AUS DEM LEHRSTUHL
FÜR ORTHOPÄDIE
DIREKTOR PROF. DR. MED. DR. H.C. J. GRIFKA
DER FAKULTÄT FÜR MEDIZIN
DER UNIVERSITÄT REGENSBURG

KINEMATIC AND RADIOLOGICAL CHANGES OF THE PATELLA DUE TO THE IMPLANTATION OF A NAVIGATED LIGAMENT-BALANCED TOTAL KNEE ARTHROPLASTY IN VIVO

Inaugural – Dissertation
zur Erlangung des Doktorgrads
der Medizin

der
Fakultät für Medizin
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vorgelegt von
Stephanie Diwald

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An in vivo study using a navigation system

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Index

1. Abstract

1.1 Abstract (English)

Background and purpose:

Due to increased life expectancy the demand of medical care, especially concerning joint arthroplasty, is growing. Hence, the number of Total Knee Arthroplasty (TKA) rose significantly. To ensure the longevity of implants, it is important to bear in mind one of the major complications after TKA, the patellofemoral pain syndrome (PFPS). {Springorum 2012 #4}{Borelli 2011 #74}
The purpose of this study was to examine the changes in patellar tracking after total knee arthroplasty using the ligament-balanced navigated technique and radiological evaluation.

Patients and Methods:

In this prospective study patellar tracking was measured pre- and postoperatively in 40 patients after ligament-balanced TKA using computer navigation. Furthermore, radiological parameters as mechanical leg axis, Q-angle, modified Insall-Salvati-Index, mediolateral shift and tilt of the patella and the joint line were recorded. Clinical results were assessed by 4 different questionnaires (Knee Society Score (KSS), Western Ontario and McMaster Universities Arthritis Index (WOMAC), Feller Score, HAKEMP-90).

Results:

After implantation of the TKA the mechanical axis of the leg, the Q-angle, the modified Insall-Salvati-Index and the deviation of the joint line were within the reference range according to current literature. Because of the implant there were significant changes in mediolateral shift and tilt of the patella in the dynamic measurement by means of navigation. In the static measurement using X-ray the mediolateral shift had not changed significantly, the patellar tilt, the height of the joint line and the modified Insall-Salvati-Index had changed significantly. The questionnaires KSS, WOMAC and Feller Score showed a significant improvement.

Conclusion:

After TKA there are differences in patellar kinematics compared to the preoperative arthritic knee, which the orthopaedic surgeon should be aware of. By means of a CT free navigation system the changes can be shown intraoperatively.

1.2 Abstract (German)

Hintergrund und Zielsetzung:

Aufgrund der gestiegenen Lebenserwartung nehmen auch die Ansprüche an die medizinische Versorgung zu, vor allem in Bezug auf die Gelenkendoprothetik. Folglich stieg die Anzahl an Knie-Totalendoprothesen (TKA) bedeutend. Um eine lange Standzeit der Prothesen zu gewährleisten, ist es wichtig, einer der Hauptkomplikationen nach dem Eingriff vorzubeugen, nämlich dem patellofemoralen Schmerzsyndrom (PFPS). {Springorum 2012 #4}{Borelli 2011 #74}
Ziel dieser Studie war es, die Unterschiede im Lauf der Patella zu untersuchen, nachdem eine Knie-Totalendoprothese mithilfe einer navigierten bandspannungsadaptierten Methode implantiert wurde und unter Zuhilfenahme der Auswertung von Röntgenbildern.

Patienten und Methoden:

In dieser prospektiven Studie wurde der Lauf der Patella prä- und postoperativ bei 40 Patienten gemessen, die eine bandspannungsadaptierte Knieendoprothese mithilfe der Computernavigation erhielten. Zusätzlich wurden die radiologischen Parameter Beinachse, Q-Winkel, modifizierter Insall-Salvati-Index, mediolaterale Verschiebung und Verkippung der Patella und die Abweichung der Gelenklinie miteinbezogen. Die klinischen Ergebnisse wurden mittels 4 verschiedener Fragebögen erfasst (Knee Society Score (KSS), Western Ontario and McMaster Universities Arthritis Index (WOMAC), Feller Score, HAKEMP-90).

Ergebnisse:

Nach der Implantation der Prothese waren die mechanische Beinachse, der Q-Winkel, der Modifizierte Insall-Salvati-Index und die Abweichung der Gelenklinie innerhalb der Referenzbereiche in Übereinstimmung mit der gängigen Literatur. Durch die Prothesenimplantation änderten sich signifikant die mediolaterale Verschiebung und Verkippung der Patella in der dynamischen Messung mittels Navigation. In der statischen Messung im Röntgen zeigte sich die mediolaterale Verschiebung nicht signifikant verändert, die Verkippung der Patella, die Höhe der Gelenklinie und der modifizierte Insall-Salvati-Index waren signifikant verändert. Die Fragebögen KSS, WOMAC und Feller Score zeigten eine signifikante Verbesserung.

Diskussion:

Nach Prothesenimplantation zeigen sich im Gegensatz zum präoperativen arthrotischen Knie Unterschiede in der Kinematik der Patella, worüber sich der Chirurg im Klaren sein sollte. Mithilfe des CT-freien Navigationssystems kann die Veränderung intraoperativ dargestellt werden.

2. Introduction

2.1 Anatomy of the knee joint

The knee is the largest articulation of the body where thigh and lower leg show an opposite movement. It consists of three parts:

- Femoropatellar articulation
- Medial tibiofemoral articulation
- Lateral tibiofemoral articulation

The fibula forms an independent articulation with the tibia, the tibiofibular articulation.

Hence the following movements are possible:

- Flexion and extension with a simultaneous forward glide during flexion and backward glide during extension. Furthermore, there is a slight external rotation of about 10° between the lower leg and the thigh at the end of the extension.

- Internal and external rotation of about 40-50° in flexion with slackened capsule and ligaments.

Stability is necessarily ensured by static and dynamic strengths because of the missing bony guidance:

- The static strength is provided by the capsule, ligaments and the curvature of the femoral condyles. The menisci have the effect of an absorber and load balancer which gives stability against translation movements between femur and tibia.

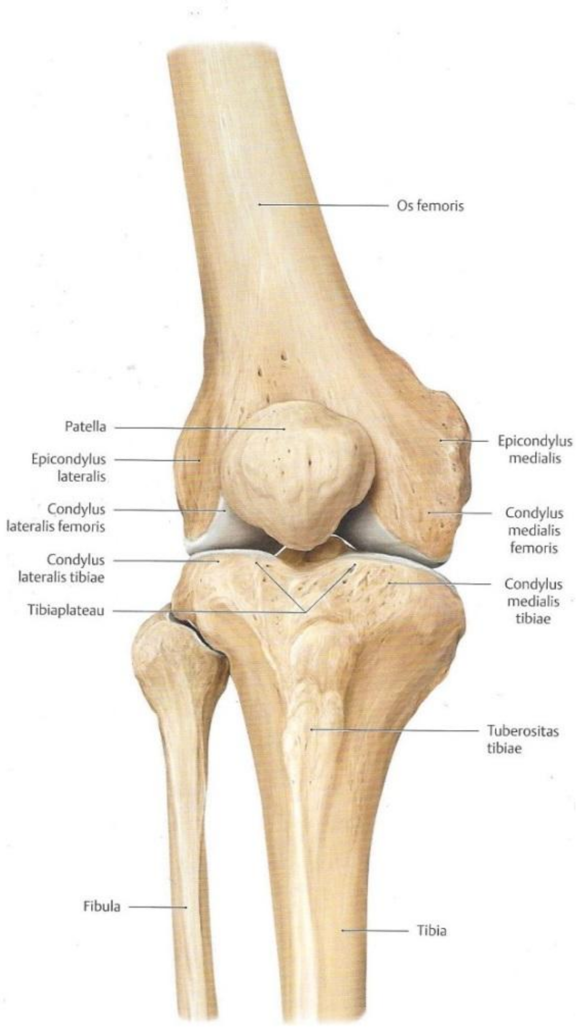

Figure 1: *Right knee in frontal position {Schulte 2007 #44}*

- The dynamic strengths are defined by the muscles running around the knee joint: M. quadriceps femoris (extension); M. gastrocnemicus (flexion); M. biceps femoris (flexion and external rotation); M. sartorius, M. gracilis, M. semitendinosus, M. semimembranosus, and M. popliteus (flexion and internal rotation).

The static and dynamic strengths are equally placed around the central axis of the knee.

The femoropatellar compartment receives strong forces under flexion which might lead to overstrain. Complications in this articulation are one of the most common problems after total knee arthroplasty (TKA). {Krämer 2007 #3}{Niethard 2005 #2}{Kainz 2012 #30}

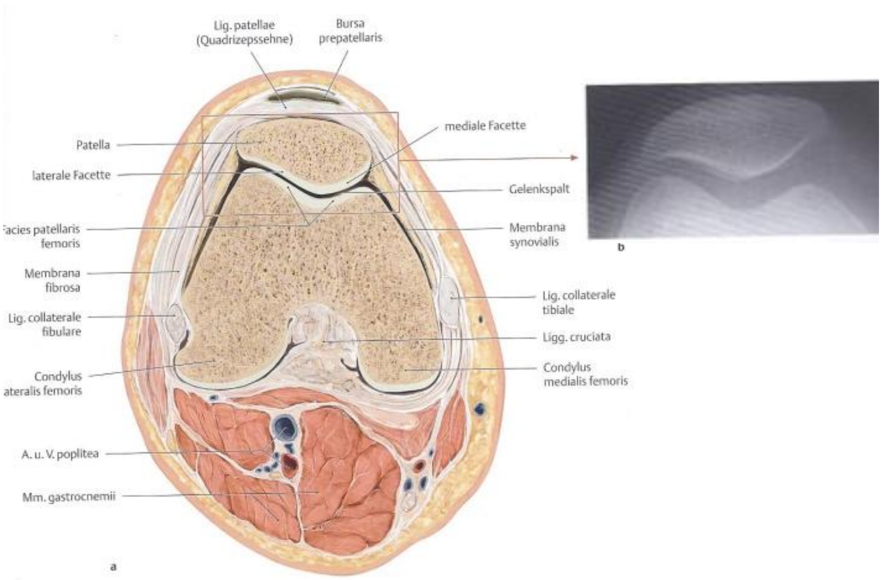

Figure 2: *Femoropatellar articulation {Schulte 2007 #44}*

The problem for patellar kinematics is how unstable the patella gets when the knee is slightly flexed. At the beginning of the flexion the patella is only guided by the ligaments, a centralisation of the patella starts at 30° of flexion. When there is a deeper flexion, the patella is guided by the bones towards the trochlea, since it becomes more stable. {Springorum 2011 #19}

'The proximal tibiofibular joint is a plane type synovial joint' between the lateral tibial condyle and the caput fibulae. It is independent from the articulatio genus. Its most important function is to dissipate torsional stresses which act on the ankle and on the lateral tibial bending moments. The distal tibiofibular articulation is a syndesmosis at the distal lower leg and at this point only mentioned for the sake of completeness. {Schulte 2007 #44}{Ogden 1974 #103}

2.2 Osteoarthritis of the knee joint

2.2.1 Definition

Gonarthrosis is one of the most frequent degenerative diseases within the field of orthopaedics. For about 5% of the elderly are affected, it plays an important sociomedical role.

Gonarthrosis is a progredient degeneration of the knee joint with cartilage destruction (chondromalacia), secondary bone lesions, osteophytes and capsule shrinkage. This leads to minimised and painful movement and osteoarthritis. {Niethard 2005 #2}{Wülker 2005 #31}

Osteoarthritis of the knee joint is divided into primary and secondary causes. Primary osteoarthritis is caused by poor genetic disposition of the articular cartilage tissue. The particular reasons therefore are unknown.

Secondary osteoarthritis can be caused by overload (e.g. deformations like varus/valgus malalignment, genu recurvatum/antecurvatum), traumata, inflammatory joint diseases (e.g. rheumatoid arthritis), metabolic diseases (e.g. gout) or by endocrinary diseases (e.g. hypothyroidism). {Krämer 2007 #3}{Niethard 2005 #2}

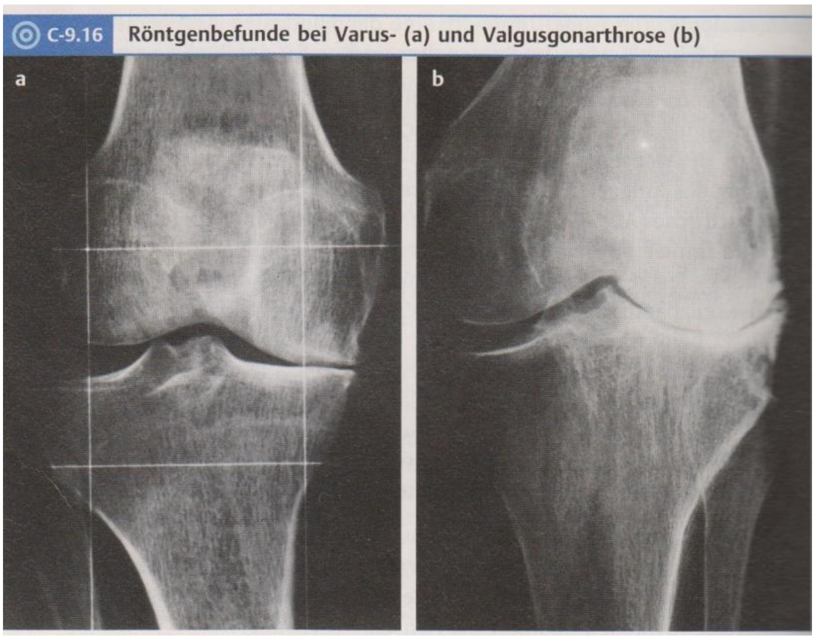

Figure 3: *X-ray of varus (a) and valgus (b) gonarthrosis {Niethard 2005 #2}*

2.2.2 Therapeutical options

There are various options, surgical and nonsurgical ones, depending on the severity of the disease. Both surgical and nonsurgical methods are used singularly as well as combined.

As it is helpful to keep the joints moving, physiotherapy (e.g. swimming, bicycling, balneotherapy) is a proven method. Furthermore it strengthens the muscles. {Niethard 2005 #2}

To reduce pain, it is important to reduce the loading factors, e.g. by losing weight, using a walking cane, or orthopaedic insoles.

Corticosteroids, nonsteroidal antiphlogistic drugs, monolytics or hyaluronic acid derivatives are used to relief pain. This medication abates pain rapidly because of its easy application.

At an advanced stage of gonarthrosis, several surgical options are available depending on the symptoms and the severity of the disease. During open debridements, all mechanical disturbing factors like inflamed synovia, osteophytes and floating/lose joint bodies are removed. In the last decade, minimal invasive arthroscopic techniques have become more and more important and thus have overcome open surgical techniques.

In cases of progressive gonarthrosis knee arthroplasty can be an encouring option.

Endoprosthetic replacements can be performed as partial or as total knee replacement. Both are routine operations nowadays and they provide highly satisfactory results with significant pain decrease and a noticeable increase of function and quality of life in patients.

The satisfaction rate in TKA patients, however, is only between 75-89 %.

Reasons could be postoperative complications such as infections (38%), instabilities (27%), insufficient integration (13%) or others.

Up to 50% - depending on literature - of patients complain about patellofemoral pain (PFP) after the operation, what could be considered as one of the most frequent postoperative complications. {Niethard 2005 #2}{Springorum 2012 #4}{Boyd 1993 #5}{Ip 2004 #6}{Callaghan 2004 #21}{Bonnin 2011 #22}{Bourne 2010 #23}{Kohn 2000 #32}{Wülker 2005 #31}

2.3 The history of total knee arthroplasty

In 1890, Themistokles Gluck, a surgeon from Berlin, published for the very first time his experiences of artificial bones and joints.

