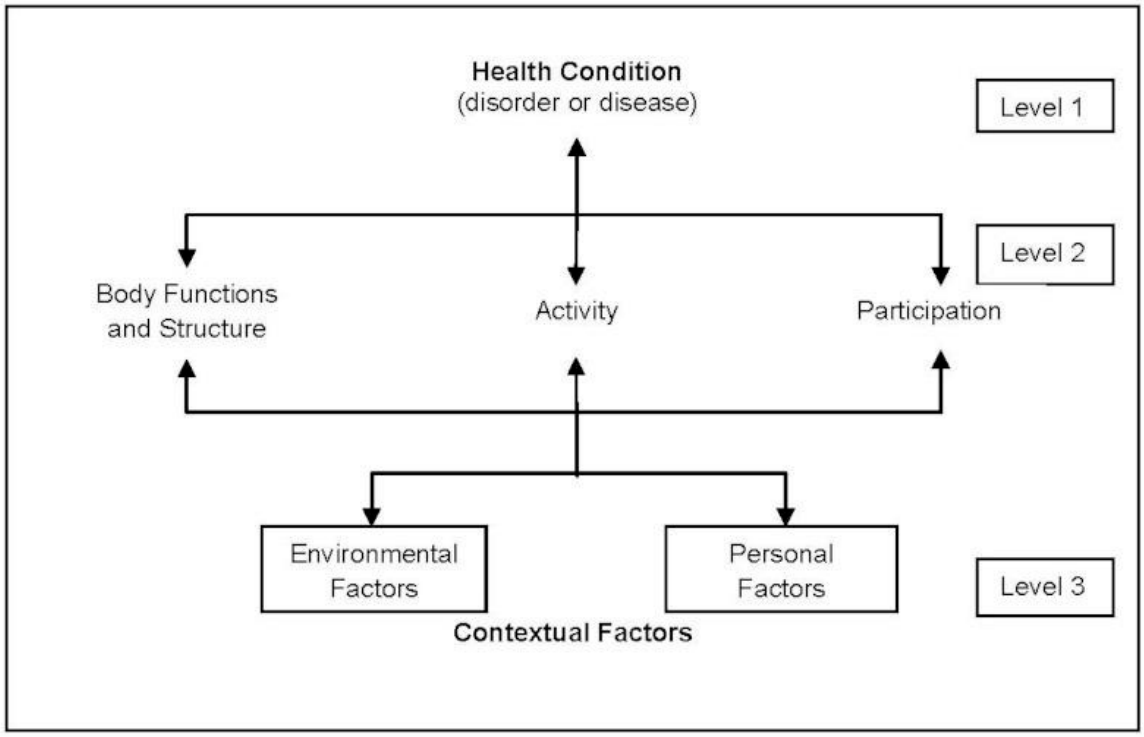

Figure 29: International ICF classification of the WHO (51)

- Structure and Function: (Body Functions and Structure) includes the anatomical structure, i.e. the knee joint. The implantation of a knee prosthesis attempts to reproduce the original structure of the knee joint as far as possible. Deviations and

pathologies of the anatomical structures lead to restrictions in the function of the joint.

- Activity: the limitation of the function of the knee joint leads to changes in motor activity. (for example walking or climbing stairs)
- Participation: Due to the limited activity, the patient is no longer able to participate in social life. (for example, he/she can no longer leave the flat).

With the implantation of a knee prosthesis, one primarily intervenes at the level of the structure, but the follow-up treatment should improve the function as well as the activity and thus in turn influence the participation of the patient.
In addition to these 3 points, the patient's personal factors also play a role (age, comorbidities, performance, motivation).
Environmental factors, such as working conditions or social support, also influence the state of health. (50)

6.1 Clinical scores

The two most common clinical scores used in total knee arthroplasty are the Hospital for Special Surgery Knee Score (HSS Knee Score) and the Knee Society Score (KSS). The KSS is a variation of the HSS score. The HSS score was introduced in the late 1970s and has a total of 7 categories with an achievable total score of 100 points. The 7 categories that are scored are: Pain, Function, Range of Motion, Muscle Strength, Flexion Deformity, Instability and Subtraction Factors. The knee is given an initial score of 0 and addition and subtraction factors are applied. The higher the score, the better the outcome. About 50% of the score is based on the clinical examination and 50% on the patient interview. (52)
For rehabilitation, a shortened, adapted form of these two scores is used. The most common are the Staffelstein score and the EVA rehab score. The following focal points are treated according to a point system. (50):

- pain
- ability walking distance, use of assistive devices
- Joint function (extension, flexion, muscle strength)

6.2 Documentation

Documentation of the findings should always be carried out as part of the follow-up treatment after the operation. The clinical examination should include knee joint mobility, signs of inflammation, blood circulation, motor function, sensitivity and wound closure. These should be recorded in a suitable documentation system. These clinical findings are supplemented by X-rays and laboratory tests as well as by nursing care (pulse, blood pressure, temperature, dressing changes, positioning and mobilisation). (8)

6.3 Physical therapy

Through the operation, the diseased bony parts of the knee joint are replaced, synovectomised and axis-appropriate conditions as well as good ligamentary support are achieved. What remains, however, is an irritated capsule-ligament apparatus and a muscular imbalance, which are additionally irritated by the operation ("second hit"). The goal of physical therapy is primarily to achieve freedom from pain. Once the pain has been eliminated, the main focus is on limiting movement. The medium-term goals of therapy are free extension and 90° bending of the knee joint. In addition to these goals, a decrease in the signs of inflammation (swelling) and a restoration of muscular balance should also be considered as part of the therapy. (8)

To improve basic motor skills, the focus is on mobility and sensorimotor skills (stability and coordination), especially in the early post-operative phase (third, fourth and fifth post-operative weeks). Improvement in endurance and strength already occurs to a small extent in rehab. The improvement of these abilities, however, only occurs at a later point in the rehabilitation process. The range of motion should already be significantly improved after 3-5 weeks. The minimum goal is 0-5-95 degrees according to the Neutral Zero method. Therapy measures include CPM (continuous passive motion), physiotherapy, bicycle ergometry, leg press, exercise baths and detonating muscle treatments.

Pain-related inhibitions of the musculature and protective modifications in the movement sequence caused by arthrosis lead to incorrect storage of movement patterns. The persistent inflammation in the joint also influences mechanoreceptors and leads to disturbances in the sense of position, as well as in the feeling for strength and movement. The operation does not contribute to the improvement, but leads to an additional disturbance of proprioception through, for example, resection of the anterior cruciate ligament. The consequences are insecurity, instability and sensory disturbances ("foreign leg"). As a therapy, one tries to work on optimising the muscle function chains (contraction and stability). This is achieved

by using the leg press, the bicycle ergometer, the sling table or physiotherapy. To improve balance and body equilibrium, soft surfaces, mini-trampolines, therapy gyroscopes and swinging platforms can be used. (50)

6.4 Drug therapy

The most important area of drug therapy is pain therapy. In addition to pain therapy, anticoagulation is also an important pillar in postoperative therapy after total knee arthroplasty.

6.4.1 Pain therapy

Post-operative pain management allows the patient to be mobilised quickly after the operation. This reduces the length of hospital stay and improves the patient's overall recovery. It also reduces the risk of postoperative thromboembolic diseases, nosocomial infections. The literature shows that regional methods of pain management are superior to intramuscular and intravenous methods. (53)

The following points are cited in the literature as advantages of regional anaesthesia over the systemic procedure: (53)

- Less blood loss
- Better analgesia at rest as well as in motion
- Faster and better mobilisation
- Improved rehabilitative outcome and shorter rehabilitation time
- Lower risk of thrombosis
- Greater patient satisfaction
- Shorter hospital stay

Postoperative analgesia must be individually adapted to the extent of the postoperative pain. Inadequate postoperative analgesia can lead to chronic pain. (53)

Various studies have shown that chronic pain is dependent on several factors. These include clinical factors, psychosocial factors, patient characteristics and perioperative factors. The biggest influencing factors were pain at other sites, catastrophising and depression. (54)

For direct postoperative pain therapy (1 week postoperatively) come:

- Peripheral conduction anaesthesia, especially for early rest pain or complex exercise pain in early mobilisation.
- the femoral nerve catheter
- the psoas compartment block with anterior ischial catheter
- As well as systemic acute pain therapy.

In the post-acute phase (after one week!), therapy can be structure related. A distinction is made between somatic (muscular or ligamentary) and neurogenic pain. For somatic muscular pain, mainly muscle relaxants are used. As muscle tension is accompanied by inflammation, short-term treatment with anti-inflammatory drugs is also possible. In ligamentary somatic pain, the focus is on inflammatory pain. Here, therapy with non-steroidal anti-inflammatory anti-inflammatory drugs is recommended. Neurogenic pain is mainly caused by irritation of the peroneal or saphenous nerve and is treated with stronger pain medication (according to the WHO grading scheme - opioids). In addition, antidepressants or antiepileptics can also be used here. (8)

6.4.2 Anticoagulation

The prevention of embolisms and thromboses is an important cornerstone in post-operative therapy. Before the operation, it is important to exclude already existing blood coagulation disorders by means of a laboratory examination. The operation is usually followed by a low-dose heparin therapy for 11-14 days. This is combined with early mobilisation and the wearing of compression bandages and anti-thrombosis stockings. (8)

7 Material and Methods

7.1 Literature Selection Pubmed

In May 2022, the free-search-engine PubMed was searched for the articles regarding the "Attune Knee". The following search terms were used in the PubMed Advanced Search Builder: "(Attune Knee) or (Attune Arthroplasty)". 78 Scientific articles were found. After the search was completed, papers with no direct reference to the topic, case reports, reviews and older meta-analysis have been excluded. (74 articles). The remaining scientific articles (4 articles) were then checked for their eligibility to join the study. Each study was evaluated separately.

7.1.1 Study selection and outcomes - Pubmed:

Studies were considered suitable for qualitative analysis if they met the following criteria:

- The used implant must have been an Attune-Knee-System
- Follow-up time had to be 2 months or longer
- Number of people receiving Attune-Knee-Replacement
- The data had to be written in English or German and published in a peer-reviewed journal
- The studies had to be published between 2012 and 2022 (if there had been multiple reports from the same study group published in this period, the report with the longest follow up period was included)

Exclusion criteria were:

- Case reports
- Reviews
- Older meta-analysis
- Imaging studies
- Cadaveric studies
- Studies with a follow up less than 2 months

7.2 Data Extraction – Pubmed:

An independent data review of all articles that meet the inclusion criteria (3) took place by two authors (A.W. and U.W.) Following criteria were assessed:

- Authors
- Year of publication
- Duration of follow up time
- Country
- Study design
- Journal
- Baseline
- Information of participants (median age, sex, BMI)
- Type of prothesis
- Surgical technique
- Revision number (if published)

Disagreements were resolved by consensus discussion between the 2 reviewers and the senior author.

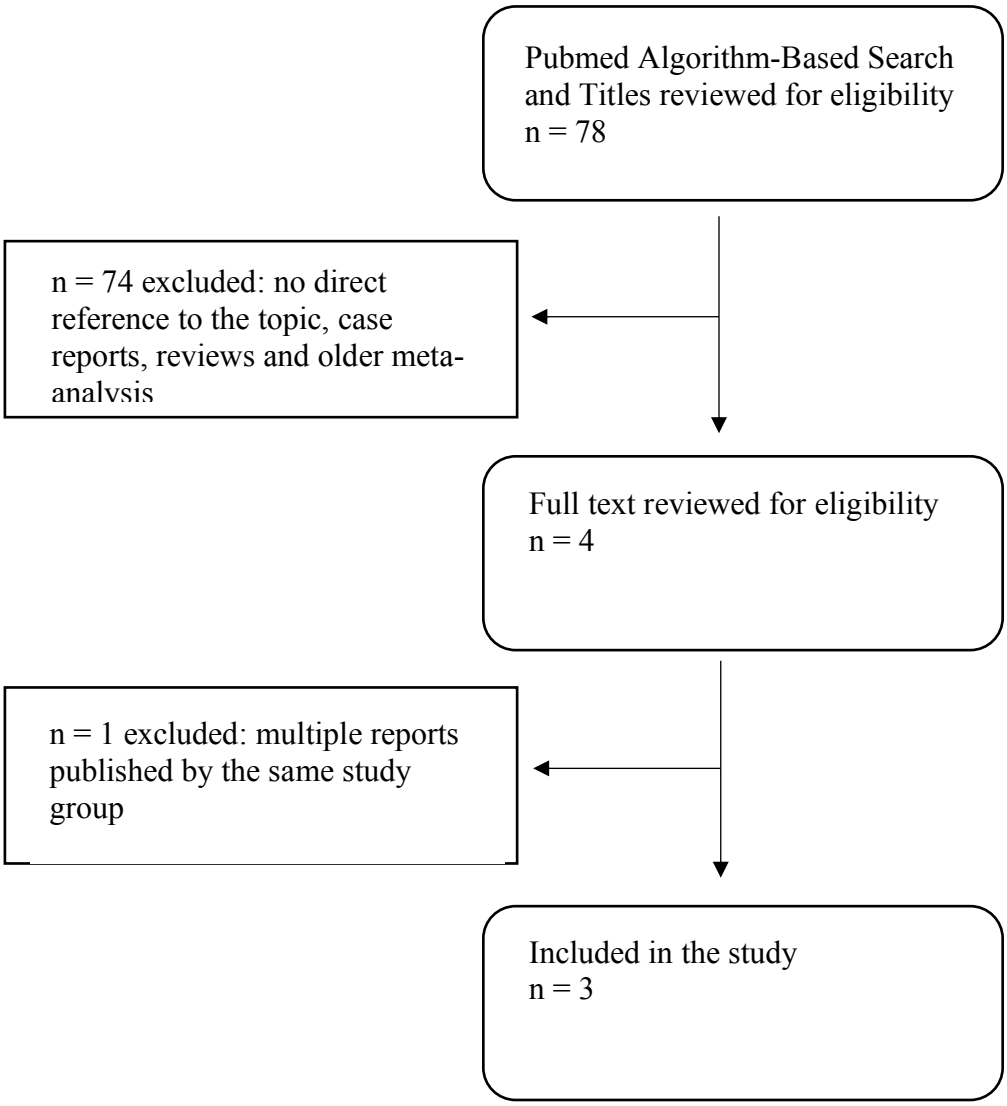

Figure 30: Flow chart of the article selection process from Pubmed

No.	Autor	Name	Follow up time	Study type	Year	No of patients
1	Kaptein BL et al	A randomized controlled trial comparing tibial migration of the ATTUNE cemented cruciate-retaining knee prosthesis with the PFC-sigma design	24 months	single-blinded randomized, noninferiority study	2020	38
2	Moorthy V et al	Similar postoperative outcomes after total knee arthroplasty with measured resection and gap balancing techniques using a contemporary knee system: a randomized controlled trial	24 months	prospective randomized controlled trial	2020	100
3	Ruckenstuhl P et al	No difference in clinical outcome, pain, and range of motion between fixed and mobile bearing Attune total knee arthroplasty: a prospective single-center trial	46 months	prospective single center cohort study	2022	67

Table 1: Articles found on Pubmed

8 Literature Selection Cochrane

In May 2022 the Cochrane library was searched for the Trials regarding the “Attune Knee”. The following search terms were used: “Attune Knee”, “Attune Arthroplasty” 16 Trials matched with this search terms. Trials with no direct reference to the topic as well as already found Trials on Pubmed have been excluded (4 Trials). The remaining trials (12 Trials) were then checked for their eligibility to join the study. Each trial was evaluated separately.

8.1 Study selection and outcome - Cochrane

12 trials were systematic reviewed by the authors and the same inclusion and exclusion criteria applied as mentioned. Of all viewed trials, 1 trial met the inclusion criteria. 11 trials were excluded after reading the title and abstract and applying the inclusion criteria. (7 trials are still recruiting and 4 trials are already completed, but no result have been posted). One trial met the inclusion criteria and were included in the study.

8.2 Data Extraction – Cochrane:

An independent data review of all trials that meet the inclusion criteria (1) took place by two authors (A.W. and U.W.) Following criteria were assessed:

- Authors
- Year of publication
- Duration of follow up time
- Country
- Study design
- Journal
- Baseline
- Information of participants (median age, sex, BMI)
- Type of prothesis
- Surgical technique
- Revision number (if published)

Disagreements were resolved by consensus discussion between the 2 reviewers and the senior author.