The treated patients suffered from osseous tuberculosis. In a first operation, he replaced the complete knee joint. In a second operation, he implanted a hinge implant made of ivory. Gluck also analysed the fixation using wedges (e.g. of pergament, cork or felt) and an early type of cement (decalcined cattle bone or a mixture of cholophony and gypsum). The problem Gluck was confronted with was increased septic loosening. Although he could remedy the effect of tuberculosis by implanting the prosthesis he could not reduce the infection, which caused the loosening. That dissuaded Gluck and his colleagues from the idea of an endoprosthesis. {Stuhler 1996 #33}{Rabenseifner 1998 #34}

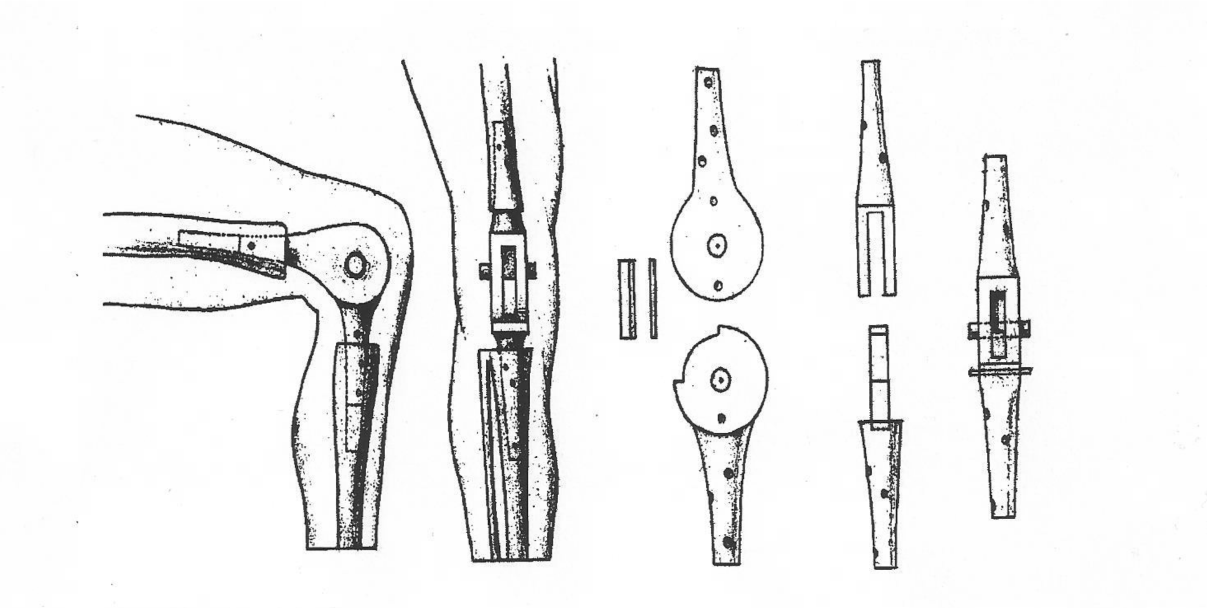

Figure 4: *First models of prosthesis of Themistokles Gluck {Rabenseifner 1998 #34}*

Only in 1947, the brothers Judet developed a hinge prosthesis made of acrylic after having seen positive results in hip arthroplasty. But acrylic could not resist the high shear forces in the knee permanently.

Ten years later, in 1957, Wallidus used successfully another material called ‘vitallium’ which is a CoCrMo alloy. It is extremely stable and unbreakable. The limiting factor of that kind of implant was that it was still only a hinged prosthesis that did not allow for natural knee kinematics. Furthermore, all of the ligaments and the capsule had to be removed, what increased the risk of aseptic loosening and infection of the arthroplasty, thus the use of that types of prosthesis had to be improved. {Wallidus 1957 #35}

Another ten years later, at the end of the 1960s, the sliding implant lead to the breakthrough. With the salvage of the ligaments additional stability could be achieved. {Charnley, Love #36}

In 1970, in New York and Boston the first ‘Duocondylar-Knees’ were implanted, resurfacing the medial and the lateral compartment. 4 years later the ‘Duopatellar Knee’ was developed based on these experiences. It had the advantage of a femoropatellar slide bearing and salvage of the posterior cruciate ligament.

In the 1980s, the ‘press fit condylar (PFC) – knee system’ was tested for the first time and further developed afterwards. It offers a variety of options including fixed or rotating platform, cruciate-retaining or cruciate-substituting implantation technique, or optional patellar resurfacing. The implant was designed to mirror the biomechanics of a natural knee. The latest innovation in knee arthroplasty are customized surgical cutting guides or customized implants. {Kim YH, Kook, Kim JS #37}{Schunck, Jerosch #38}{Scott, Thornhill #39} {Orthopedic company celebrates 25 years #40}

2.4 Surgical techniques in total knee arthroplasty

2.4.1 The traditional measured resection technique

Before surgery a preoperative radiological examination, including an a/p view standing under load, an X-ray of the knee joint in two planes and a ‘patella sunrise view’, is essential. With these data it is possible to calculate the correction of the axis and the approximately expected size of the implants using X-ray templates.

After opening the knee joint with a medial parapatellar approach, a stylet is positioned intercondylarly in the femur with intramedullar direction. Depending on the preoperative X-rays the distal cutting block is usually aligned 5° to 7° towards the anatomical axis of the femur.

After that the size of the femoral component is determined. The rotation of the femoral component is marked in orientation of the posterior condylar line, – standardised with 3° of external rotation.

The ‘tibial resection line’ can also be determined using a stylet or using an extramedullar system. The latter is applied to measure the tibial axis via the malleoli and the tibial tuberosity. It is also possible to adjust the dorsal descent of the tibial plateau with the aid of a setscrew at the end of the tibial alignment.

To measure the particular size of the inlay, either a sensor or a spacer of different height is placed in the rectangular gap where the resection was made. {Jerosch 2000 #42}{Kohn 2000 #32}{Rabenseifner 2013 #43}

2.4.2 CT free navigation

To get the information the CT based method is used basically, that means imaging of the femoral head, the knee joint and the upper ankle joint. But the difference is that the references are located in femur and tibia simultaneously. This allows the operating surgeon to assess the stress ration of the ligament in flexion and extension and to assess the range of motion. This way, it is possible to adapt the rotational adjustment of the femoral component depending on the stress ration of the ligament.

Because of the inherent imperfection of the human being, precision in surgery will always be defective and the introduction of navigation systems in surgery is therefore largely extended. {Bäthis 2003 #45}

In this study, patella navigation during the operation was used to assess the aforementioned patellar tracking.

2.5 Problems of conventional measured resection technique

2.5.1 Mechanical leg axis

The mechanical axis of the leg is the axis between the centre of the femoral head (caput femoris) and the middle of the talus. The mechanical centre line is called Mikulicz line. In the physiological leg it runs directly through the middle of the knee joint so that the strengths are distributed optimally there. If there is a deformity of the axis, this line can be located laterally (= genu valgum) or medially (=genu varum). {Wülker 2005 #31}

Figure 5: *Mikulicz line*
{Niethard 2005 #2}

To plan a TKA standardised X-ray diagnosis is necessary. Thereby the central beam of the X-ray should be positioned in the middle of the patella and there should be no rotation in the hip joint above.
During the operation the prosthesis should be positioned perpendicularly to the mechanical leg axis. A deviation leads to a significant additional load of the particular compartment where the prosthesis moved to. This leads to higher wear up to less retention. {Bäthis 2004 #46} {Ritter 1994 #55} {Jeffery 1991 #56}

2.5.2 Tibial and femoral angle of the prosthesis

An exact femoral portal of entry and an intramedullary orientation of the stylet are necessary to achieve optimal implant alignment. It is important to avoid deviations because of a wrong positioned access to the medullary cavity. A tilting of the stylet can cause a deviation of the axis up to 8°. The operating surgeon should also be aware of anatomical deformities, e.g. a fractured femur, that can cause deviation, too. {Jeffery 1991 #56}{Novotny 2001 #47}{Reed 1997 #48}

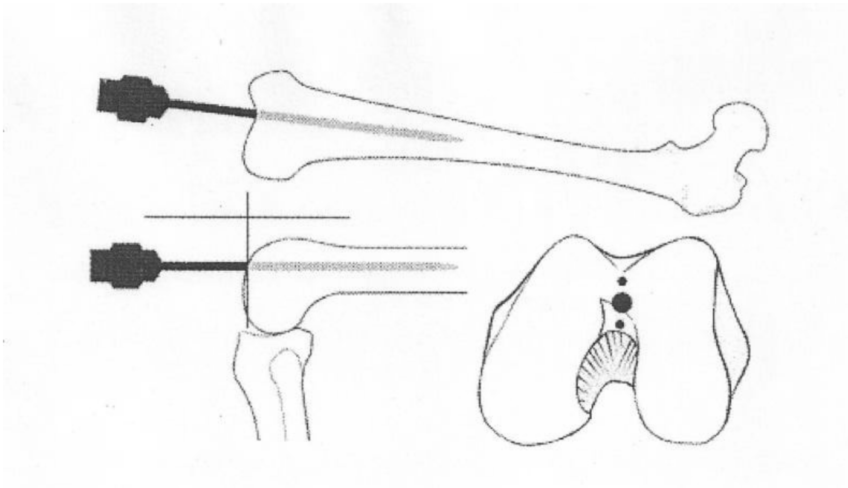

Figure 6: *Exactly positioned stylet {Munzinger 2004 #49}*

If the surgeon decided to make an intramedullary alignment, this problem could also occur at the tibia. An extramedullar stylet can cause errors because it can be unstable or the exact orientation towards the landmarks can be error-prone. {Sambatakakis 1991 #57}

2.5.3 Tibial slope

The tibial plateau descends dorsally. Its alignment is adapted depending on the tibial alignment using a traction screw. Thereby, a physiological slope of about 3°-5° should be achieved. If this angle is too large, the femoral component slides dorsally during flexion causing luxation or simply higher contact pressure ending in higher wear of the posterior compartment. {Wasielewski 1994 #58}
Assuming that the tibial plateau descends ventrally, it can cause an anterior tilt which can limit the flexion. Furthermore, if the flexion gap is too narrow 'posterior wedging' can be a result. This can also be a reason for uneven movement resulting in early loosening. {Dorr 1986 #53}

2.5.4 Femoral rotation

The femoral rotation has a significant effect regarding localised contact pressure and patellar maltracking. There are two methods to achieve exact alignment: the anterior and the posterior referenced method which offer 0°, 3°, 5°, or 7° of femoral rotation. In both methods the cutting block is adjusted to the anterior femoral cortex (anterior referenced alignment) or the posterior condyles (posterior referenced alignment). The rotation should be adjusted parallel to the epicondylar axis and rectangular to the Whiteside Line.

If there is suspected malrotation in a TKA, a CT scan can deliver objective results. Thus, the surgical 'epicondylar line' is usually a means to measuring. The CT scan is made in the supine position with extended knee. In correct rotation the surgical 'epicondylar line' and the posterior 'condylar line' should be parallel as shown in figure 7. {Springorum 2012 #4}

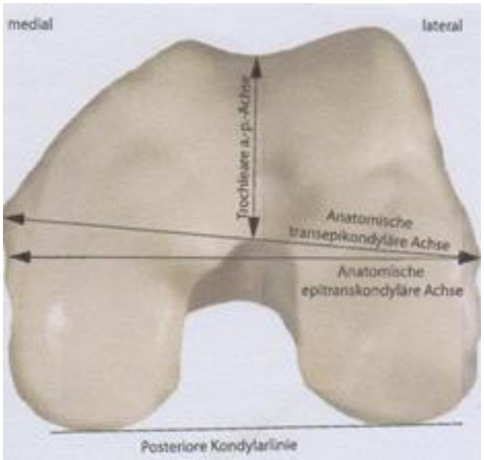

Figure 7: *Transepicondylar axis (TEA) {Springorum 2012 #4}*

2.5.5 Tibial rotation

The tibial component can be aligned statically or dynamically. The static alignment is defined via the bony landmarks of the tibia. Therefore, the axis of the tibial tray is positioned towards the medial third of the tuberositas tibiae. Another possible bony landmark is the posterior edge of the tibia.

In the dynamic alignment, the operating surgeon moves the knee using an inlay on trial basis and marks the tibial rotation. This method is only possible after slight soft tissue release before. {Hofmann 2003 #54} {Laskin 2003 #50} {Romero 2003 #51}

2.6 Patellar tracking

Patella tracking is based on the parameters shift, tilt, flexion and rotation:

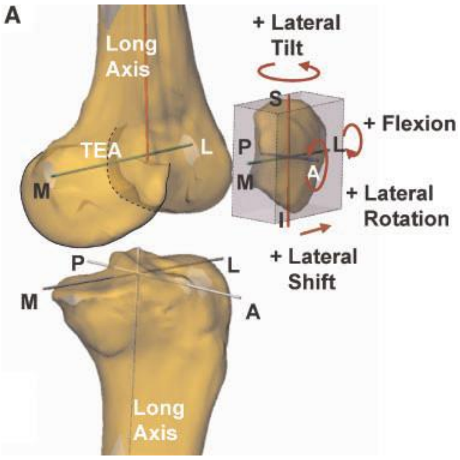

Figure 8: *Coordinate systems used to quantify the clinical motions of the patella {Nha 2008 #41}*

The patellar shift is defined as medial or lateral movement of the centre of the patella along the transepicondylar axis (TEA). During physiological movement the patella shifts slightly medially until the early flexion of 30°, beyond it shifts consistently laterally up to 90°. At flexion angles more than 90° there is only a slight lateral shift.

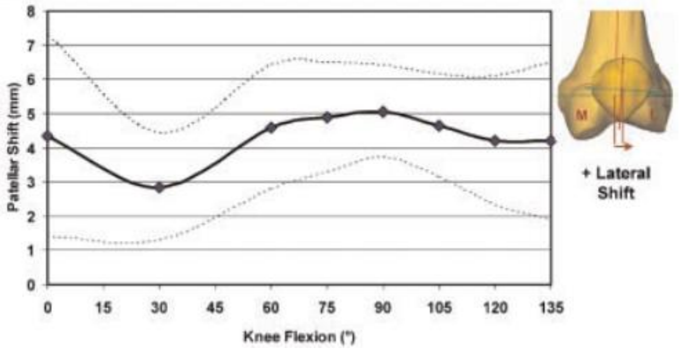

Figure 9: *ML shift of the patella {Nha 2008 #41}*

Patellar tilt is defined as the rotation of the patella around its long axis. In a physiologic knee the patella tilts laterally until a flexion of 75° and medially beyond 75°.

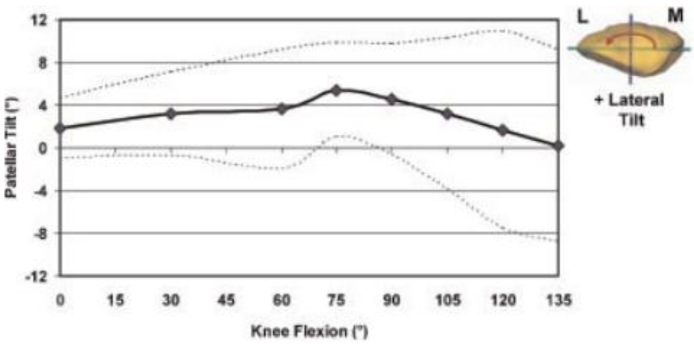

Figure 10: *Patellar tilt with respect to knee flexion {Nha 2008 #41}*

Patellar flexion is defined as the rotation of the patella around the transepicondylar axis. Patellar flexion increases with knee flexion, but at a lower rate. E.g. at a maximum knee flexion of 135°, the patellar flexion is about 95°.

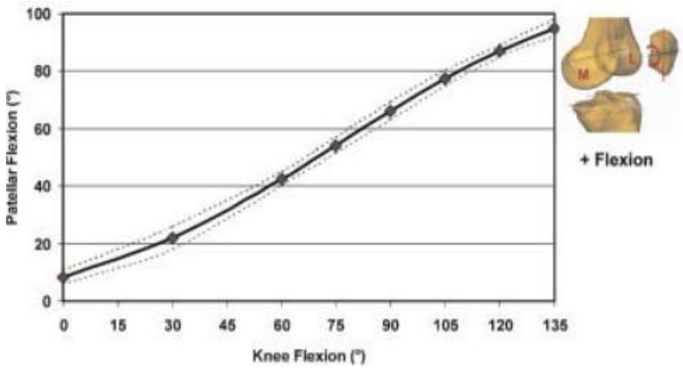

Figure 11: *Patellar flexion as a function of knee flexion {Nha 2008 #41}*

Patellar rotation is defined as the rotation of the patella around it's a/p axis. The patella rotates laterally with increasing flexion up to 120°. Beyond this angle the rotation reduces.

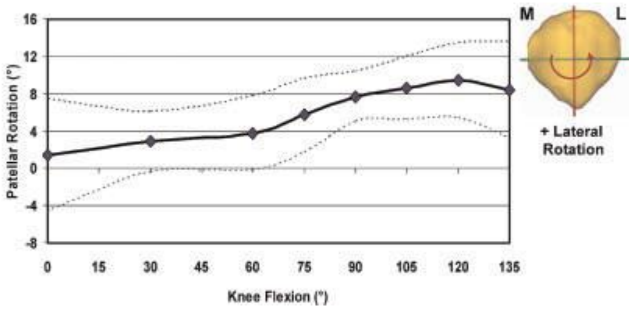

Figure 12: *Patellar rotation with respect to knee flexion {Nha 2008 #41}*

In conclusion, patellar movement is relatively small in relation to the femoral movement during in vivo weightbearing knee flexion. {Nha 2008 #41}

2.7 Patellar maltracking and postoperative anterior knee pain

Patellar maltracking means that the patella does not slide properly during knee flexion. So, it does not move smoothly within the trochlear groove of the distal femur.

Hence, it is a purpose to balance the patella during surgery to achieve physiological kinematics. This prevents increased retropatellar pressure postoperatively. Pressure on the femoropatellar articulation is made responsible inter alia for patellofemoral pain (PFP) after TKA. {Rosenstein 2007 #7}.