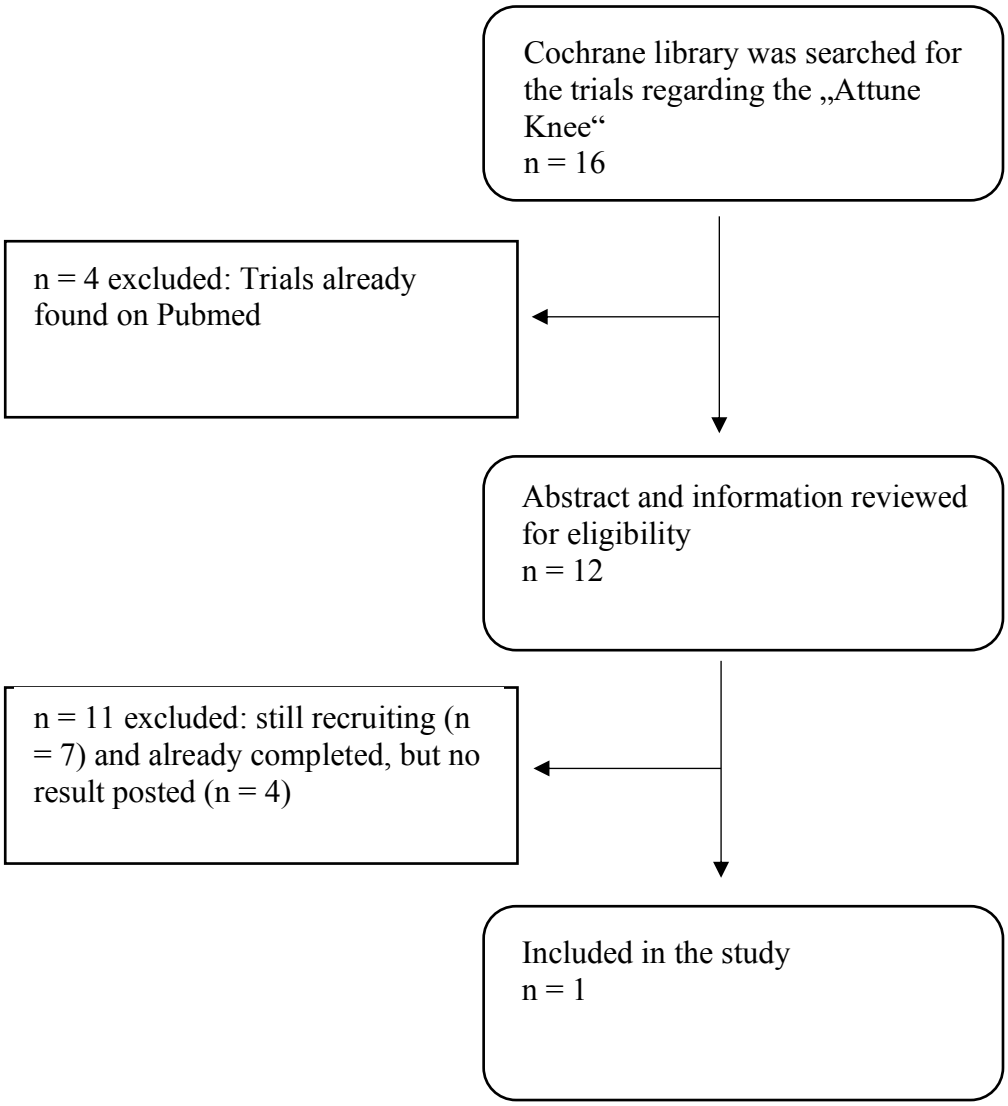

Figure 31: Flow chart of the trials selection process from Cochrane

No.	Autor	Name	Follow up time	Study type	Year	No of patients
1	Y Ashraf et al	Has the modern design of Attune total knee replacement improved outcome in patients with isolated patellofemoral arthritis?	24 months	prospective trial	2020	42

Table 2: Trials found on Cochrane

9 Literature Selection for Arthroplasty Registers

On the 28 of May 2022 the NORE (Network of Orthopaedic Registries of Europe)(55) was checked for existing registers to include them in our study. In Addition, a free-hand search was performed using the searching terms: "(arthroplasty register) or (knee arthroplasty register)" at the searching engine "Pubmed" and "Google". This method has been described in various studies. (56,57)

Register have had to meet following criteria to be included:

1. Reports had to be publicly available
2. Reports had to be written in German or in English
3. The Attune-Knee-System must be mentioned in the report
4. Data had to be consistently reported for at least three consecutive years 2021-2020-2019 (date of retrieval 08.06.2022)
5. Reports hat to be not older than 5 years

Reports not available in German or English or reports with incomplete data were excluded from the study.

Initially, 26 Arthroplasty registers were found via the NORE Website and 5 via the free-hand search.

9.1 Register selection and outcomes

After initial identification of 31 knee arthroplasty register, 11 registers (Danish Knee Arthroplasty Register, Catalan Arthroplasty Register (RACat), NRKN – Czech Republic Arthroplasty Register, The Hungarian Arthroplasty Register, The National Arthroplasty Register of Slovenia (RES), French Arthroplasty Register, Romanian Arthroplasty Register, Saudi Arabia Arthroplasty Registry, Egyptian Community Arthroplasty Register, Japanese Arthroplasty Register JAR, Lithuanian Arthroplasty Register) were excluded as they were not available in German or English language. 1 Register (RIPO – Register for Orthopaedic Prosthetic Implantation) was not publicly available. 6 Registers (Belgian National Arthroplasty Registry, Scottish Arthroplasty Project Report, Dutch Arthroplasty Register, Finnish National Arthroplasty Register, Canadian Joint Replacement Registry,

Italian Arthroplasty Registry) were excluded as they did not consider the Attune-Knee-System. 3 Registers (RPA – Portuguese National Arthroplasty Register, SAR – Slovakian National Arthroplasty Register, PNJR – Pakistan National Joint Registry) were excluded as the Data had not been consistently reported. Due to exclusion and inclusion criteria, 23 register were excluded from the study.

All arthroplasty registers that satisfied the inclusion criteria presented their data in the form of an annular report for each year separately. Finally, 10 registers (Norwegian National Arthroplasty Register, Swedish Knee Arthroplasty Register, EPRG German Arthroplasty Register, Swiss Arthroplasty Register, NJR National Joint Registry for England, Wales & Northern Ireland, Valdoltra (Slovenia) Arthroplasty Register, American Joint Replacement Registry (US AJRR), New Zealand Joint Registry, AOA National Joint Replacement Registry – AUSTRALIA, Irish National Orthopedic Register) offered sufficient data.

9.2 Data Extraction – Arthroplasty Registries:

The Register that fulfilled the inclusion criteria were searched for the annual report from 2019, 2020 or 2021. The latest annual report was extracted with respect of:

- the number of total TKA implantations of the Attune Knee performed
- the operation method (cruciate-retaining/posterior-stabilized, mobile/fixed bearing, cemented/uncemented, Patella resurfacing)
- the number of hospitals documenting
- the median age at implantation
- the gender
- the BMI
- the cumulative revision rates
- the total number of revisions
- the revision rate after 1,2,3,4,5 years

These data were analyzed for each arthroplasty register and compared with each other. Disagreement was resolved by discussing or, if necessary, by the decision of the senior author according to the PRISMA guidelines. (58)