Altogether, there are various causes for PFP but increasing and localised contact pressure and patellar maltracking are primarily responsible. {Kessler 2008 #8}{Malo 2003 #9}{Catani 2013 #28}

Various causes are discussed:

For example Miller et al., Belvedere et al., Luring et al., Kessler et al., Steinbrück et al. described rotational malalignment of the tibial and/or femoral component as reason for patellar maltracking.

Berger et al., Kienapfel et al., Farrokhi et al. mentioned femoral internal rotation to change patellofemoral kinematics. Internal rotation of the femoral component is a possible reason for APFP.

Berger et al. detected correlations between combined internal rotation of the femoral and tibial component and the severity of postoperative patellofemoral complications.

Olcott and Scott, Miller et al., and Luring et al. noticed that the rotation of the femoral component according to the transepicondylar line showed better results than the orientation according to Whiteside’s line or 3° external relative to the posterior condyles because the rotation of the femoral component to the transepicondylar line achieves a better restoration of the physiological patellar kinematics.

Only 2 studies, the studies of Anglin et al., and Belvedere et al. measured patellar kinematics before and after TKA in vivo using the accuracy of computer navigation.

To our best knowledge, there exists no data on patellar kinematics intraoperatively so far.

{Anglin 2015 #61}{Belvedere 2007 #62}{Berger 1998 #63}{Farrokhi 2011 #64}{Kessler 2008 #8}{Kienapfel 2003 #65}{Miller 2001 #66}{Olcott 1999 #67}{Steinbrück 2013 #68}

2.8 Important parametres

2.8.1 Q-angle (Quadriceps angle)

The Q-angle provides information about the stability of the TKA.

The anatomical shape of the patella and the anatomical groove of the femoral trochlea are important factors for patellar stability. It should have a 'V-shape with wide angle and circular base' to ensure normal patellar tracking. Therefore Walker et al. analysed the 'forces between the trochlea and the patella for various Q-angles and flexion angles' whether the patella tilts or rotates in the femoral trochlea as causes for wear and deformation. The results revealed 'that the patella is fully stable and without tilting at all flexion angles for a Q-angle of 14° or less'. Q-angles more than 14° lead to severe misalignment and instability. So, in surgical practice the Q-angles are usually reduced in TKA. {Walker 2001 #15}

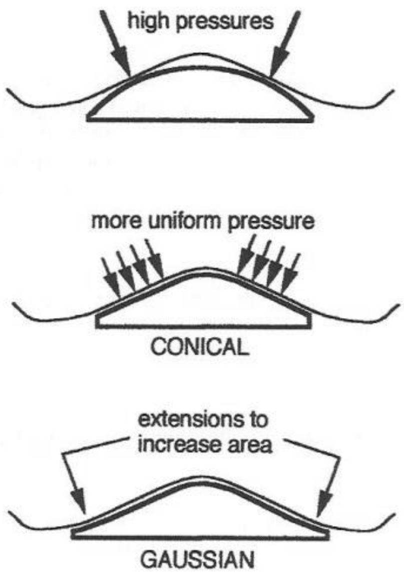

Figure 13: *The three main types of patellae component used in total knees {Walker 2001 #15}*

It is shown up in Fig. 14 that even at full extension of the knee QF (force in quadriceps group) and TF (force in patella tendon) are not collinear which leads to shear stresses that are applied to the patella. Only if the patella is treated as frictionless pulley, which it is not in vivo, then QF = TF. {Walker 2001 #15}{Matthews 1977 #16}

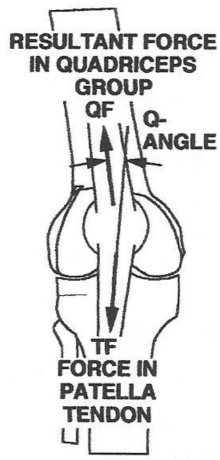

Figure 14: *Definition of the Q-angle {O´Donoghue 1976 #14}*

In Fig. 15, the connection between the flexion angle of the knee and the shear/compression ratio (= S/C ratio) is portrayed as result of the analysis by Walker et al. It can be seen that an increasing Q-angle causes an increasing S/C ratio and in this way a decreasing stability of the patella.

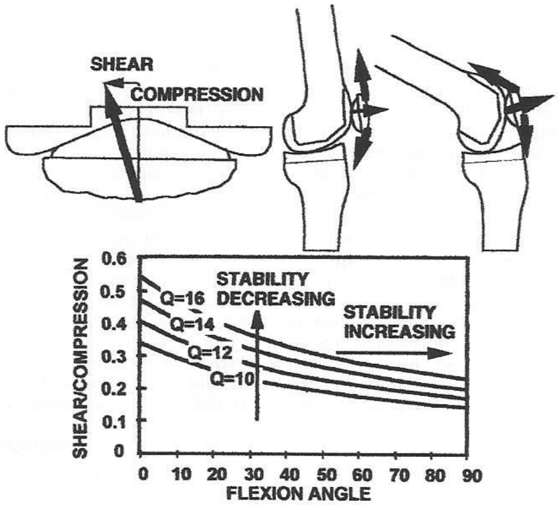

Figure 15: *As the Q-angle increases, the S/C ratio increases, and the patella becomes less stable. As the flexion angle increases, the patella becomes more stable {Walker 2001 #15}*

In Fig. 16, the concrete figures of instability are described. For Q = 14° there is only a small unstable region up to 10° of flexion; for decreasing Q-angles full stability in all flexion angles can be gathered from this table. {Walker 2001 #15}

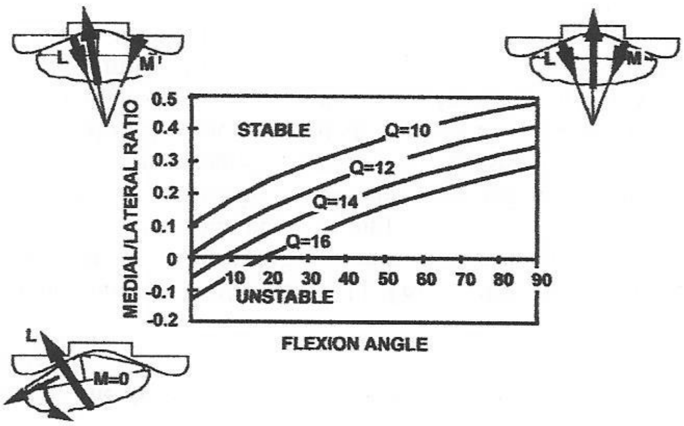

Figure 16: *The unstable region is shown up to 20° for a Q-angle of 16° and up to 10° for a Q-angle of 14°. Below 14° there is complete stability {Walker 2001 #15}*

2.8.2 Modified Insall-Salvati-Index

The distance between the tibial tuberosity and the most distal patellofemoral point of the articulation is divided through the length of the patellar articular surface. The standard values are in between 0.74 and 1.50.

A numeric value more than 1.50 defines a patella alta. A numeric value less than 0.74 defines a patella baja. There are several reasons for a patella baja. It can be a patella baja because of (scarred) shortening of the ligamentum patellae. Otherwise it can be a pseudo patella baja caused by a proximalisation of the joint line. {Pfitzner 2009 #18}{Springorum 2011 #19}{Kazemi 2011 #20}{Shabshin 2004 #26}

2.8.3 Joint line

It is important and challenging to reproduce the natural joint line in TKA. The functional results of a replaced knee can be significantly compromised if the joint line is far from its natural position. This can cause an increase in patellofemoral forces and leads to subluxation, dislocation or fracture. Apart from the patella the postoperative flexion can also be affected or there can be an increase in varus-valgus laxity.

A review of several clinical studies shows a range of proposed joint line displacement thresholds from 3-13 mm. At values over these thresholds motion, pain, above all patellofemoral pain and function of the knee are affected negatively. {Mason 2006 #52}

2.9 Clinical assessment

For the clinical assessment the following standardised questionnaires were used:

1. The KSS (Knee Society Score) consists of the following parts: the Knee Score and the Function Score. In each score the maximum is 100 points. The Knee Score is based on pain, range of movement, flexion contractures or extension lag and alignment. The Function Score quantifies activities of daily living, such as walking distance, stair climbing and the use of walking aids. Thus, a total score of 200 points indicates full function associated with no pain. {Liow 2000 #24}

2. The WOMAC Index (Western Ontario and McMaster Universities Osteoarthritis Index) is a generalised scoring system for osteoarthritis. It contains the 3 parts pain, stiffness and functionality. The total score ranges from 0 to 96 points. Here, the lower the score, the better the result. To receive a better comparison pre- and postoperatively, the results are expressed as a percentage. {Ackerman 2009 #10}

3. The PATELLAR SCORE / FELLER SCORE is a scoring system which evaluates especially the patellar function by enquiring about anterior knee pain, the strength of the quadriceps, the ability of getting up from a chair as well as climbing stairs. A total score of 30 points indicates full function and no pain regarding the patella. {Feller 1996 #69}

4. The HAKEMP-90 (Handlungskontrolle nach Erfolg, Misserfolg und prospektiv) was used as personality questionnaire. It evaluates the action control after success and failure. In this study the two sections HOM (Handlungsorientierung nach Misserfolg = self-calming) and HOP (= prospektive Handlungsorientierung = self-motivation) in stressful situations are assessed {Kuhl 1990 #25}. In each section it is possible to achieve 12 points at maximum, so in this study 24 points in total signify full action control.
A third score, the score HOT/LOT is possible to include, but it is influenced by many other variables, so it can be excluded according to the author. {Kuhl 2012 #12}
This third score was not used in this study.

2.10 Patella navigation

Because of the former discussed errors of the conventional technique the navigation technique got a standard method in daily clinical practice. Although navigation demands longer operation time – depending on literature between 8 and 15 minutes it results in much better alignment of the implants. Controlled ligament-balancing achieves better stability in flexion and extension. {Jerosch 2007 #70}{Bäthis 2003 #45}

Bäthis et al. investigated the difference between CT based and CT free navigation. The CT based version allows a precise preoperative planning but this is associated with additional costs and administrative effort, as well as exposure to radiation. The CT free navigation provides ‘intraoperative visualisation of the leg axis, ligament balancing and joint kinematics’.

Errors in cutting are avoided in both modules similarly. {Bäthis 2003 #45}

2.11 Objective of the study

Patellar tracking is defined as patellar shift, patellar tilt, patellar flexion and patellar rotation. Every change of the above mentioned physiological conditions leads to patellar maltracking. But also extrapatellar parametres like the mechanical axis of the leg, the Q-angle, the modified Insall-Salvati-Index, the femoral rotation, or the joint line have an influence on patellar tracking and are important to be carried out precisely during the operation.

The purpose of this study was to examine the changes in patellar tracking before and after a ligament-balanced navigated TKA. Patellar kinematics after TKA are not well understood so far.

3. Materials and methods

3.1 Background of the study

We included 40 patients (19 women, 21 men) designated for TKA between November 2012 and October 2013.

As mentioned before, anterior knee pain is one of the most common postoperative complications after TKA, and according to various studies, for example of Miller et al. (2001b), Kienapfel et al. (2003), and Heinert et al. (2011), patellar maltracking is one of the underlying reasons. {Miller 2001 #66}{Kienapfel 2003 #65}{Heinert 2011 #71}

In this study the preoperative patellar kinematics of the osteoarthritic knee were compared with the kinematics after the operation. All patients received a navigated TKA using a ligament-balanced technique.

The following parametres were measured intraoperatively before and after TKA:

- Patellar shift
- Patellar tilt
- Rotation
- Epicondylar distance
- Axial and sagittal femoral and tibial component alignment and its influence on patellar kinematics using generalised linear models. This concept, the ‘analysis of combined component alignment and its effect on patellar kinematics intraoperatively using patellar navigation’ {Keshmiri 2015 #72} shall prevent the feared patellar maltracking.

Patients were asked to complete the questionnaires preoperatively, 7 and 28 days after the surgical procedure.

Radiological assessment was carried out pre- and 7 days postoperatively.

3.2 Patients

For this study 46 patients were recruited. All of them had primary osteoarthritis of the knee (Kellgren and Lawrence grade III-IV), were designated for TKA, and received a standard, cemented, cruciate retaining TKA with fixed platform (PFC Sigma; DePuy, Warsaw, IN). The TKA was implanted in ligament-balanced technique using computer navigation, including the record of intraoperative patellar tracking (BrainLAB, Feldkirchen, Germany).

6 patients were excluded according to the criteria of ‘varus/valgus deformity > 15°; sagittal or medio-lateral instability > 5 mm (grade 1+); extension deficiency; insufficient, or missing posterior cruciate ligament; tibial or femoral bone loss; previous patella dislocation; or previous surgical intervention on the relevant knee’. {Keshmiri 2015 #72}

Hence, the final study population includes 40 patients (19 women, 21 men). The parametres age, weight and BMI are displayed in Table 1.

	Age (years)	**Weight (kilogram)**	**BMI**
Female (average)	**64.6**	**83**	**32.01**
Male (average)	**65.3**	**93**	**30.81**
Total (average) **→ range (from –to)**	**65** **51-89 years**	**88** **58-144 kg**	**31.41** **22.72 – 49.83**

Table 1: *Demographic data of patients*

To create equal conditions before and after TKA neither patella replacements nor other surgical patellar interventions were performed.

The patients have been suffering from pain before undergoing surgery for an average period of 53 months (4.4 years). Remarkable is, that men waited almost twice as long to undergo the operation of the procedure.

	Time of pain (months)
Female (average)	**36**
Male (average)	**69**
Total (average)	**53**

Table 2: *Schedule of pain*

3.3 Surgical procedure using patellar navigation

- The operation was started with a midline skin incision.
- Then, a standard medial parapatellar approach was used.
- The capsule was marked at predefined locations with the result that later anatomical reconstruction was ascertained.
- 2 passive optical reference arrays were attached on the distal medial femur and the proximal medial tibia.
- The centre of the hip was measured by circumduction.
- The landmarks for the femorotibial kinematics were reported by the navigation system in digital form.

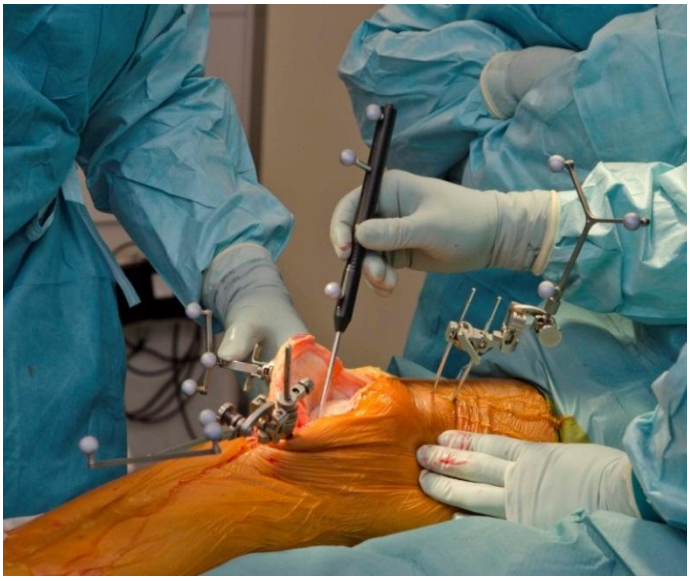

Figure 17: *Measuring the landmarks {Keshmiri #100}*

- Next step was to fix the patellar array onto the anterior side of the patella.

Figure 18: *Fixing the navigation array on the patella by using a screw {Keshmiri #100}*

- BrainLab specifies the 'patella coordinate frame' as 'a point at the medial, superior, and inferior edge and at the middle of the posterior articular ridge of the patella'.
- The joint capsule was sutured.

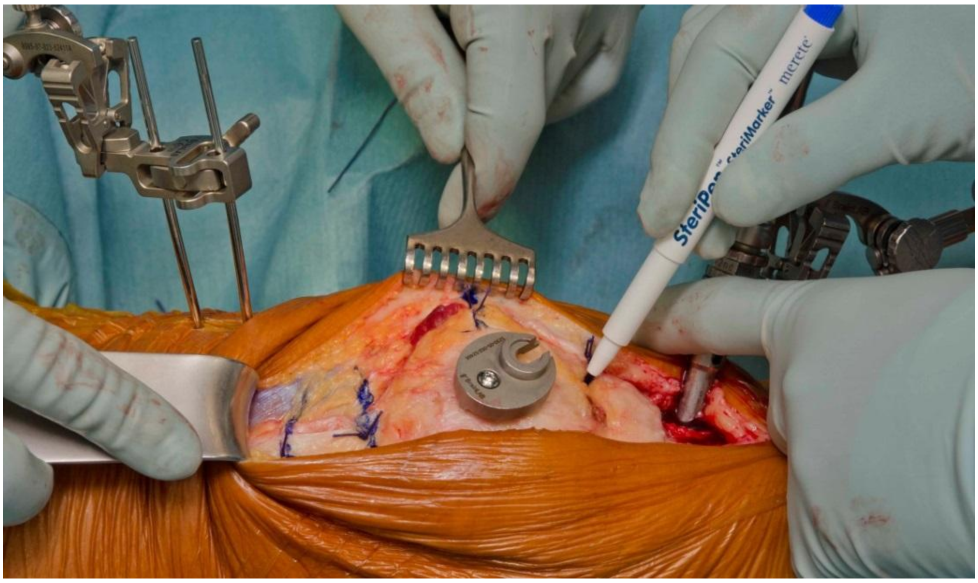

Figure 19: *Suture of the capsule and marking {Keshmiri #100}*

- Then, 'natural patellar kinematics and the relative orientation between femur, tibia and patella were recorded between 30° and 90° flexion during passive motion.'
- Navigation calculated during the motion cycle the position of the 'registered patella coordinate frame relative to the coordinate frame of the femur'. Furthermore, the absolute and relative values for 'patellar mediolateral shift (medial: +, lateral: -); axial tilt (medial: - lateral: +), and coronal rotation (external: -, internal: +) of the patella' were gathered. During the motion cycle, the epicondylar distance was recorded. It is described as 'the line from the previously chosen point at the middle of the posterior articular ride of the patella perpendicular to the transepicondylar line, which is built from the registered femoral epicondyles'. The epicondylar distance is important as it 'gives information about the anterior-posterior position of the patella throughout the flexion cycle in relation to the femur.'

Figure 20: *Patella tracking before the implantation {Keshmiri #100}*

- The osteophytes were removed at the medial and the lateral compartment.
- The tibial cut was made.
- The double tensiometre was fixed at ‘0° of extension and 90° of flexion with a distraction force of 90 N.’
- In the frontal plane 0° were targeted between the femoral and tibial mechanical axis.
- To gain ligament balancing, the ‘flexion gap was adapted through bony cuts by the navigation software.’
- According to Berger et al. the femoral component rotation was ‘set by ligament balancing and the rotation of the tibial component.’
- After the implantation of the prosthesis the patellar kinematics were carried out with the component placement suggested by the navigation system.

{Keshmiri 2015 #72}{Bäthis 2003 #45}{Berger 1998 #63}

- In all cases the patellae were left in their natural state, that means no surgical intervention was performed regarding the patella.
- Then, the measurement was made by the surgeon lifting the limbs vertically at the distal femur without touching the tibia. This motion cycle was performed twice. Thereby, values up to 30° of flexion were removed as these values were irregular because of missing muscle tone and floppy patellae. Furthermore, the ‘definitive femoral component rotation and flexion and the tibial component rotation and slope were recorded intraoperatively’. All data were gathered using patellar tracking software application for TKA (Patellar Tracking; BrainLab AG, Feldkirchen, Germany).

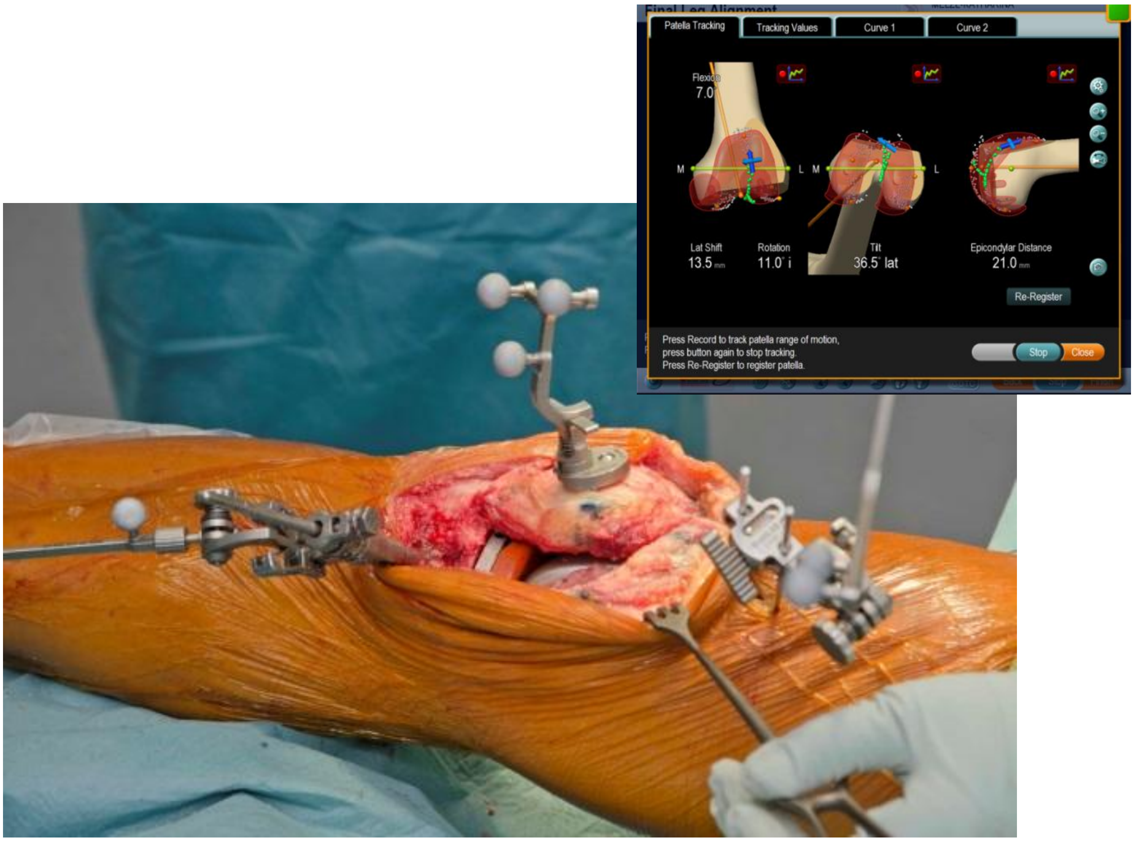

Figure 21: *Patella tracking after the implantation with fixed components {Keshmiri #100}*

3.4 Examinations

For this study standardised radiological and clinical assessments were used pre- and postoperatively.

3.4.1 Radiological assessment

In this study radiological assessment was carried out pre- and postoperatively with regard to the alignment (varus/valgus angle), the Q-angle, the modified Insall-Salvati-Index, the patellar shift and tilt and the joint line. Therefore long leg imaging (a/p and lateral) and a patella sunrise view were taken.

3.4.1.1 Leg axis

It is defined by the angle between the centre of the hip to the femoral centre of the knee joint and the centre of the tibial knee joint to the centre of the ankle joint. It was measured before and after the operation aiming at an angle of 180° postoperatively to achieve homogeneous distribution of the pressure. This is important to counteract uneven wear as one of the causes of aseptic loosening. The a/p X-ray image should be taken while the patient is standing and the axial measurement can only be precisely done by taking a long leg radiograph. {Pietsch 2006 #13}

The physiological axis of the leg is defined as 180°. Values between 177° and 183° define the neutral average value. Angles < -177° are defined as genua vara, angles > 183° as genua valga. {Bäthis 2004 #46}

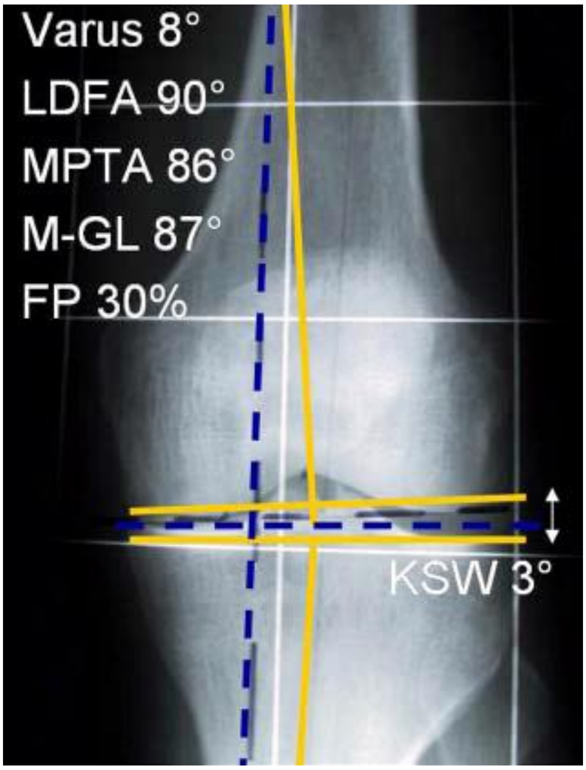

Figure 22: *Long leg measurement {Pietsch 2006 #13}*

3.4.1.2 Q-angle

The Q-angle (Quadriceps angle) was assessed by calculating the angle between the direction of the rectus femoris (QF) as resultant force of the quadriceps group and the patella ligament (=TF). The reference value is 8-10° in males and 12-16° in females. {O´Donoghue 1976 #14}

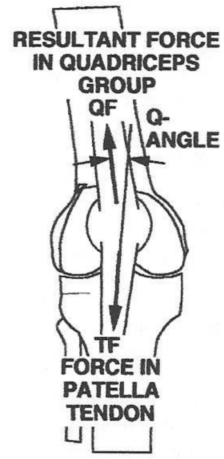

Figure 14: *Definition of the Q-Angle {O´Donoghue 1976 #14}*

3.4.1.3. Modified Insall-Salvati-Index

The knee should be 30° flexed, ideally. Then, the modified Insall-Salvati-Index was calculated by dividing the distance between the tibial tuberosity and the most distal patellofemoral point of the articulation (A) by the length of the patella articular surface (B). The standard of the modified method is the ratio A/B between 0.74 and 1.50. {Shabshin 2004 #26} {Springorum 2011 #19}

Figure 23: *Modified Insall-Salvati-Index {Springorum 2011 #19}*

3.4.1.4 Patellar shift and tilt

Patellar shift and tilt were measured pre-and postoperatively using patella defilée imaging in 60° flexion.

The patellar shift is defined as medial or lateral movement of the centre of the patella along the transepicondylar axis (TEA) (medial shift: +, lateral shift: -).

The patellar tilt is defined as the rotation of the patella about its long axis (medial tilt: +, lateral tilt: -) {Nha 2008 #41}

3.4.1.5 Joint line

In this study the deviation of the joint line was assessed using a long-leg axis imaging under weight-bearing. The joint line is defined as the contact line of the distal femur and the proximal tibia. The height was measured as distance to the fibula head in the tibial shaft axis. {Maderbacher 2015 #73}

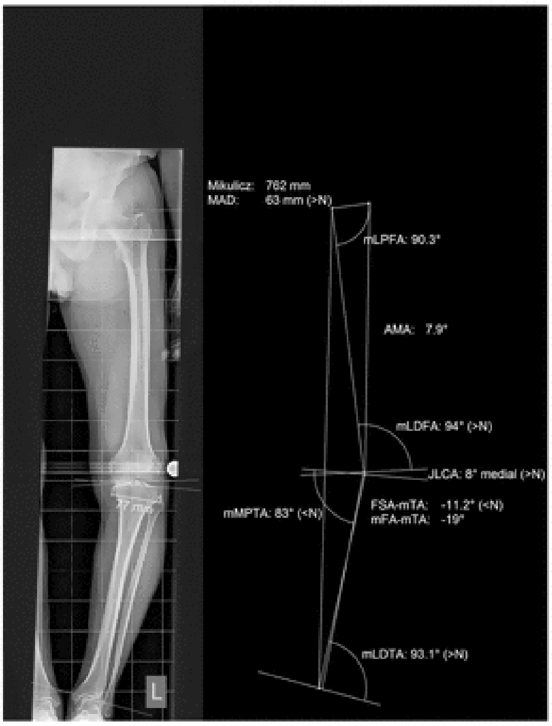

Fig. 1 Measurements in long-leg radiographs. Using weight-bearing scaled long-leg radiographs, we assessed the centre of the hip, the centre of the distal femur, the centre of the proximal tibia, the centre of the talus, and the shaft axes, both the tibia and the femur, and determined the mechanical axis, the mechanical medial proximal tibial angle, the lateral distal femoral angle, and the femoral anatomical mechanical angle

Figure 24: *Measurements in long-leg radiographs {Maderbacher 2015 #73}*

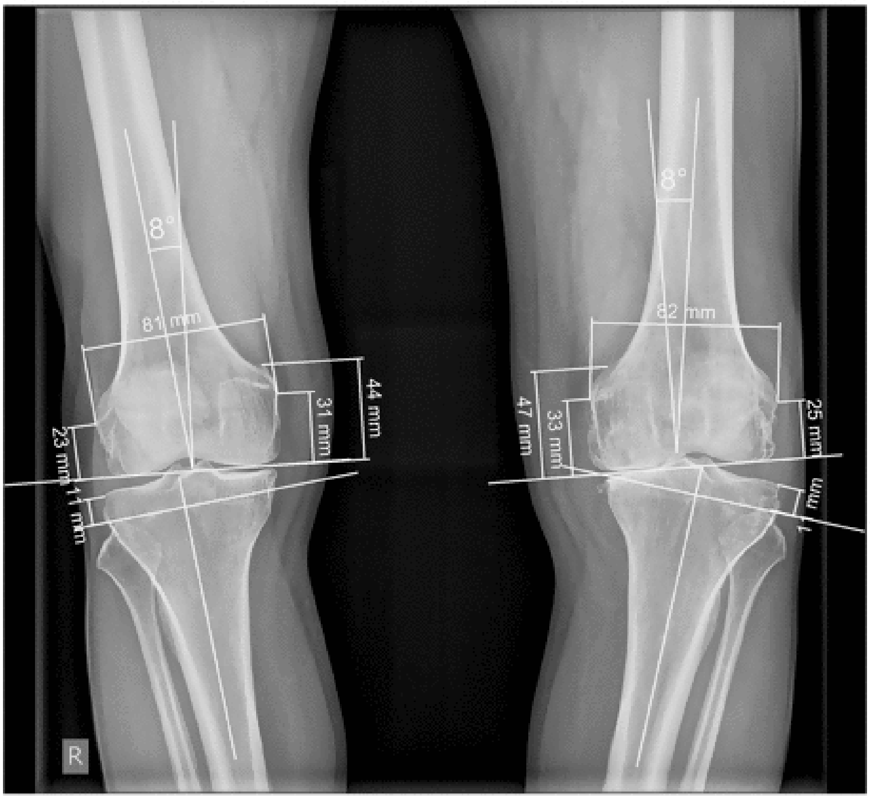

Fig. 2 Measurements in both knee radiographs. The mechanical femoral and tibial axis was inserted from the long-leg radiograph (in this case AMA = 8°). Distance between the fibular head and the joint line: perpendicular to the mechanical tibial axis, a line was placed at the most proximal point of the fibular head. Parallel to the mechanical tibial axis, the distance between the perpendicular line to the fibular head and the lateral proximal tibial cortex was measured to determine the distance between the fibular head and the joint line. A line perpendicular to the mechanical femoral axis was placed tangentially to the most distal point of the medial and the lateral femoral condyle. Distances between the adductor tubercle and the medial and lateral epicondyle to the joint line were determined by measuring the distances parallel to the femoral mechanical axis between the bony landmarks to the tangent and to the medial and lateral condyle. Femoral width was defined as the shortest distance between the medial and the lateral epicondyle

Figure 25: *Measurements in both knee radiographs {Maderbacher 2015 #73}*

3.4.1.6 Femoral rotation by means of navigation

Femoral rotation was assessed during the operation by means of navigation. It was measured related to the epicondylar line. External rotation is reported as a negative value, internal rotation as a positive value. {Keshmiri 2015 #72}

3.4.2 Clinical assessment

The 4 questionnaires: KSS, WOMAC, Feller/Patellar Score and the HAKEMP-90 were carried out preoperatively, and 7 and 28 days postoperatively.

3.4.3 Statistical evaluation

For the statistical evaluation first, the normal distribution of the data was checked using the Kolmogorow-Smirnow-Test. For normally distributed data the paired t-test was further used, for not normally distributed data the Wilcoxon signed rank test was further used (SigmaPlot, Erkrath – Amtsgericht Wuppertal, Germany).

3.4.4 Complications

Postoperative complications were monitored until the 28th day after surgery.

4. Results

4.1 Radiological assessment

4.1.1 Leg axis

The mean of the preoperative leg axis was 175.15° (SD 5.67; range 162° - 189°).

There were 27 (67.5%) patients with genua vara, 9 (22.5%) patients within the neutral average value and 4 (10%) with genua valga.

After the operation the mean of the leg axis was 180.53° (SD 1.4; range 177° - 184°).

There were 39 (97.5%) patients within the neutral average value. 1 (2.5%) patient had a slight genu valgum of 184°, none had a genu varum.