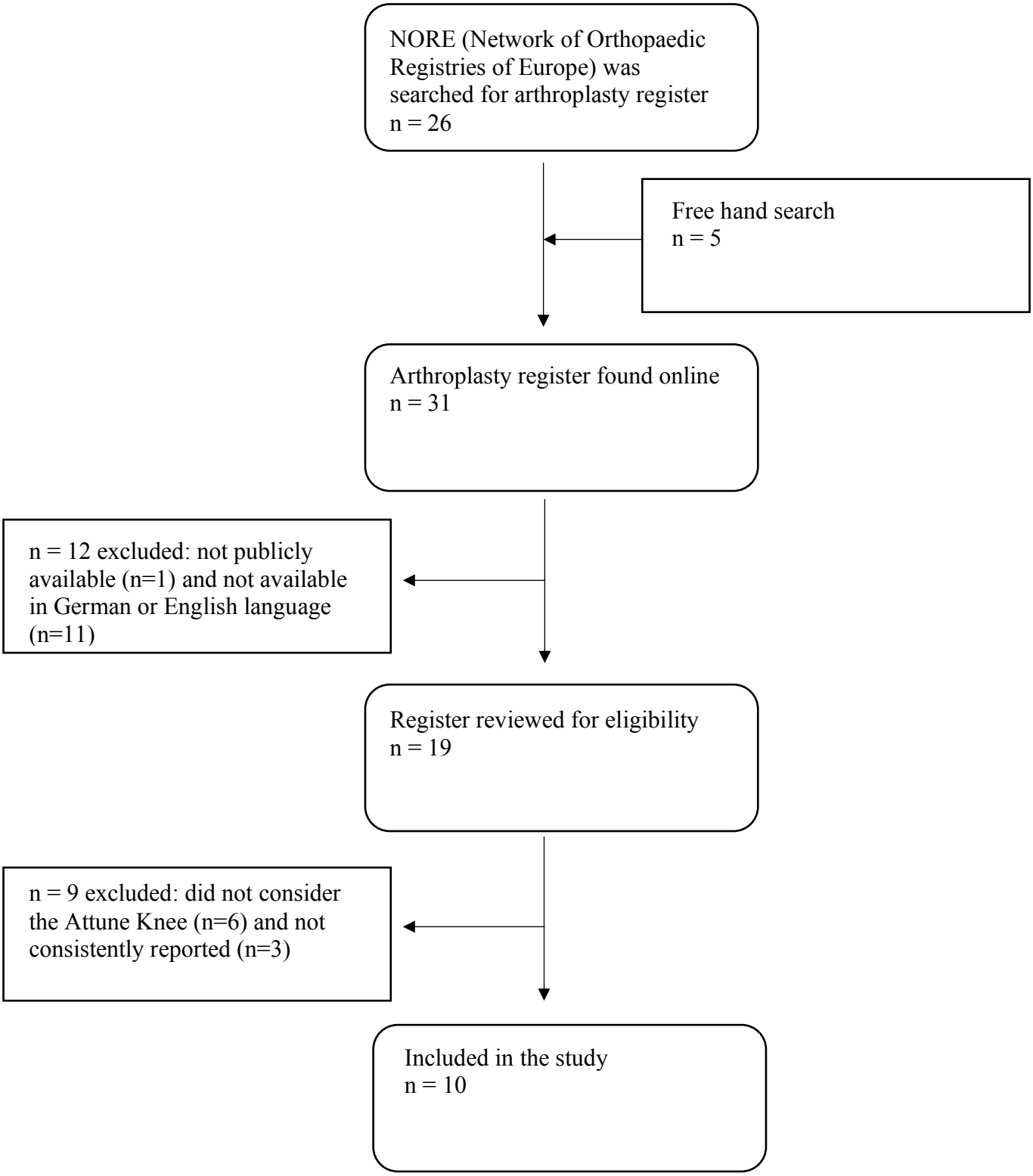

Figure 32: Flow chart of the register selection process from NORE (Network of Orthopaedic Registries of Europe) and free-hand search

Via NORE Website:

Name	Inclusion or exclusion	Reason
Belgian National Arthroplasty Registry	Exclusion	Attune Knee System not included
The Danish Knee Arthroplasty Register	Exclusion	Language
Norwegian National Arthroplasty Register	Inclusion	
Scottish Arthroplasty Project Report	Exclusion	Attune Knee System not included
Swedish Knee Arthroplasty Register	Inclusion	
Catalan Arthroplasty Register (RACat)	Exclusion	Language
EPRG German Arthroplasty Register	Inclusion	
Dutch Arthroplasty Register	Exclusion	Attune Knee System not included
RPA – Portuguese National Arthroplasty Register	Exclusion	Not consistently reported
SAR – Slovakian National Arthroplasty Register	Exclusion	Not consistently reported
Swiss Arthroplasty Register	Inclusion	
NRKN – Czech Republic Arthroplasty Register	Exclusion	Language
Finnish National Arthroplasty Register	Exclusion	Attune Knee System not included
The Hungarian Arthroplasty Register	Exclusion	Language
RIPO – Register for Orthopaedic Prosthetic Implantation	Exclusion	not publicly available
The National Arthroplasty Register of Slovenia (RES)	Exclusion	Language
French Arthroplasty Register	Exclusion	Language

NJR National Joint Registry for England, Wales & Northern Ireland	Inclusion	
The Romanian Arthroplasty Register	Exclusion	Language
Valdoltra (Slovenia) Arthroplasty Register	Inclusion	
American Joint Replacement Registry (US AJRR)	Inclusion	
New Zealand Joint Registry	Inclusion	
AOA National Joint Replacement Registry – AUSTRALIA	Inclusion	
PNJR – Pakistan National Joint Registry	Exclusion	Not consistently reported
Canadian Joint Replacement Registry	Exclusion	Attune Knee System not included
Saudi Arabia Arthroplasty Registry	Exclusion	Language

Table 3: Registers found on the NORE Website with inclusion and exclusion (reason)

Via free-hand search:

Name	Inclusion or exclusion	Reason
Italian Arthroplasty Registry	Exclusion	Attune Knee System not included
Egyptian Community Arthroplasty Register	Exclusion	Language
Irish National Orthopaedic Register	Inclusion	
Japanese Arthroplasty Register JAR	Exclusion	Language
Lithuanian Arthroplasty Register	Exclusion	Language

Table 4: Registers found via free-hand search with inclusion and exclusion (reason)

10 Outcome measures:

The main objective was to find out differences between the clinical studies found on Pubmed and Cochrane and the registers as well as differences within the registers and clinical studies.

Due to heterogeneous data and unpublished revision rates in studies and trails from Pubmed and Cochrane the main objective was to find differences in the additional information of participants (median Age, sex, BMI) and to compare this information to the data extracted from the registers.

Within the registries, a comparison was made between:

- the median Age
- Gender M/W
- Differences between countries
- Revision rates after 1,2,3,4,5 years
- total or relative revision Rate
- the technique (CR/PS&FB/MB)

11 Results

11.1 Results Age, Gender, BMI (Body Mass Index)

The median age, median BMI and the gender for Attune-Arthroplasty published by the German Arthroplasty Registry (EPRD), the National Joint Registry England, Wales, Northern Ireland, the Isle of Man, States of Guernsey (NJR) and in the study's of Kapstein BL et al, Moorthy V et al, Ruckenstuhl P et al and Y Ashraf et al were included in the calculation. The arithmetic mean was used to calculate the mean values (The number of implantations was not considered).

Study/register	Median Age in Years	Gender M in%	Gender W in %	Median BMI
Kaptein BL et al	69	47,3	52,6	29
Moorthy V et al	67,25	22	76	28
Ruckenstuhl P et al	66,6	38.7	61.3	30,55
Y Ashraf et al	64	47,6	52,4	29,9
EPRD	70,5	37,1	62,9	No data
NJR	69,6	43,3	56,7	No data

Table 5: Results Age, Gender and BMI

If multiple gender and age data were available in a study/register, the arithmetic mean was calculated.

11.1.1 Age

The median age of patients who received an Attune Knee was 67,8 years. A difference can be seen between the studies and the registers. The median age in the studies is 66,7 years, 3,3 years less than in the registers (70 years). It should be noticed that significantly fewer individuals were included in the Pubmed studies than in the EPRD and NJR registers.

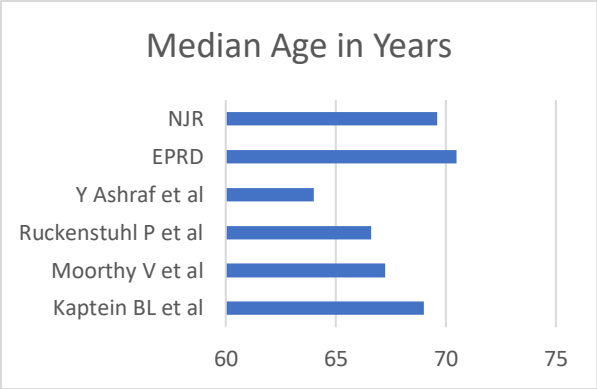

Figure 33: Median age in years

11.1.2 BMI

The BMI (Body Mass Index) is the most used measure of anthropometric heigh and weight characteristics in adults. BMI has four categories: underweight, normal, overweight, and obese. (59)

The median BMI (Body Mass Index) of patients who received an Attune Knee is 29,4 kg/m^2.

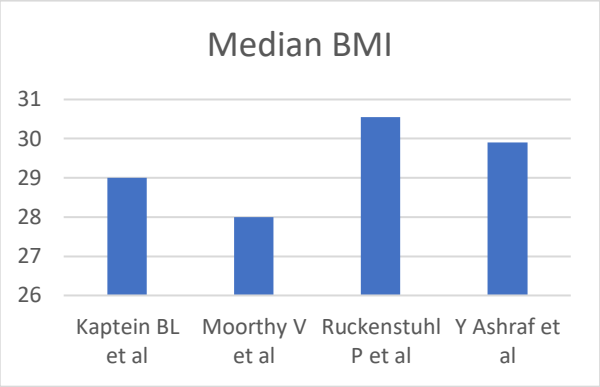

Figure 34: median BMI

In Wester population-based studies, generally the median BMI is about 24 to 27 kg/m^2 in the normal population. (59,60)

For BMI, only data from Pubmed studies were used, as registers did not provide Attune specific data here.

11.1.3 Gender balance

The studies/registers shows that more women than men received total knee arthroplasty (Attune). In all studies/registers in which Attune Knee was mentioned, the average was 60% women and 40% men. The data are very heterogeneous, especially the study by Moorthy V et al with a female proportion of 70%. The studies by Kapstein BL et al (M 47.3%; W 52.6%) and Y Ashraf et al (M 47.6%; 52.4%) show similar gender distributions. The study by Ruckenstuhl P et al (M 38.7%; W 61.3%) published higher data than those of Kapstein BL et al and Y Ashraf et al..