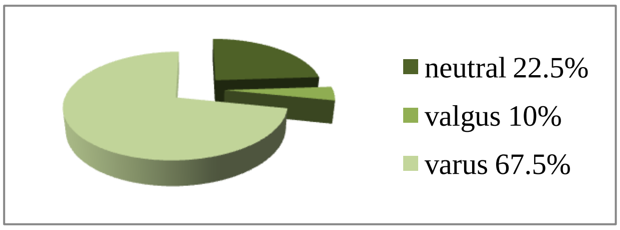

Figure 26: *Preoperative deviation of the axis (tolerance range)*

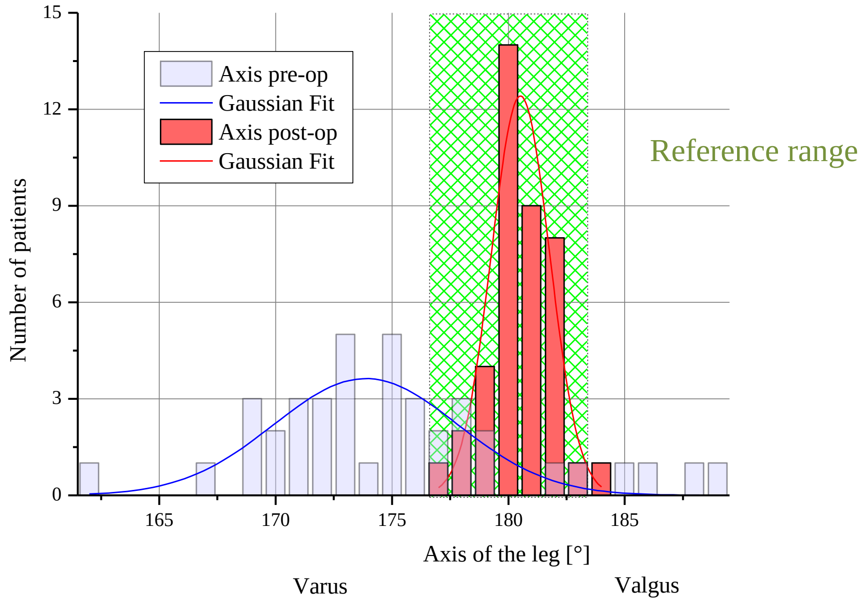

Figure 27: *Pre- and postoperative deviation of the axis (absolute values)*

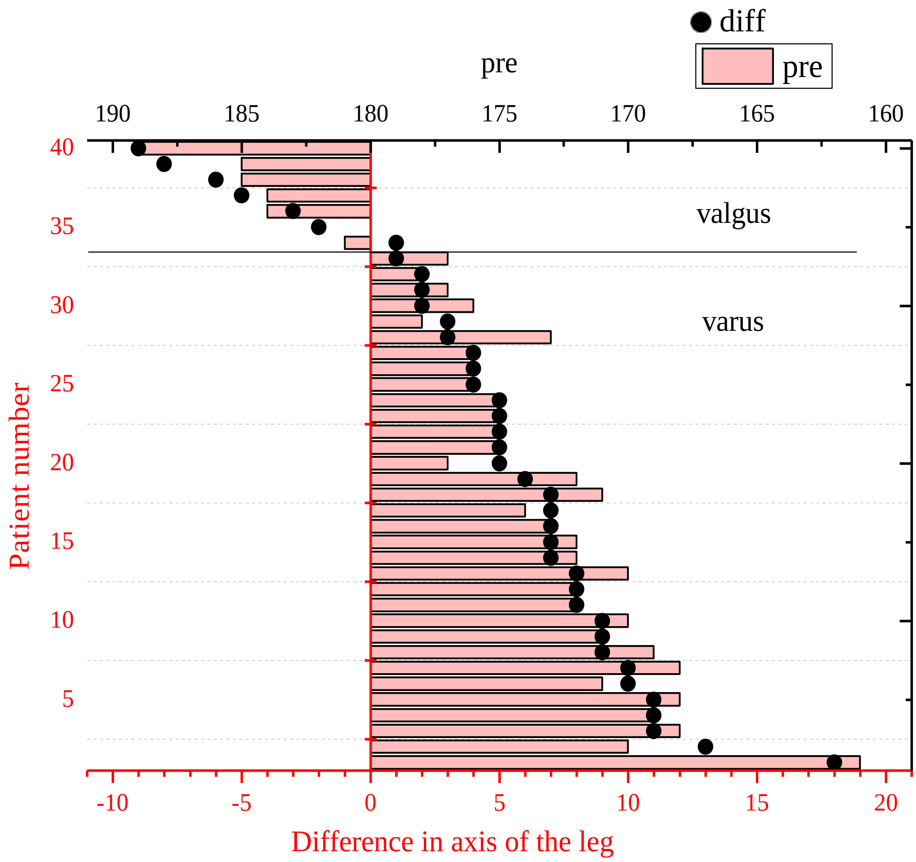

Figure 28: *Pre- and postoperative deviation of the axis in each case*

Figure 28 shows the deviation of the preoperative leg axis (bar chart) in relation to how many degrees the axis has been modified (dots) in each case.

4.1.2 Q-angle

<u>Females preoperatively</u>

Preoperatively, the mean Q-angle in females was 14.26° (SD 2.2; range 12° – 18°).

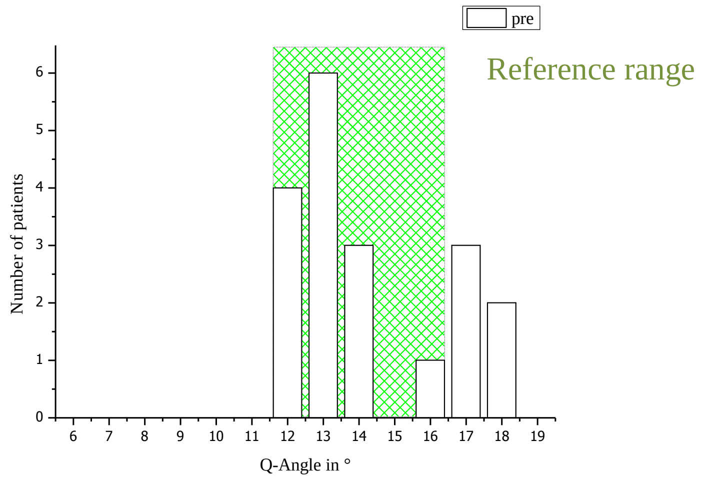

Figure 29: *Preoperative deviation of the Q-angle (females)*

<u>Males preoperatively</u>

Preoperatively, the mean Q-angle in males was 10.19° (SD 2.8; range 7° - 17°).

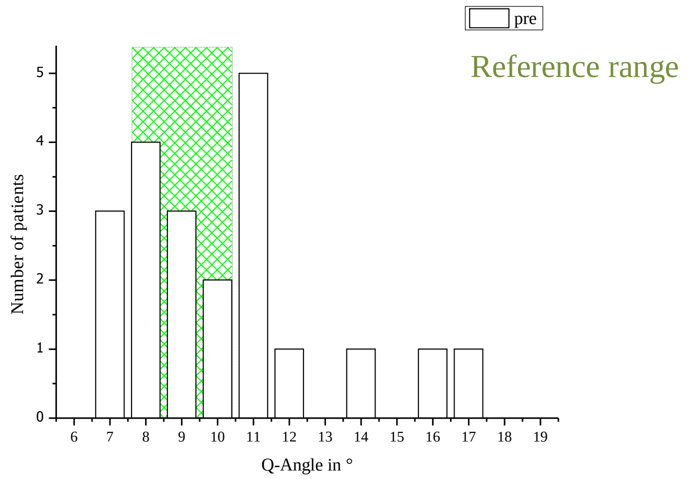

Figure 30: *Preoperative deviation of the Q-angle (males)*

Females postoperatively

Postoperatively, the mean Q-angle in females was 12.32° (SD 1.2; range 10° - 15°)

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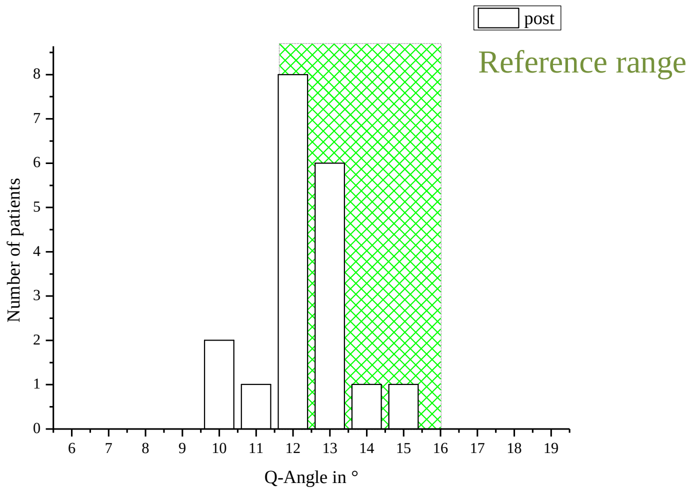

Figure 31: *Postoperative deviation of the Q-angle (females)*

Males postoperatively

Postoperatively, the mean Q-angle in males was 8.48° (SD 0.9; range 7° - 10°).

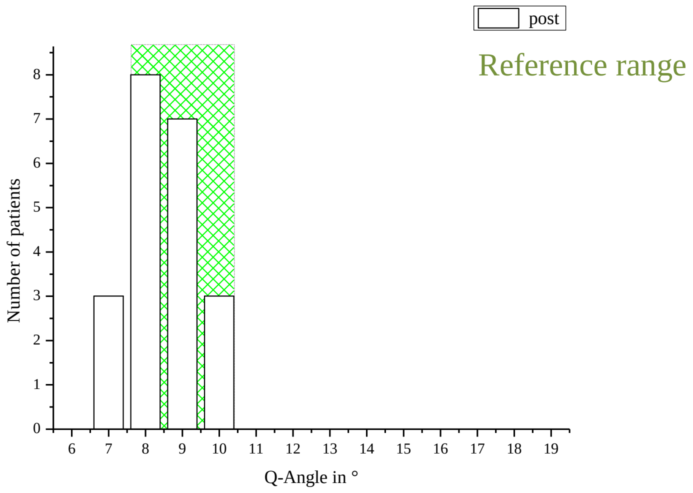

Figure 32: *Postoperative deviation of the Q-angle*

4.1.3 Modified Insall-Salvati-Index

The preoperative mean modified Insall-Salvati-Index was 1.40 (SD 0.2; range 1.0 - 1.7).

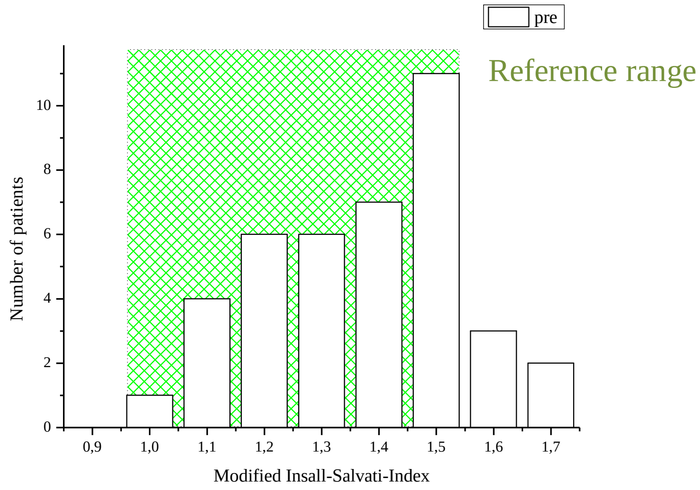

Figure 33: *Preoperative modified Insall-Salvati-Index (absolute values)*

Postoperatively, the modified Insall-Salvati-Index was 1.24 (SD 0.1; range 0.9 - 1.4).

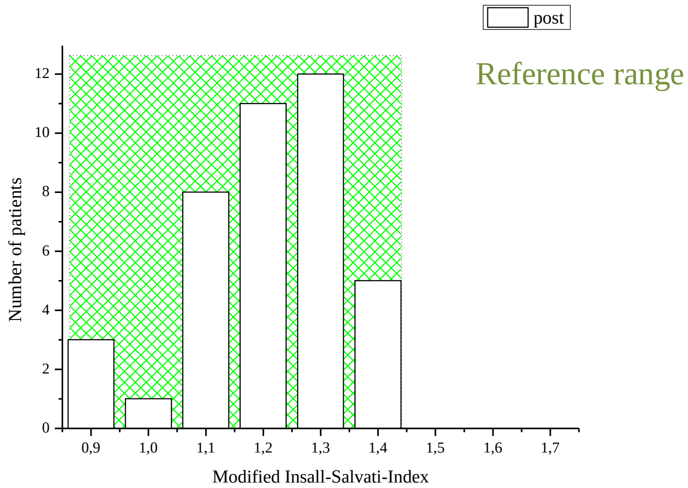

Figure 34: *Postoperative modified Insall-Salvati-Index (absolute values)*

The deviation in medians pre- to postoperatively was 0.13. Changes were statistically significant ($p<0.001$).

4.1.4 Patellar shift

The patellar shift was measured using X-ray.

Preoperatively, the mean patellar shift was -3.3 mm (SD 4; range -14mm – 5mm).

32 (80%) patients had a lateral patellar shift, 8 patients (20%) had medial patellar shift.

Postoperatively, the mean shift was -2.4 mm (SD 3.8; range -10mm – 3 mm).

28 (70%) patients had a lateral shift of the patella, 12 (30%) patients had a medial shift.

The mean difference pre- and postoperatively was -0.9 mm (SD 5 mm; range 11 – 1). The changes were not significant (p=0.26).

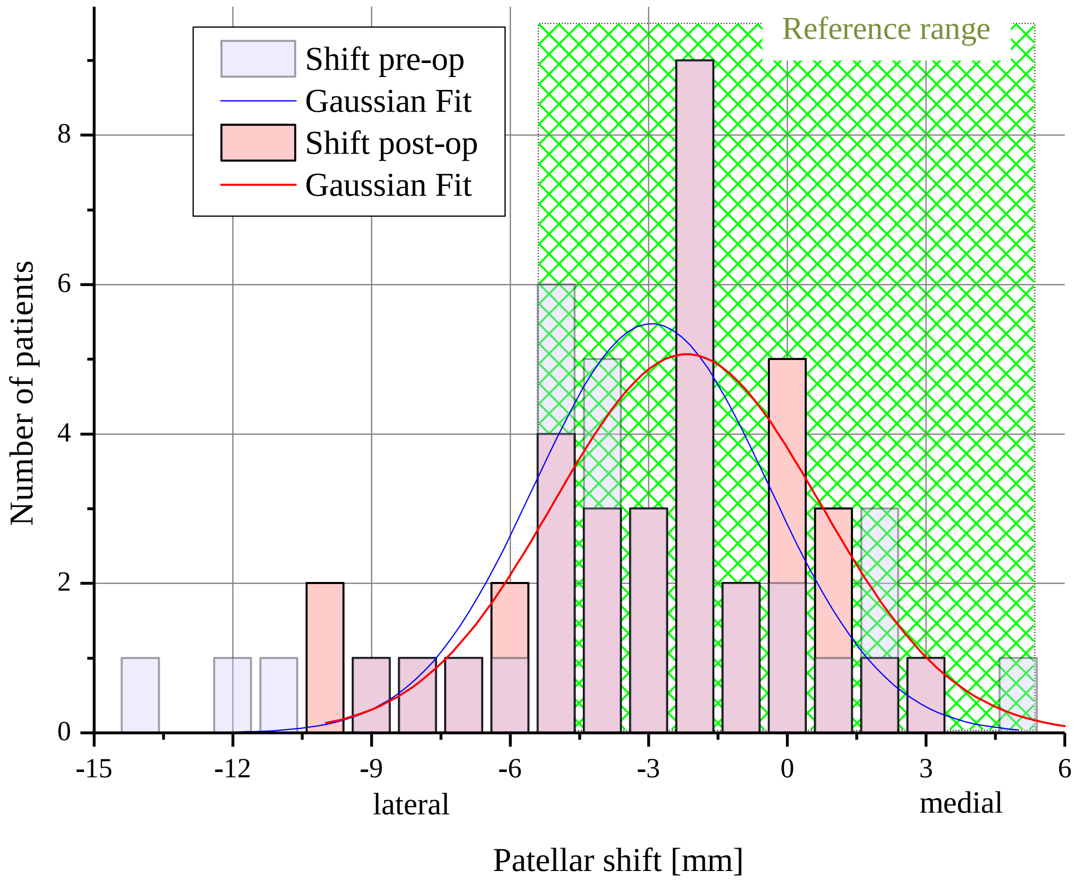

Figure 35: *Pre- and postoperative deviation of the patellar shift (absolute values)*

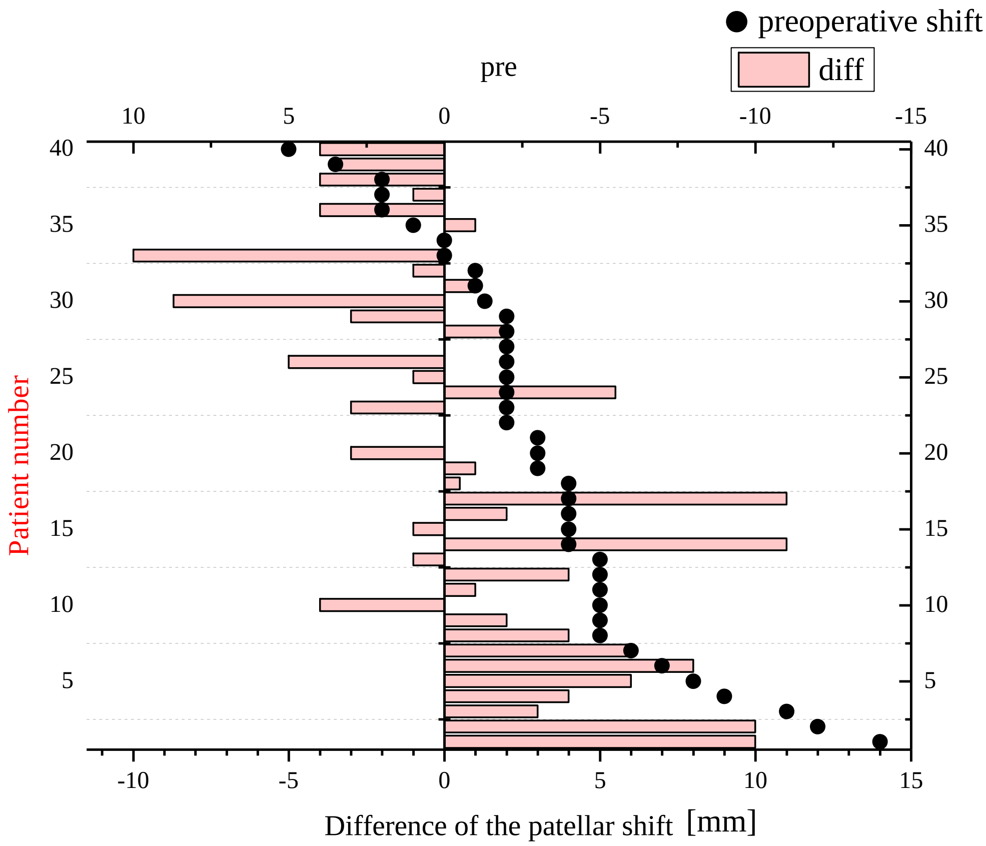

Figure 36: *Pre- and postoperative deviation of the patellar shift in each case*

Figure 36 shows the deviation of the patellar shift preoperatively (dots) in relation to how much it has been modified during the operation (bar chart) in each case.

4.1.5 Patellar tilt

The patellar tilt was measured using X-ray.

Preoperatively, the mean patellar tilt was -4.19° (SD 5.4; range -16° - 14.5°).

In 31 (77.5%) patients the patella tilted laterally, in 9 (22.5%) patients the patella tilted medially.

Postoperatively, the mean tilt was -0.2° (SD 4.3; range -9° - 8°).

In 18 (45%) patients the patella tilted laterally, in 22 (55%) patients the patella tilted medially.

The X-ray evaluation pre- and postoperatively showed a mean difference of 3.99° (SD 4.8°, range -14 – 9). The changes were statistically significant ($p<0.001$).

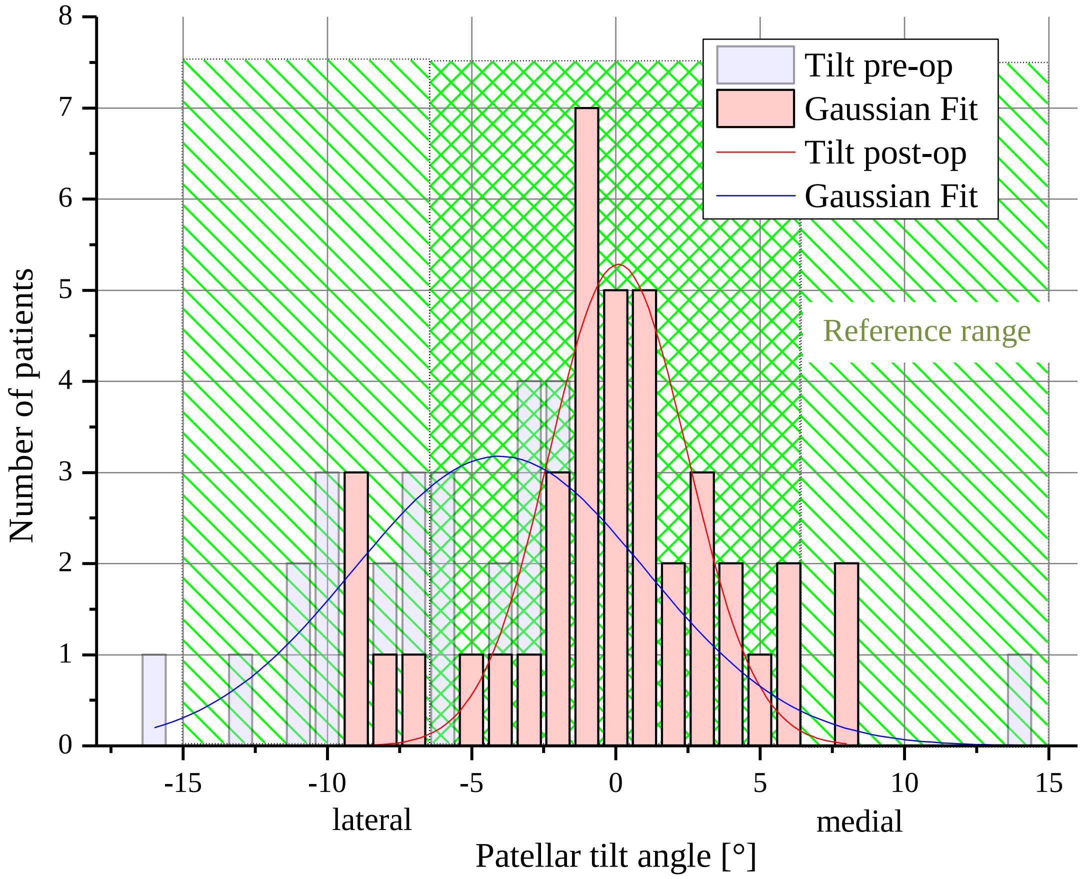

Figure 37: *Pre- and postoperative deviation of the patellar tilt (absolute values) (chequered: reference range; striped: extended reference range = patients were found pain-free)*

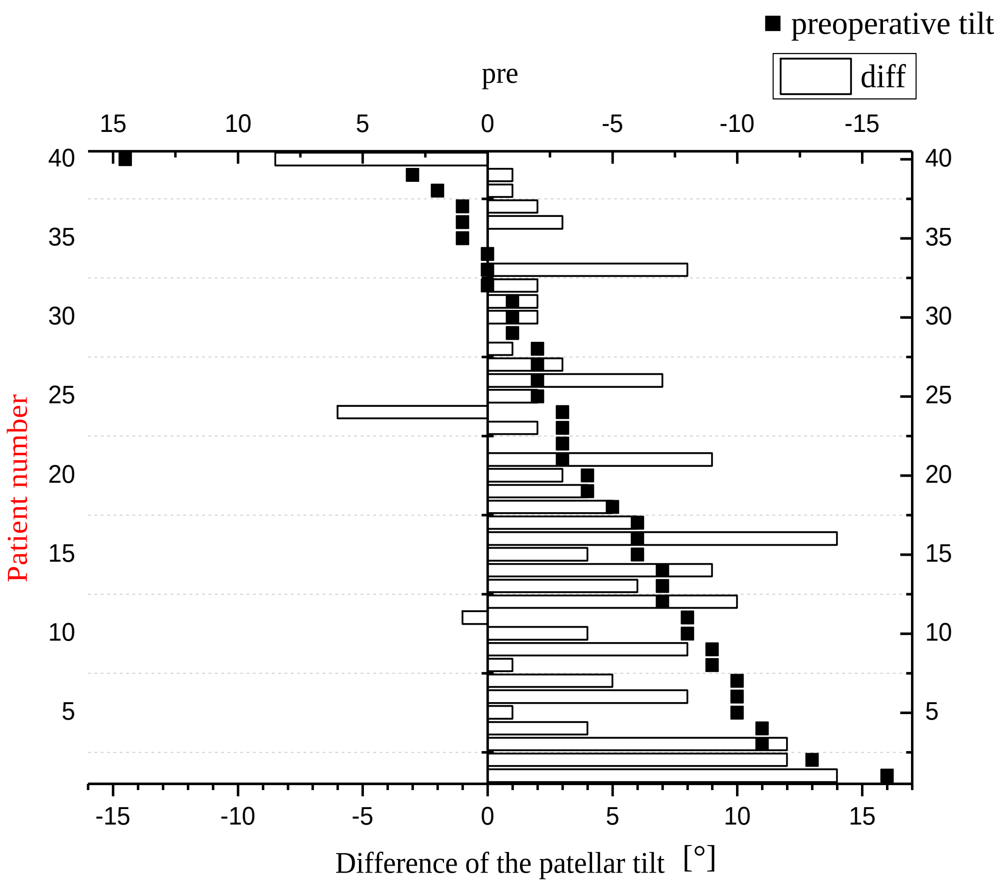

Figure 38: *Pre- and postoperative deviation of the patellar tilt in each case*

Figure 38 shows the deviation of the patellar tilt preoperatively (boxes) in relation to how much it has been modified during the operation (bar chart) in each case.

4.1.6 Joint line

Preoperatively, the mean distance was 10.44 mm (SD 5.47; range 0 mm – 23 mm).
Postoperatively, the mean distance was 12.53 mm (SD 3.8; range 5 mm - 21 mm).
The preoperative and postoperative joint line showed a mean difference of 2.1 mm of elevation (±3.5 mm; range -5 to +12 mm). The change of the joint line was significant ($p<0.001$).

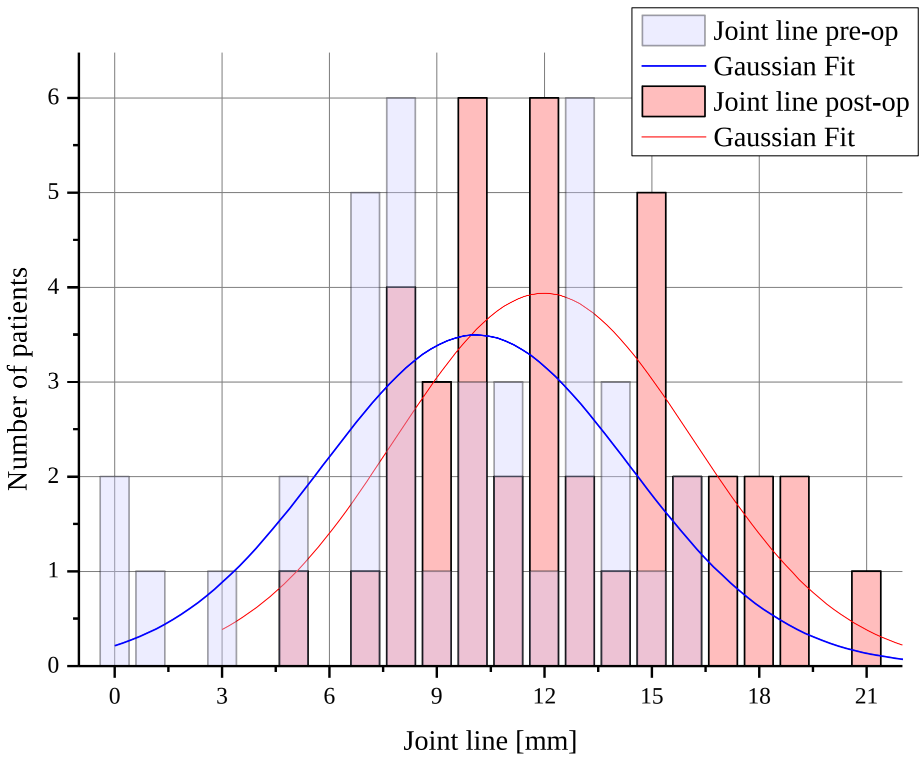

Figure 39: *Pre- and postoperative deviation of the joint line (absolute values)*

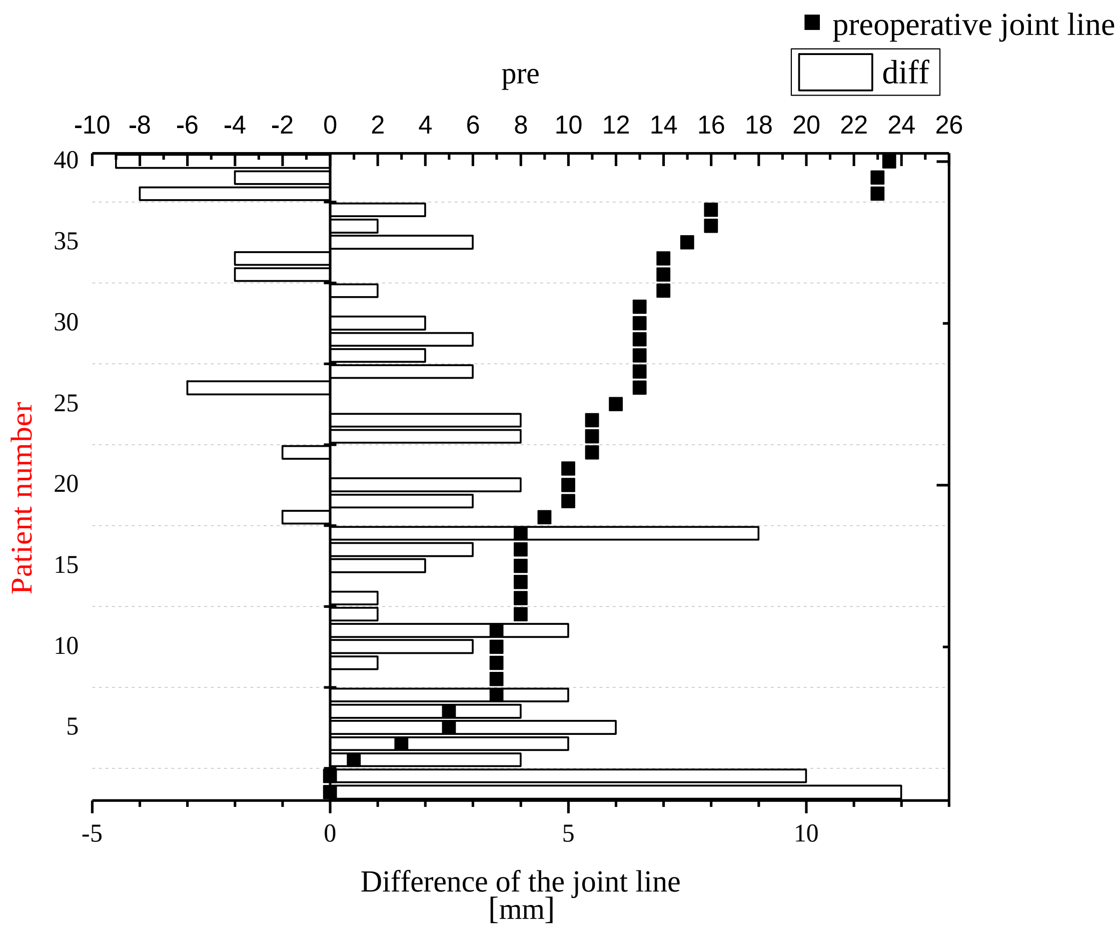

Figure 40: *Pre- and postoperative deviation of the joint line in each case*

Figure 40 shows the deviation of the joint line (boxes) in relation to how much it has been modified during the operation (bar chart) in each case.

4.1.7 Femoral rotation by means of navigation

Postoperatively, the mean deviation of the rotation of the femoral component was -4.68° (SD 6.3; range: -16° - 13.5°).

In 34 (85%) patients the femoral component was implanted in external rotation, in 5 (12.5%) patients in internal rotation. In 1 (2.5%) patient there was nearly no rotation.