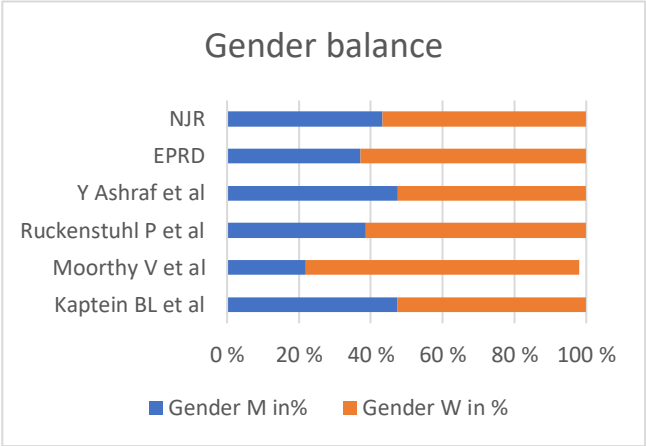

Figure 35: Gender Balance

11.2 Results Revision:

The revision rate for Attune-Arthroplasty after one, three and fifth years are published by the German Arthroplasty Registry (EPRD), the Swiss National Knee Joint Registry (SIRIS), the American Joint Replacement Registry (AAOS), the Australien Orthopaedic Ass. National Joint Replacement Registry (AOANJRR) and the National Joint Registry England, Wales, Northern Ireland, the Isle of Man, States of Guernsey (NJR). All prothesis used in table (6) are cemented and were implanted in 2020 unless otherwise mentioned. If no distinction was made between mobile bearing/fixed bearing or cruciate retaining/posterior stabilization, the suffix "All" was used.

National registry	PS/CR	FB/MB	Total number of follow-up arthroplasties	Revision Rate after 1 year	Revision Rate after 3 years	Revision Rate after 5 years
EPRD	CR	FB	5802	1,6	3,1	3,6
	CR	MB	1417	1,4	2,8	3,2
	PS	FB	1362	2,5	4	5,9
	PS	MB	417	1	1,4	No data
SIRIS	All	All	2954	1,7	5	6,3
AAOS[1]	PS	All	37719	0,69	1,55	2,06
	CR	All	17426	0,52	1,08	1,4
NJR[2]	CR	FB	18550	0,37	1,43	1,9
	CR	MB	3493	0,15	0,88	1,47
	PS	FB	10159	0,45	1,62	2,48
AOANJRR[3]	CR	All	18176	1	2,4	3,1
	PS	All	8840	0,9	2	2,7

1 cumulative revision rates from 2012-2019

2 cumulative revision rates from 2003-2020

3 cumulative revision rates from 1999-2020

Table 6: Data from clinical knee replacement registries (Revision rates after 1,3 and 5 years)

National registry	Total number of follow-up arthroplasties	Year Data	Cumulative revision rate	Total number of Revisions
SKAR	114	2009-2018	2,14	
VAR	182	2002-2020		0
NZOA	12075	1999-2020		193
NOCA[3]	672	2014-2019	5,3	

3 cementless included

Table 7: Data from clinical knee replacement registries (cumulative revision rates or total number of revisions)

National registry	Revision Rate after 1 year	Revision Rate after 3 years	Revision Rate after 5 years
EPRD	1,625	2,825	3,175
SIRIS	1,7	5	6,3
AAOS[1]	0,605	1,315	1,73
NJR[2]	0,323	1,31	1,95
AOANJRR[3]	0,95	2,2	2,9

1 cumulative revision rates from 2012-2019

2 cumulative revision rates from 2003-2020

3 cumulative revision rates from 1999-2020

Table 8: Revision Rates countries

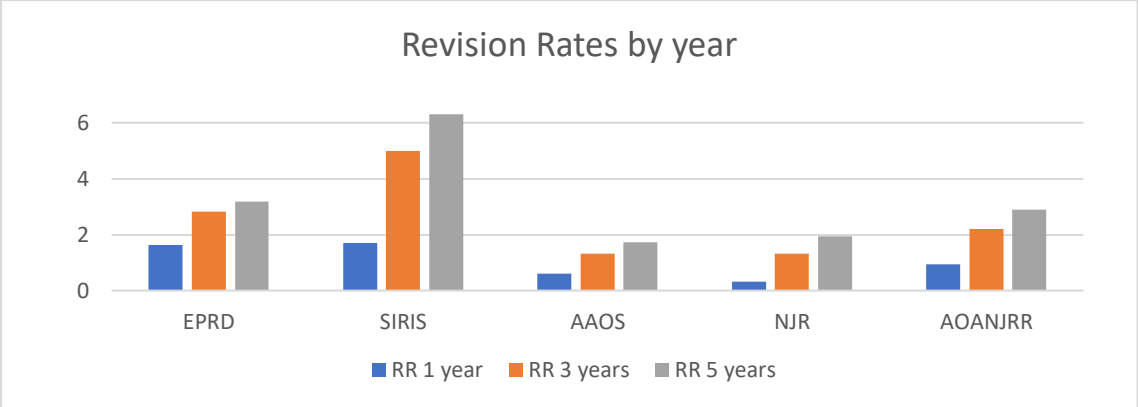

Figure 36: Revision rates per year (countries)

Those countries that have published a classification of revision rats by year show heterogeneity in the data. The highest revision rates without differentiation between posterior stabilization/cruciate retaining or mobile bearing/fixed bearing were published in Switzerland (SIRIS) (after 1 year 1.7%, 3 years 5% and 5 years 6.3%). The second highest rates were published in Germany (EPRD) (after 1 year 1.6%, 3 years 2.8% and 5 years 3.2%). The Swiss registry (SIRIS) shows high revision rates up to 6,3% after 5 years. After the first year, Germany and Switzerland still show relatively similar revision rates of 1.6% (Germany) and 1.7% (Switzerland). After 5 years, the data are very heterogeneous with 3.2% in Germany (EPRD) and 6.3% in Switzerland (SIRIS). The revision rates in America (AAOS) and England, Wales, Northern Ireland (NJR) show quite similar revision rates.

The registers of Sweden (SKAR) and Irish National Arthroplasty register (NOCA) have cumulative revision rates of 2,14% (Sweden) and 5,3% (Norway). New Zealand has a total number of revisions of 193 for 1207 Attune protheses implanted. In Slovenia (Valdoltra - VAR) 0 revisions were performed for 182 implanted Attune protheses.

11.3 Results Fixed Bearing (FB) and Mobile Bearing (MB)

A comparison of the revision rates between the fixed bearing and mobile bearing systems was carried out in those countries that published sufficient data. Revision rates from Germany (EPRD), England, Wales, Northern Ireland (NJR) and New Zealand (NZOA) were used. If no distinction was made between mobile bearing/fixed bearing or cruciate retaining/posterior stabilization, the suffix "All" was used.

National registry	PS/CR	FB/MB	Total no. of follow-up arthroplasties	Revision Rate after 1 year	Revision Rate after 3 years	Revision Rate after 5 years	No of Revisions total
EPRD	CR	FB	5802	1,6	3,1	3,6	
	PS	FB	1362	2,5	4	5,9	
NJR[2]	CR	FB	18550	0,37	1,43	1,9	
	PS	FB	10159	0,45	1,62	2,48	
NZOA[4]	All	FB	4941				73