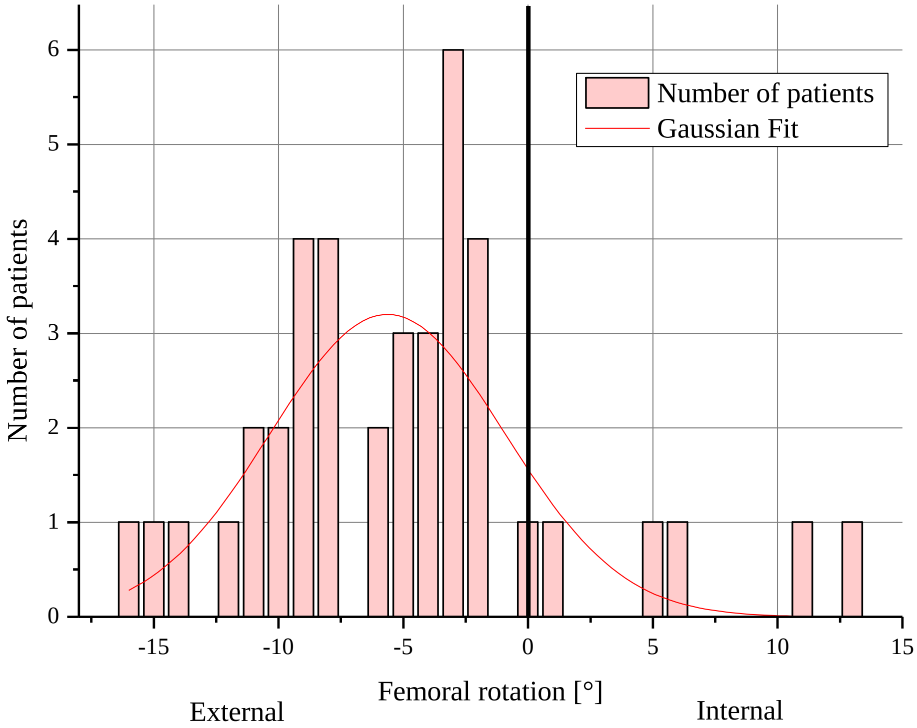

Figure 41: *Postoperative deviation of the femoral rotation (absolute values)*

4.1.8 Overview: Patellar tracking using navigation

	Flexion	Mean difference (SD)	95% CI	p-value
Shift	30°	1.6 (4.2)	0.2 to 2.9	0.02
	45°	1.4 (4.2)	0.1 to 2.8	0.03
	60°	1.3 (4.1)	0.0 to 2.6	0.04
	75°	1.1 (4.2)	–0.1 to 2.5	0.1
	90°	0.6 (3.9)	–0.6 to 1.9	0.3
Epicondylar distance	30°	1.2 (4.4)	–0.2 to 2.6	0.1
	45°	1.7 (3.6)	0.5 to 2.8	< 0.01
	60°	1.7 (3.6)	0.5 to 2.8	< 0.01
	75°	1.6 (3.4)	0.5 to 2.7	< 0.01
	90°	0.9 (3.6)	–0.2 to 2.1	0.1
Rotation	30°	–0.5 (3.5)	–1.6 to 0.6	0.4
	45°	–0.5 (3.9)	–1.8 to 0.7	0.4
	60°	–1.0 (4.1)	–2.3 to 0.2	0.1
	75°	–0.9 (4.3)	–2.3 to 0.4	0.2
	90°	–1.2 (4.0)	–2.5 to 0.0	0.1
Tilt	30°	–1.2 (6.4)	–3.3 to 0.8	0.2
	45°	–1.3 (5.6)	–3.2 to 0.4	0.1
	60°	–0.4 (4.9)	–2.0 to 1.1	0.6
	75°	1.2 (4.7)	–0.2 to 2.7	0.1
	90°	3.2 (4.4)	1.8 to 4.6	< 0.01

Table 4: *Pre- vs. postoperative patellar tracking (lateral shift: +; reduction in epicondylar distance: +; internal rotation: -; lateral tilt: -)*

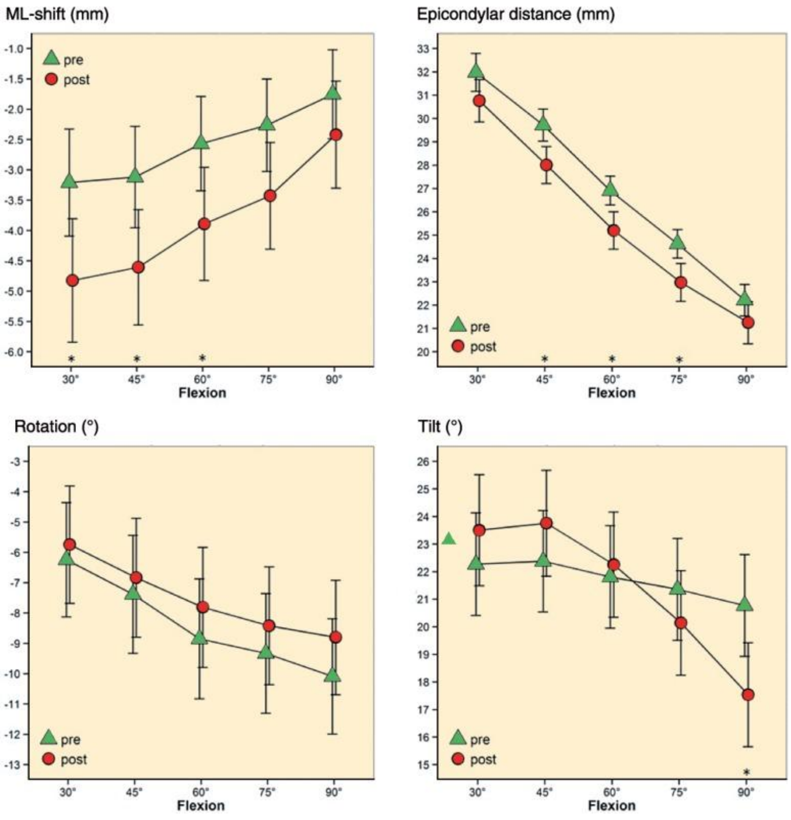

Figure 42: *Pre- and postoperative patellar kinematics (mediolateral shift: medial, +; lateral, −; axial tilt: medial, −; lateral, +; coronal rotation: external, −; internal, +; epicondylar distance (mm) during range of motion: open triangle (preoperatively) and closed circle (postoperatively)). Mean values with standard errors. Asterisks above the x-axis indicate significant differences during range of motion.*

Postoperatively, there was a statistically significant difference between the pre- and postoperative shift between 30° and 60° of flexion. Between 45° - 75° of flexion there was a significant decrease in epicondylar distances during the whole motion cycle. Between 30° and 60° of flexion the patellae tilted more laterally after the operation, beyond (60°-90°) the patellae tilted statistically significant more medially compared to the tilt before surgery. The patellae rotated more medially but this was not statistically significant.

4.2 Clinical assessment

4.2.1 Knee Society Score (KSS)

Preoperatively, the mean was 97 points (SD 20.5; range 61 – 154 points), 7 days postoperatively 97 points as well (SD 29.73; range 54 - 190), and 28 days postoperatively 134 points (SD 19.8; range 85 - 187).

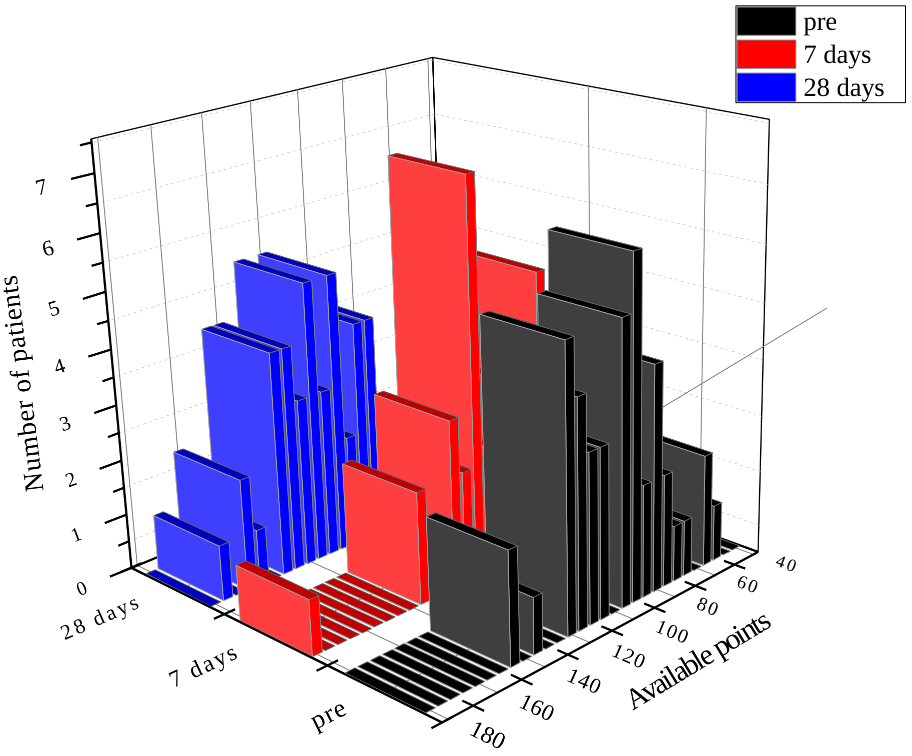

Figure 43: *Knee Society Score pre- and postoperatively*

The Knee Society Score is often given separately in Knee Score (A) and Function Score (B):

	pre		7 days post		28 days post	
	A	B	A	B	A	B
mean	**43.23**	**53.5**	**68.98**	**28.5**	**78.38**	**55**
SD	14.02	13.07	16.21	21.43	14.16	11.55

Table 3: *Pre- and postoperative deviation of Knee Score (A) and Function Score (B)*

The change was statistically significant (p = < 0.001).

4.2.2 Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)

Preoperatively, the mean was 55.7% (SD 12.2; range 26% - 75%), 7 days postoperatively 33.65% (SD 14.4%; range 17% – 70%) and 28 days postoperatively 28.3% (SD 15.9%; range 0% - 71%).

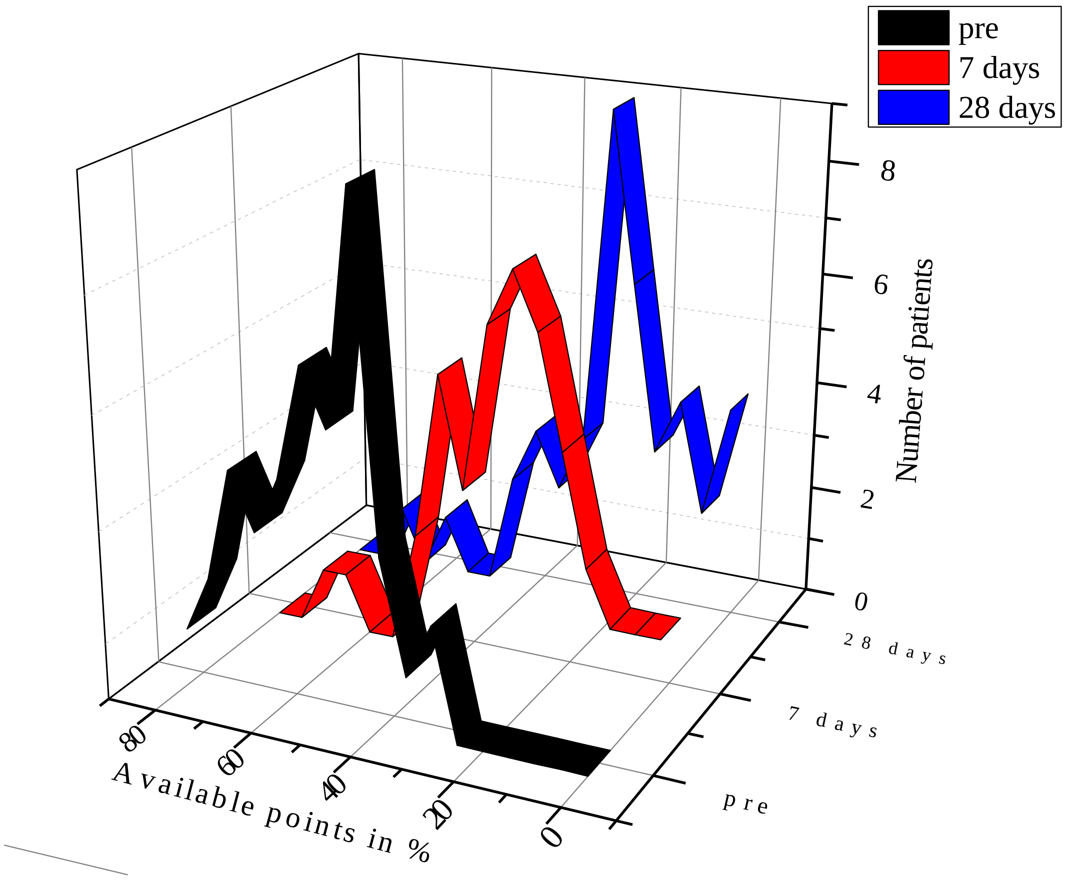

Figure 44: *WOMAC Score pre- and postoperatively*

The change was statistically significant (p = < 0.001).

4.2.3 Feller/Patella Score

Preoperatively, the mean was 18 points (SD 6.16; range 4 – 29 points), postoperatively 22 points (SD 3.75; range 13 – 28 points).

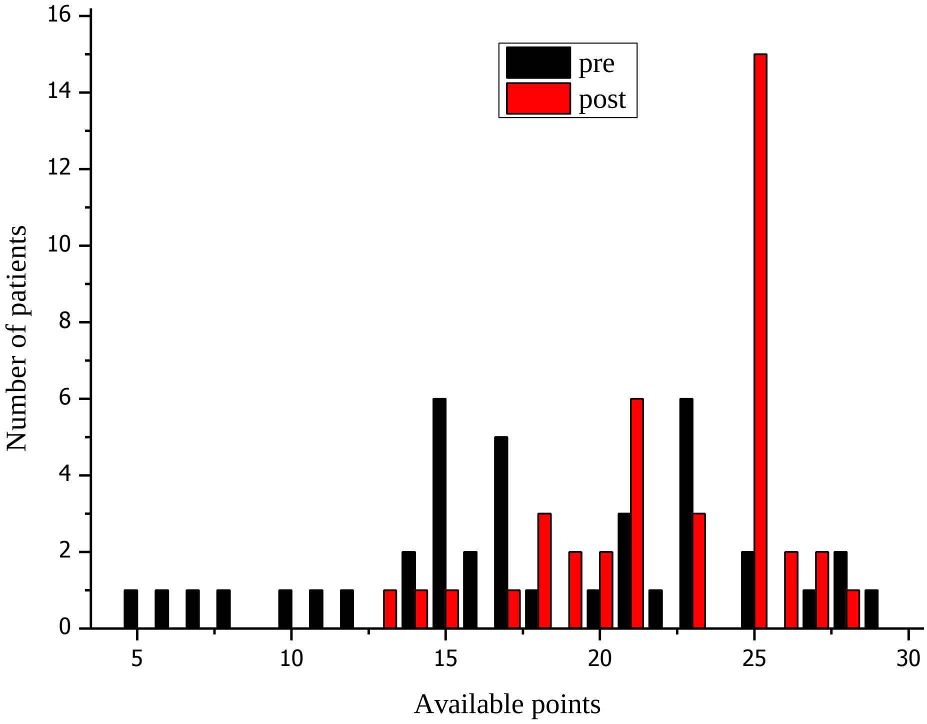

Figure 45: *Patellar Score pre- and 7 days postoperatively*

The change was statistically significant (p = < 0.001).

4.2.4 HAKEMP-90

The mean was 18 points (SD 8; range 0 - 24 points).

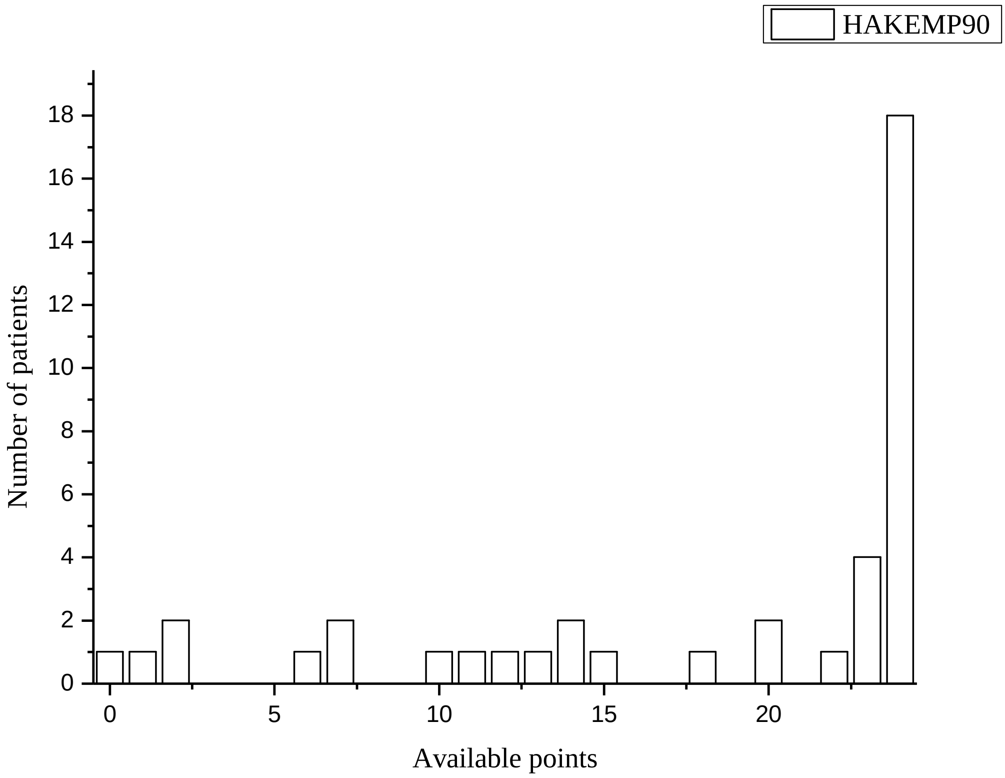

Figure 46: *HAKEMP -90 (absolute values)*

4.2.5 Complications

There were 2 patients with delayed wound healing on day 7 without revision surgery and 1 patient with deep vein thrombosis at day 28.