2 cumulative revision rates from 2003-2020

4 data from 1999-2020

Table 9: Results FB

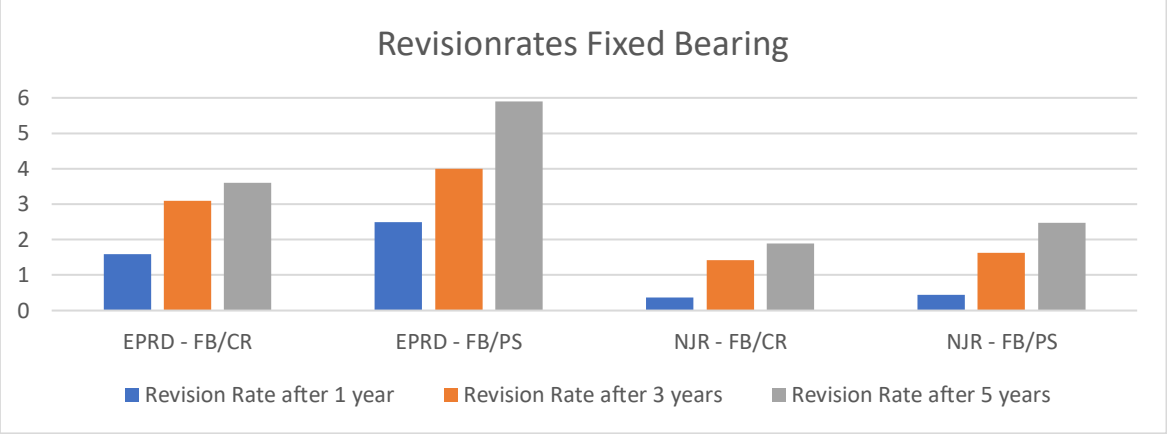

Figure 37: Revision rates fixed bearing

There is an increase in the revision rates for both the CR and PS techniques after 1, 2 and 5 years. A comparison of revision data between countries showed that Germany (EPRD) has

higher revision data compared to England, Wales and Northern Ireland (NJR) for both the fixed bearing/cruciate retaining combination (EPRD CR/FB after 1 year 1.6%, after 3 years 3.1% and after 5 years 3.6%, NJR CR/FB after 1 year 0.37%, after 3 years 1.43% and after 5 years 1.9%) and for the fixed bearing/posterior stabilization combination (EPRD FB/PS after 1 year 2.5%, after 3 years 4% and after 5 years 5.9%)(NJR FB/PS after 1 year 0.45%, after 3 years 1.62% and after 5 years 2.48%). It was found that in FB, the CR surgical technique has an advantage over the PS surgical technique.

National registry	PS/CR	FB/MB	Total number of follow-up arthroplasties	Revision Rate after 1 year	Revision Rate after 3 years	Revision Rate after 5 years	No of Revisions total
EPRD	CR	MB	1417	1,4	2,8	3,2	
	PS	MB	417	1	1,4	No data	
NJR[2]	CR	MB	3493	0,15	0,88	1,47	
NZOA[4]	All	MB	5995				113

2 cumulative revision rates from 2003-2020

4 data from 1999-2020

Table 10: Results MB

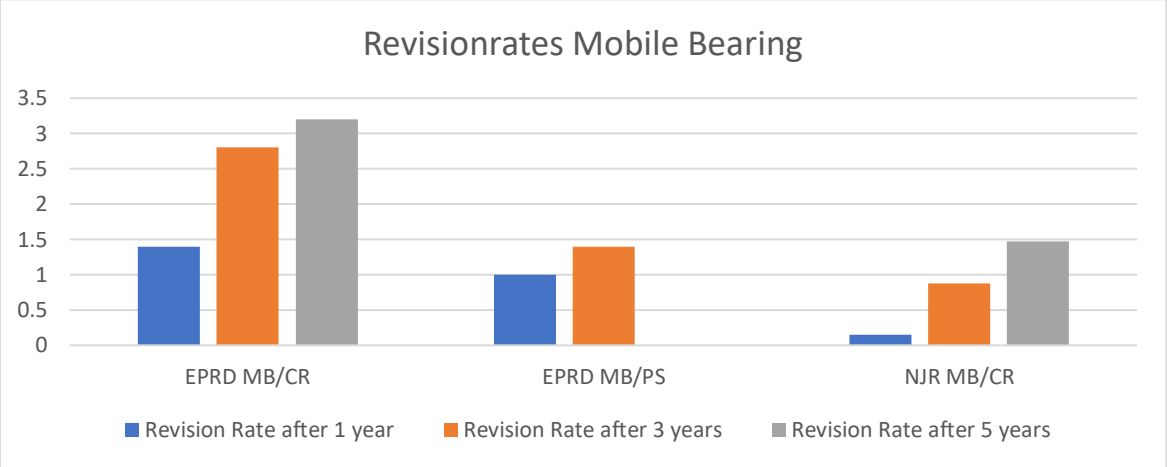

Figure 38: Revision rates mobile bearing

As can be seen in Table (10), the revision rate increases after 1,3 and 5 years for both CR and PS technique in implanted MB system. For the mobile bearing/cruciate retaining variant, higher revision rates were also published in Germany (EPRD) than in England, Wales and Northern Ireland (NJR). (EPRD - CR/MB 1 year 1.4%, 3 years 2.8% and 5 years 3.2%) (NJR - CR/MB 1 year 0.15%, 3 years 0.88% and 5 years 1.47%).

<u>Comparison mobile bearing and fixed bearing</u>

A comparison of the design principles between mobile bearing and fixed bearing shows an advantage for mobile bearing over fixed bearing in the registers of Germany (EPRD) and England, Wales and Northern Ireland (NJR). The difference is particularly significant for mobile bearing or fixed bearing in combination with posterior stabilization. The mobile bearing/ posterior stabilization combination shows lower revision rates (EPRD - 1% after 1 year and 1.4% after 3 years) than the fixed bearing/posterior stabilization variant (EPRD - 2.5% after 1 year, 4% after 3 years and 5.9% after 5 years). It should be mentioned that only the German register was used for this purpose, since the other registers do not differentiate here, and secondly the number of implanted prostheses is very low compared to the other implantation methods. (PS/MB 417 implanted prostheses in the EPRD registry, PS/FB 1362 implanted prostheses in the EPRD registry).

11.4 Results Cruciate Retaining (CR) and Posterior Stabilization (PS)

A comparison of the revision rates between the cruciate-retaining (CR) and the posterior-stabilization (PS) technique was carried out in those countries that published sufficient data. Data from Germany (EPRD), England, Wales, Northern Ireland (NJR), Australia (AOANJRR), America (AAOS), Sweden (SKAR) and New Zealand (NZOA) were used. If no distinction was made between mobile bearing/fixed bearing or cruciate retaining/posterior stabilization, the suffix "All" was used.

National registry	PS/CR	FB/MB	Total no. of follow-up arthroplasties	Revision Rate after 1 year	Revision Rate after 3 years	Revision Rate after 5 years	No of Revisions total
EPRD	CR	FB	5802	1,6	3,1	3,6	
	CR	MB	1417	1,4	2,8	3,2	
NJR[2]	CR	FB	18550	0,37	1,43	1,9	
	CR	MB	3493	0,15	0,88	1,47	
AOANJRR[3]	CR	All	18176	1	2,4	3,1	
AAOS[1]	CR	All	17426	0,52	1,08	1,4	164
SKAR	CR	All	10				No data
NZOA[4]	CR	All	7424				123

1 cumulative revision rates from 2012-2019

2 cumulative revision rates from 2003-2020

3 cumulative revision rates from 1999-2020

4 data from 1999-2020

Table 11: Revision Rates CR

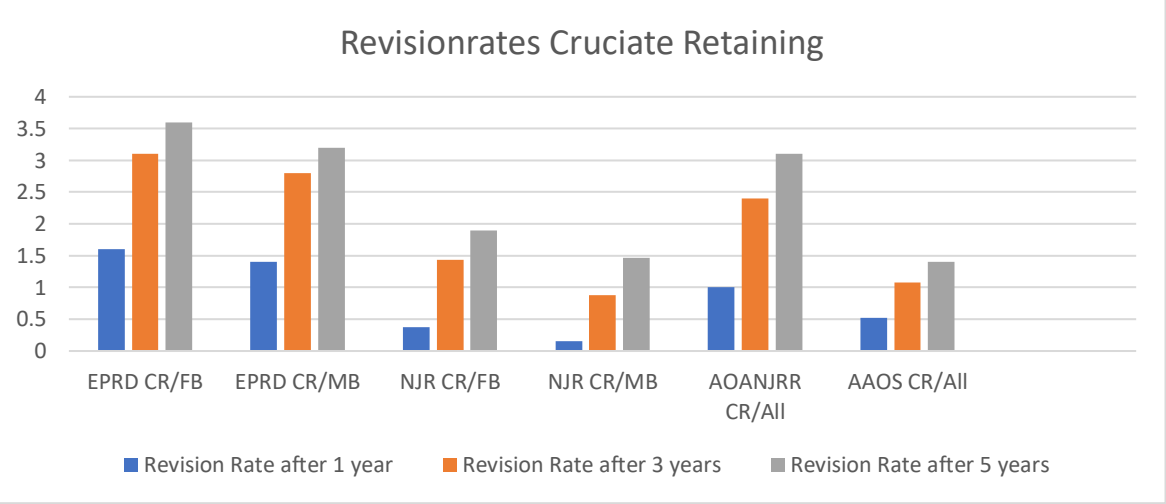

Figure 39: Revision rates cruciate retaining

There is an increase in the revision rates for both the FB and MB-System after 1, 3 and 5 years in all registers. The registers from Germany and England, Wales and Northern Ireland distinguish between FB and MB in the CR technique. The registries from America, Australia, Sweden, and New Zealand do not distinguish between fixed and mobile bearing. The abbreviation "all" was used for this purpose.

National registry	PS/CR	FB/MB	Total no. of follow-up arthroplasties	Revision Rate after 1 year	Revision Rate after 3 years	Revision Rate after 5 years	No of Revisions total
EPRD	PS	FB	1362	2,5	4	5,9	
	PS	MB	417	1	1,4	No data	
AAOS[1]	PS	All	37719	0,69	1,55	2,06	
NJR[2]	PS	FB	10159	0,45	1,62	2,48	
AOANJRR[2]	PS	All	8840	0,9	2	2,7	
NZOA[4]	PS	All	4616				70

1 cumulative revision rates from 2012-2019

2 cumulative revision rates from 2003-2020

3 cumulative revision rates from 1999-2020

4 cumulative revision rates from 1999-2020

Table 12: Revision Rates PS

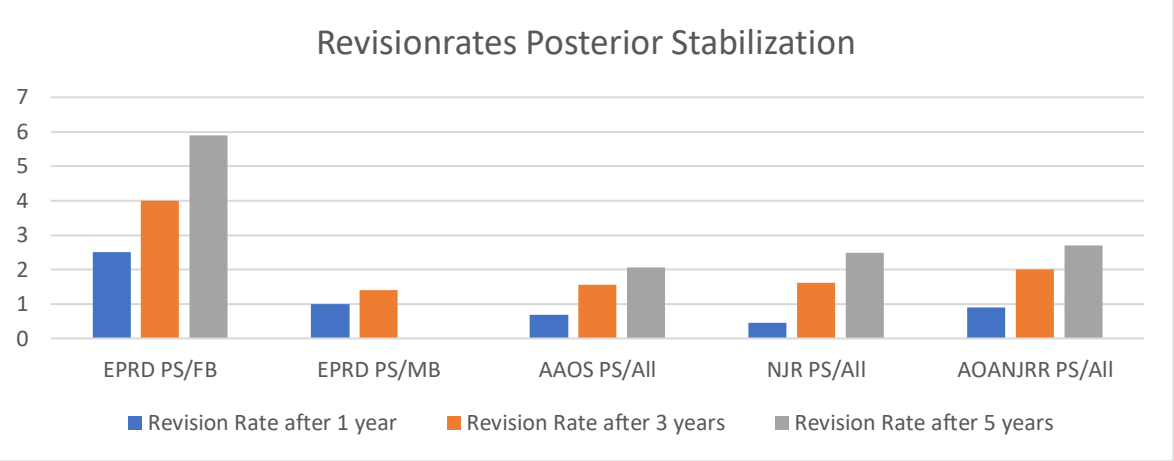

Figure 40: Revision rates posterior stabilization

As can be seen in Table 1, in all Attune systems implanted with the PS technique, there is an increase in the revision rate after 1,3 and 5 years. The differentiation between the countries regarding posterior stabilization is difficult due to the very different published variants. Germany (EPRD) is the only country to differentiate between mobile bearing and fixed bearing in posterior stabilization implantation. A comparison of revision data in

America (AAOS) and Australia (AO-ANJRR) for posterior stabilization without differentiation between fixed bearing and mobile bearing shows increased revision data in Australia (AO-ANJRR). (AO-ANJRR PS/ALL after 1 year 0.9%, 3 years 2%, 5 years 2.7%) (AAOS PS/ALL after 1 year 0.69%, after 3 years 1.55% and after 5 years 2.06%).

Comparison cruciate retaining and posterior stabilization:

Regarding the comparison between cruciate retaining and posterior stabilization revision rates in relation to mobile bearing/fixed bearing, very heterogeneous data emerge. The German registry (EPRD) shows an advantage in revision rates for cruciate retaining (CR/FB 1 year 1.6%, 3 years 3.1% and 5 years 3.6%) compared to posterior stabilization (PS/FB 1 year 2.5%, 3 years 4% and 5 years 5.9%) when implanted in combination with fixed bearing. In contrast, the cruciate retaining variant (CR/MB 1 year 1.4%, 3 years 2.8% and 5 years 3.2%) shows increased revision data compared to the posterior stabilization variant (PS/MB 1 year 1%, 3 years 1.4% and 5 years 5.9%) when implanted with mobile bearing. A comparison of posterior stabilization and cruciate retaining in combination with fixed bearing in England, Wales, and Northern Ireland (NJR) shows a benefit for cruciate retaining implantation (CR/FB 1 year 0.37%, 3 years 1.43%, 5 years 1.9% versus PS/FB 1 year 0.45%, 3 years 1.62%, and 5 years 2.48%). In Australia (AOANJRR) and America (AAOS), only cruciate retaining and posterior stabilization revision data were published without differentiation between mobile bearing or fixed bearing. Very heterogeneous data have been published here. The American registry shows an advantage in revision rates for the cruciate retaining variant (AAOS - CR 1 year 0.52%, 3 years 1.08%, and 5 years 1.4%, PS 1 year 0.69%, 3 years 1.55%, and 5 years 2.06%), while the Australian registry shows an advantage for the posterior stabilization variant. (AO-ANJRR - CR 1 year 0.52%, 3 years 1.08%, and 5 years 1.4%, PS 1 year 0.69%, 3 years 1.55%, 5 years 2.06%).

12 Discussion

The main purpose of this study was to extract data (epidemiological data, data from surgical methods and revision rates) regarding the Attune Knee System from studies and registries and compare them.
As mentioned in the study, a comparison of the gender distribution between studies and registries shows that an Attune knee was used more frequently in women (60%) than in men (40%). A possible explanation for this could be the higher risk of women to develop osteoarthritis. (61,62) Various studies also show that women have worse preoperative factors (pain, worse function, obesity) compared to men. (63,64)
The average age for an Attune Knees system in this study was 67.8 years. Patients in the studies (Pubmed and Cochrane) are on average 3.3 years younger than those in the registries. A meta-analysis by Kuperman et al showed that older patients (over 75 years of age) who underwent total knee replacement had a higher mortality rate and a longer hospital stay. The study also showed that there was no difference in pain and functional status between younger (under 65 years) and older patients after total knee arthroplasty.(65)
The median BMI of individuals who received Attune Knee was 29.4 kg/m2. The highest value for BMI was published by Ruckenstuhl P et al with 30.55. The lowest value was that of Moorthy V et al with a value of 28. For BMI data, only Pubmed studies provided sufficient information. Therefore, no registries were included in the calculation here. Those people who have received a total knee arthroplasty show positive effects on BMI after surgery. Weight loss was observed in 31% of cases. In general, obese patients showed a greater improvement in functional parameters than patients with normal BMI.(66)

The published revision rates showed similar data for mobile bearing and fixed bearing, but very heterogeneous data for posterior stabilization and cruciate retaining. The revision rate is influenced by various factors (surgeon, the hospital environment, the health care system, preventive factors) and is therefore difficult to interpret the cause of high/low rates. (67) A detailed evaluation of the data would be needed to capture the cause of the differences. The study included mobile bearing/fixed bearing as well as posterior stabilization/cruciate retaining. Other influencing factors were not published and therefore could not be included. Three registries AAOS (2012-2019), AO-NJRR (1999-2020) and NJR (2003-

2020) published only cumulative revision rates, which were compared in the study with the annual revision rates of the other countries. Changes in the revision rate due to improvements in arthroplasty care over time were not considered.

A comparison of fixed bearing (FB) to mobile bearing (MB) shows a lower revision rate after 1,3 and 5 years for MB (EPRD and NJR). High revision rates are particularly evident with the combination of fixed bearing and posterior stabilization. Comparative studies (68–71) between FB and MB without differentiation of knee systems show no significant differences between FB and MB. To improve range of motion (ROM) and reduce wear the mobile bearing design was developed primarily for younger patients. From a biomechanical point of view, the mobile bearing design provide less tibiofemoral contact stresses under tibiofemoral malalignment conditions as well as less wear rate in in-vitro stimulator tests. However, these theoretical advantages in long-term durability life for mobile bearing have not yet been proven in any study. The routine use of MB is not recommended. (72,73)

Cruciate retaining (CR) and posterior stabilized (PS) designs are commonly used for primary total knee arthroplasty. The comparison between CR/PS in the registries shows very heterogeneous data. Studies without specific prothesis showed no difference in revision rates as well as clinical outcomes between PS and CR in total knee arthroplasty (all knee systems included) (74–76) When choosing between cruciate retaining and posterior stabilization, many surgeons tend to favor those methods that they are more proficient in due to training. However, the type should be selected on a great store of knowledge and other factors (knee deformity, stability) rather than surgeon's preconceptions or preferences. (75,77)

The amount of implanted Attune prostheses in clinical studies is lower compared to the registers. In summary, 327 patients were observed in all clinical trials. In comparison, 2954 knee replacements were published in Switzerland. There is a big difference in the number of knee prostheses of the evaluated clinical trials and registries.

I would like to mention that revision rates are not the only measure of outcome. In addition to the revision rate, quality of life and patient satisfaction also play a central role. These

parameters were not included in the study because functional parameters were either not published (registries) or were too heterogeneous to compare (clinical trials).

13 Conclusion

In conclusion, this thesis presented evidence proving that patients who received an Attune Knee System with the Mobile Bearing design shows within the first 5 years after implantation lower revision rates than those who received the Fixed Bearing design. It is also evident that within Fixed Bearing, the cruciate retaining technique shows an advantage in revision rates.

14 Conflict of interest

No benefits in any form have been received or will be received from a commercial party directly or indirectly to the subject of this article. No funding was received for this study. No ethical approval was necessary due to the nature of the study design.

15 Supplementary material

15.1 Data from the Pubmed and Cochrane search engines on the Attune Knee System

Statistics clinical studies

Pubmed Number	Autor	Name	Follow up time:	Study Typ:	Year	Number of Patients	bearing		technique		Age median	Sex		BMI
							fixed	mobile	gap balancing	measured resection		M	F	
1	Kaptein BL et al	A randomized controlled trial comparing tibial migration of the ATTUNE cemented cruciate-retaining knee prosthesis with the PFC-sigma design	24 Months	single-blinded randomized, noninferiority study	2020	38					69	18	20	29
2	Moorthy V et al	Similar postoperative outcomes after total knee arthroplasty with measured resection and gap balancing techniques using a contemporary knee system: a randomized controlled trial	24 months	prospective randomized controlled trial	2020	100			50		68,4	10	40	27,9
3	Ruckenstuhl P et al	No difference in clinical outcome, pain and range of motion between fixed and mobile bearing Attune total knee arthroplasty: a prospective single-center trial	46 months	prospective single center cohort study	2022	67	33				65,7	10	23	31,8
4	Hauer G et al (EXCLUDED!)	Mid-term results show no significant difference in postoperative clinical outcome, pain and range of motion between a well-established total knee arthroplasty design and its successor: a prospective, randomized, controlled trial	24 months	propsective, randomized, parallel-group study	2020	80					71,1	-	-	28,8
Cochrane														
1	excluded	Total Knee Replacement with the Attune vs. the Press Fit Condylar (PFC)				Recruiting								
2	excluded	RSA RCT: attune RP TKA Versus LCS RP TKA				Recruiting								
3	excluded	RSA-RCT: Attune S+ TKA Versus Sigma TKA				Recruiting								
4	excluded	RSA RCT: ATTUNE™ TKA Versus PFC Sigma TKA (APKnee)				completed, but no Results posted								
5	excluded	Trial Comparing Alignment Techniques - RSA of ATTUNE Knee System				Recruiting								
6	excluded	RSA of the ATTUNE Knee System: RCT Comparing Traditional Vs Enhanced-Fixation Device Designs				Recruiting								
7	Ashraf Y et al	Has the modern design of Attunetotal knee replacement improvedoutcome in patients with isolatedpatellofemoral arthritis?	24 months	prospective trial	2020	42					64	20	22	29,9
8	excluded	Comparison of TKAs Using Force Plate Analysis				Recruiting								
9	excluded	A clinical study to assess whether there is a difference in outcomes in patients receiving either the PFC or the Attune knee replacement				completed, but no Results posted								
10	excluded	Cemented vs. Cementless TKA				completed, but no Results posted								
11	excluded	Multi-Center Clinical Evaluation of the ATTUNE Cementless Rotating Platform Total Knee Arthroplasty in the Japanese Patient Population				no result posted!								
12	excluded	Attune With TruMatch TM Personalized Solutions Instruments				Recruiting								

15.2 Data from the National Knee Registries on the Attune Knee System

16 References

Statistics Attune-Knee-System

Register	Year Report	Year Data	Technique CR/PS		Patella resurfacing	refers to the total number of followed-up arthroplasties in the given category	Number	refers to the number of hospitals documenting these arthroplasties	Age	refers to the median age and the age quartiles of the patients who received these arthroplasties	Gender: Wm %	refers to the median age and the age quartiles of the patients who received these arthroplasties	Gender: Wm %	refers to the median age and the age quartiles of the patients who received these arthroplasties	Revision total	kummulativ Revision rates	Revision Rate after 1 year	after 2 years	after 3 years	after 4 years	after 5 years	after 6 years	after 7 years
The German Arthoplasty Registry (EPRD)	2021	2020	CR	FB			5802	94	67		38		62				1,6	2,6	3,1	3,2	3,6	3,6	
	2021	2020	CR	MB			1417	21	70		36		64				1,4	2	2,8	3,2	3,2		
	2021	2020	PS	FB			1362	65	69		37		63				2,5	3,8	4	5,6	5,9		
	2021	2020	PS	MB			417	20	76		36		64				1	1,4	1,4	1,4			
	2021	2020	CR	FB			4656	92	67		39		61										
	2021	2020	CR	MB		Yes	1186	21	69		38		62										
	2021	2020	PS	FB		Yes	1163	60	69		37		63										
	2021	2020	PS	MB		Yes	377	19	77		36		64										
Swiss National Knee Joint Registry (SIRIS)	2021	2020	all	all	unlinked bicondylar TKA		2954										1,7	3,7	5	5,7	6,3	6,9	7,7
American Joint Replacement Registry (AAOS)	2021	2012-2019	PS		cemented		37719								532		0,69		1,55		2,06		2,85
	2021	2012-2019	CR		cemented		17426								164		0,52		1,08		1,4		1,58
Australian Orthopaedic Ass. National Joint Replacement Registry (AOANJRR)	2021	2020	CR		all		3130																
	2021	2020	PS		all		1774																
	2021	2020	CR		cemented		2858																
	2021	2020	PS		cemented		1650																
	2021	2020	CR		cementless		175																
	2021	2020	PS		cementless		79																
	2021	1999-2020	CR				18176								392		1		2,4		3,1		
	2021	1999-2020	PS				8840								159		0,9		2		2,7		
National Joint Registry England, Wales, Northern Ireland, the Isle of Man, States of Guernsey (NJR)	2003	2020		FB		Yes	13599		70		39		61				0,35		1,24		1,86		
	2003	2020		FB		No	15122		69		47		53				0,45		1,72		2,32		
	2003	2020		MB		Yes	3190		69		40		60				0,2		0,8		1,08		
	2003	2020		MB		No	1763		69		52		48				0,19		1,07		1,78		
	2003	2020	CR	FB	cemented		18550		69		44		56				0,37		1,43		1,9		
	2003	2020	CR	MB	cemented		3493		70		42		58				0,15		0,88		1,47		
	2003	2020	PS	FB	cemented		10159		70		42		58				0,45		1,62		2,48		
	2003	2020	CR	FB	cemented	Yes	7413		70		38		62				0,24		1,13		1,54		
	2003	2020	CR	FB	cemented	No	11137		69		48		52				0,46		1,62		2,12		
	2003	2020	CR	MB	cemented	Yes	2140		70		37		63				0,19		0,86		1,32		
	2003	2020	CR	MB	cemented	No	1353		70		49		51				0,08		0,89		1,64		
	2003	2020	PS	FB	cemented	Yes	6183		70		41		59				0,47		1,36		2,22		
	2003	2020	PS	FB	cemented	No	3976		70		44		56				0,42		2,03		2,92		
Swedish Knee Arthroplasty Register (SKAR)	2020	2019	CR			No	10									2,14							
	2020	2009-2018				No	114																
Valdoltra Knee Arthroplasty Register (VAR)	2022	2002-2020					182								0								
The New Zealand Joint Registry (NZOA)	2021	2020					2217																
	2021	1999-2020					12075								193								
	2021	1999-2020			all		11482								185								
	2021	1999-2020			cemented		72								2								
	2021	1999-2020			hybrid		521								6								
	2021	1999-2020		FB	cementless		4941								73								
	2021	1999-2020		MB			5995								113								
	2021	1999-2020	CR				7424								123								
	2021	1999-2020	PS				4616								70								
Irish National Orthopaedic Registry (NOCA)	2021	2014-2019					672								6	5,3							
Norwegian Arthroplasty Registry (NAR)	2021	2020					443																
		2019					484																
		2018					424																
		2017					122																

CR: Cruciate Retaining, PS: Posterior Stabilisation, MB: Mobile Bearing, FB: Fixed Bearing

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