5. Discussion

Due to the increasing number of TKA – in 2009 alone 175.000 primary TKAs were implanted in Germany, the associated revision rate is rising, too. {Borelli 2011 #74}
Patellofemoral problems are known as one of the major reasons for revision surgery. Thus, the patellofemoral joint is a challenge in treatment. The aim, above all, is to reduce the retropatellar pain syndrome. {Springorum 2012 #4} {Lygre 2010 #75}
Correct patellar tracking is only achieved successfully if the patella moves smoothly in the trochlear groove. To receive such a smooth movement it is necessary to know how the patella moves in the natural knee. {Keshmiri 2014 #110}

The objective of this study was to examine the kinematic and radiological changes of the patella following a ligament-balanced navigated TKA.

5.1 Radiological assessment

5.1.1 Effects of postoperative leg axis on the longevity of the implant

The reconstruction of the leg axis is one of the most discussed causes for premature loosening of the implant in TKA.

Studies of Rand and Coventry described a deviation of 1 mm in 38% of the conventionally implanted TKA ‘Lucent Lines’ which still increased in 34% through time. Above all patients whose axis deviated more than 3° varus or 4° valgus were affected. {Rand 1988 #76} Jeffrey et al. reported in a study with conventionally implanted ‘Denham-Knees’ that only in 3% of the patients within the tolerance range premature loosening occurred. Beyond the tolerance range of +/- 3° leg axis deviation, premature loosening occurred in 24% within 8 years on average. {Jeffery 1991 #56}

Tew et al. described controversially in their studies that there was no significant difference regarding the premature loosening between well aligned and malaligned axes. But he admitted that malalignment aggravates other issues. {Tew 1985 #77}

In recent studies Decking et al., Tingart et al. and Cheng et al. required the restoration of the mechanical leg axis and the accuracy of implant positioning as target of the procedure. In their studies all of them examined how this can be best achieved. Therefore, they compared the accuracy of a navigation system with the conventional technique. {Decking 2005 #104}{Tingart 2008 #105}{Cheng 2012 #106}

Tingart et al. described in their study that the ‘mechanical leg axis was significantly better in the computer-assisted group (95%, within +/- 3° vaurs/valgus) compared to the conventional group (74%, within +/- 3° varus/valgus) ($P<0.001$)’. Using navigation they could achieve a ‘more accurate restoration of the leg alignment‘ as well as a more accurate ‘component orientation compared to the conventional jig-based technique’. But further investigation regarding the long-term outcome is required. {Tingart 2008 #105}

Decking et al. also described a statistically significant difference between the computer-navigated and the conventional method. In more cases of computer-navigation implantation they reached the desired straight axis (3-month follow up). {Decking 2005 #104}

Cheng et al. reported in a meta-analysis between computer-assisted surgery and the conventional technique, that the computer-assisted knees had an improved mechanical leg axis as well as a better component orientation. {Cheng 2012 #106}

5.1.2 Radiological errors of evaluation

A basic problem of the evaluation is the measurement of radiographs. The largest error source is the rotation of the knee joint during the imaging. Clemens et al. detected a miscalculation of 0° - 2° for a rotation of ± 20° in the hip joint. {Clemens 2003 #79}

Wright et al. could show that the radiological assessment is reliable if the leg has no bending contracture and not more than 10° rotation from the neutral position. Hence, a conscientious training of the personnel and the use of standardised X-ray protocols is indispensable to achieve exact measurement results. {Wright 1991 #80}

A CT scan is only necessary in specific cases because of higher costs and significant amounts of radiation. Furthermore, the load of the knee joint during imaging is only possible with special equipment which is only available in few hospitals. Hence, long leg imaging using X-ray is the gold standard. {Pietsch 2006 #13}

The data of this study were collected using long-leg radiographs. To avoid incorrect imaging the X-rays were exclusively taken by trained personnel using a specific X-ray protocol. To guarantee a high standard wrong rotated imaging was repeated.

5.1.3 Q-angle

One of the extrinsic factors that can cause patellofemoral pain syndrome (PFPS) is abnormal patellar alignment. An exact definition for this does not exist but a common method to assess malalignment is the Q-angle. In the study of Biedert et al. there was no significance between the Q-angle and the position of the patella resulting in no diagnostic relevance although they admitted that it has ‘some value as an estimate of the degree of the theoretical skeletal malalignment’. Their study participants were patients suffering from PFPS but had not undergone TKA (yet). {Biedert 2001 #81}

According to Walker et al. the patella is ‘fully stable and without tilting at all flexion angles for Q-angles of 14° or less’. Q-angles greater than 14° lead to severe patellar misalignment. Hence, in surgical practice the Q-angles are usually reduced from normal after TKA seeking stability which is a precondition for sleek movement to avoid patellar wear and PFPS. {Walker 2001 #15}

In this study 15.8 % of the females and 14.3% of the males were beneath the reference range postoperatively (cf. figures 31, 32). According to Walker's results this is clinically justifiable as they provide full stability and no tilt at all flexion angles.

5.1.4 Modified Insall-Salvati-Index

The Insall-Salvati Index is the most widely used index for the assessment of the patellar height. Because of disadvantages like the lack of patellar morphology, the modified Insall-Salvati-Index was used in this study because it significantly reduces these errors.
Values < 0.74 define a patella baja, values > 1.50 define a patella alta. {Shabshin 2004 #26}

Berg et al. compared 4 measurement methods for patellar height ratios. They considered the Blackburne-Peel method to be the 'most reproducible and consistent measurement of patellar height.' Due to their investigation the modified Insall-Salvati-Index had the greatest interobserver measurement error. This should be kept in mind using this modified Insall-Salvati-Index. {Berg 1996 #82}

5.1.5 Patellar shift and tilt

Nha et al. examined in vivo patellar tracking during the full range of a healthy weight-bearing knee flexion using magnetic resonance imaging and dual orthogonal fluoroscopy. In that study 'the mean patellar shift was within 3 mm over the entire range of flexion'. At early flexion the patella showed a slight medial shift and at further flexion it shifted consistently lateral until 90°.
The tilt was also examined. Thereby, the mean tilt was within 6°. It tilted laterally when the knee was flexed from 0° to 75°, and tilted medially beyond 75°. {Nha 2008 #41}

Gerber et al. pursued the issue whether the patella shall be resurfaced or not in TKA. Therefore, they investigated 30 primary TKA replacements by 'calculation of the radiological patellar shift and tilt relative to the natural groove on preoperative X-rays and to the prosthetic groove in the postoperative evolution'. They matched these results with the range of motion the patients obtained after 2 years and with persisting pain. In the 'residual problem group', defined as patients with persisting pain and < 90/0/0 flexion/extension the postoperative shift was >5 mm and the postoperative tilt >15°.

Although Gerber et al. recommended a tilt up to 6° as ideal (shown in Figure 37 as chequered reference range) they could find patients free of pain with a tilt up to 15° (2 years postoperatively). This is shown in Figure 37 as extended reference range (striped). Furthermore they noticed, that there was a correlation between persisting pain and a considerable preoperative tilt, a preoperative diminished range of motion and a relevantly elevated shift before surgery. {Gerber 1998 #90}

It is to note that the X-ray imaging in this study was used unscaled but in this case it is not relevant as the values are given as absolute values. Altogether, patella defilée imaging evaluated manually was unsatisfactory to assess shift and tilt.
Table 4 and figure 42 show the assessment of patellar shift and tilt during the motion cycle using navigation. So far no comparable data in literature exists.

5.1.6 Patellar resurfacing

The aforementioned results of Gerber et al. refer to the unresurfaced patella because the natural patella has an astonishing ability to adapt itself to the prosthetic groove by remodeling of the bony contour and structure. Thus, only in cases with severe preoperative malposition of the patella and very poor bone quality patellar resurfacing may be considered but is no standard so far. {Gerber 1998 #90}

Also Feller et al. recommend an unresurfaced patella. They carried out a study in which they compared the outcome of patellar resurfacing with the retention in TKA. As they did 'not find any significant benefit from resurfacing the patella during TKA for osteoarthritis if it was not severely deformed' they got to the conclusion that this treatment is not necessary. {Feller 1996 #69}

Keblish et al. did an interesting prospective study regarding patellar resurfacing. They investigated patients with bilateral replacements. Hence, they resurfaced the patella on one side but not on the other side. Regarding 'subjective preference, performance on ascending and descending stairs or the incidence of anterior knee pain' and the radiographs, they could not find differences in both sides. For this reason, they also recommend the 'retention of the patellar surface' as an 'acceptable option'. {Keblish 1994 #107}

In this study in all cases the patellae were naturalised in accordance with surgical practice and the cited recommendation.

5.1.7 Joint line

According to Maderbacher et al., the clinical and functional outcome is improved by restoring the joint line (JL). This is one of the major goals in TKA implantation as every change, elevation or descending, is associated with poor outcome because it alters the craniocaudal position of the patella, the tibiofemoral kinematic and the joint stability.
In primary TKA the JL is obligatorily changed when the classic resection of the proximal tibia and distal femur 90° to the mechanical axis is used. Maderbacher et al. found a 'varus JL deviation of 4.2° in relation to the orthogonal line to the mechanical tibial axis.' Hence, in classic varus knees, the JL is usually maintained medially and lowered laterally due to lateral femoral underresection and tibial overresection. Contrary to this, the JL can be theoretically restored performing anatomical resection. But when using stems – no matter whether in primary or revision TKA, the classic resection technique is necessary because of implant restrictions. Revision surgery always entails more difficulties. According to the data of Maderbacher et al. no bony structure is reliable to estimate the original JL in this case. {Maderbacher 2014 #91}

Martin et al. reported an increasing midflexion laxity in the case that the JL was shifted 5 mm proximally and anteriorly and it was tightened when it was lowered and set 5 mm posteriorly in TKA. {Martin 1990 #108}

Figgie et al. as well as Partington et al. described poorer clinical and functional outcome after TKA in the case of an elevation of the JL of > 8mm. {Figgie 1986 #92}{Partington 1999 #93}

A review of several clinical studies shows a range of proposed joint line displacement thresholds from 3-13 mm. At values over these thresholds motion, pain, above all patellofemoral pain and function of the knee were affected negatively. {Mason 2006 #52}

5.1.8 Femoral rotation

According to Heesterbeek et al., postoperative femoral rotation between 12° of external rotation and 3° of internal rotation was not a 'predictor for postoperative tilt and displacement'. {Heesterbeek 2011 #85}

In laboratory experiments of Anouchi et al. and Rhoads et al. for example, femoral component rotation variation was higher. But both report that there were no significant changes in patellar tracking postoperatively when the femoral component was positioned in slight endorotation (5° Anouchi); and exorotation (5°Anouchi, 3° Rhoads) was even described as favorable to prevent patellar maltracking. {Anouchi 1993 #86}{Rhoads 1990 #87}

There are also controversial studies. Miller et al. described more patellar tilt when the femoral component was positioned in extrarotation but there was no effect on patellar displacement. {Miller 2001 #88}

In this study the mean femoral rotation was -4.68 (SD 6.3) (cf figure 41). In 85% the femoral component was positioned in external rotation which according to the aforementioned studies of Anouchi et al. and Rhoads et al. is considered to have a positive effect on patellar tracking.

5.1.9 Effects of component alignment

An incorrect implantation of the particular components was the cause of poor long-term results according to Thomas et al. Thereby he emphasized the correct positioning in frontal plane, rotational position of the femoral component and the dorsal slope of the tibial plateau. {Thomas 1999 #83}

It is obvious that femoral and tibial rotation influence patellar tracking, although there is no consensus regarding current literature. {Barrack #84}{Berger 1998 #63}{Kienapfel 2003 #65}

5.1.10 Patellar tracking

In the study ‘Significant influence of rotational limb alignment parameters on patellar kinematics’ Keshmiri et al. published the results of an in vitro study regarding patellar kinematics in healty knees to describe the natural patellar tracking during passive motion before and after total knee arthroplasty.

All knees were free from significant arthrosis, and had intact joint capsules, tendons and ligaments. During the whole motion cycle the parametres mediolateral shift, mediolateral tilt, patellar rotation and additionally, the epicondylar distances were measured using the same patellar tracking software which was used in this study (BrainLAB; Feldkirchen, Germany). Most healthy knees showed an ‘increase in medial shift with increased tibiofemoral flexion. The shift between 30° and 90° of flexion ranged within 2 mm. In 90% of cases, the patella tilted ‘more laterally with increased flexion in a nearly linear behaviour’, the ‘mean tilt was within 4°’.

A ‘nearly linear increase in patellar external rotation could be observed in every knee’, the ‘mean rotation was within 7°’. And the epicondylar distance showed an ‘almost linear decrease’. Furthermore, the ‘rotational limb alignment parameters have a significant influence on natural patellar kinematics’. {Keshmiri 2014 #110}

The postoperative results of this study show similar results (cf table 4, figure 42). Patellar shift, rotation and epicondylar distance are in accordance, the postoperative tilt did not show a linear increase but tilted for flexion angles between 30° and 60° more laterally and beyond 60° statistically significant more medially.

There exists no comparable data in literature with navigated patella tracking so far. There is some knowledge of patellofemoral pressure after TKA. Patellofemoral pressure rises after TKA significantly with preservation of the patella and doubles or even tripels by resurfacing the patella. {Leichtle 2014 #111}

5.2 Clinical assessment

The rating system of the knee replacement shall be applicable before and after surgery to fathom the level of benefit achieved by surgery. Furthermore, it shall be usable for all patients so that genuine comparisons between different groups of patients, techniques or implants can be made.

There are various questionnaires used worldwide to assess the outcome of TKA:

- Disease specific tools like the WOMAC, the McMaster-Toronto Arthritis Patient Preference Questionnaire, the KSS and the Oxford Knee Score.
- The global health tool: Short Form-36, (SF-36) health survey
- The cost-to-utility outcome tools: quality adjusted life years {Ghanem 2010 #95}

It must be taken into account that most of the patients undergoing knee replacement surgery are often elderly people. Hence, co-morbidities can affect 'levels of mobility and function independent of the knee joint'. This results in being challenging for the objectivity of any rating system of TKA. This does not mean that the general condition of a patient is not important because it is evident that it will have a substantial influence on preoperative decision-making. But the objective target of a knee rating system must be to evaluate the knee in isolation. {Davies 2002 #94}

In this study we used the following internationally accepted questionnaires that have been used successfully for a long time:

5.2.1 Knee Society Score

The KSS was first developed in 1989 to evaluate both the postoperative function of the knee prosthesis and the functional abilities after TKA. {Scuderi 2012 #96}

Ghanem et al. reviewed the responsiveness and validity of several questionnaires, inter alia the Knee Society Score. They separated the KSS in pain, clinical and functioning score and presented their results pre- and 24 months postoperatively. {Ghanem 2010 #95}

Interestingly, Hirschmann et al. ran a 'prospective, longitudinal, single-cohort study' regarding psychological factors like depression, anxiety, and control beliefs in patients undergoing TKA. And indeed these patients had significantly poorer clinical outcomes. {Hirschmann 2013 #97}

5.2.2 WOMAC Score

The WOMAC is one of the most widely used questionnaires and was developed for patients with knee and/or hip osteoarthritis.
Navarro et al. ran a ‘prospective cohort pre-test/post-test study of patients undergoing primary hip or knee arthroplasty.’ Regarding the WOMAC Score they could report a statistically significant functional improvement after TKA in all dimensions of the test especially for knee patients. {Navarro 2008 #101}

Ghanem et al. also presented the WOMAC. They separated the score in WOMAC pain and WOMAC functioning but had also similar results pre- and postoperatively compared to this study. {Ghanem 2010 #95}

In a prospective follow up study Angst et al. compared the responsiveness of the WOMAC with the generic Short Form-36 (SF-36). Their patients were all suffering from osteoarthritis of the legs and were undergoing a ‘comprehensive inpatient rehabilitation intervention’. The pain scales were more responsive than the function scales in both questionnaires but the function scale of the WOMAC was ‘significantly more responsive than the SF-36’ calculated by using standardised response mean (SRM). {Angst 2001 #102}

In this study only the WOMAC was used because of the aforementioned higher responsiveness. The WOMAC scales were associated with the radiological severity of the osteoarthritis and limitations of range-of-motion. Patients with more severe symptoms had less functional disability and more limitations in their roles at home and at work.

5.2.3 Feller/Patellar Score

The Feller/Patellar Score is specifically designed as a scoring system for the patella by Julian Feller. Feller et al. used this score and the HSS (Hospital for Special Surgery score) to assess whether the patella should be resurfaced in TKA or not. {Feller 1996 #69}
Since the Feller score in this study was collected 7 days postoperatively it should be assumed that it has certainly risen in the meantime. Thus, the Feller Score should be better assessed as early as by the end of rehab to receive significant values. (Cf. figure 45)

5.2.4 HAKEMP-90

The HAKEMP-90 was used as personality questionnaire. {Kuhl #25}.
In our study 18 patients achieved full score which suggests that they can deal much better with frustration and have a higher tolerance for pain (cf. figure 46).

5.2.5 Patients' satisfaction after total knee arthroplasty

Although TKA has revolutionised the treatment of patients with end-stage osteoarthritis of the knee the question arises why 11-25% of patients are dissatisfied postoperatively. {Springorum 2012 #4}

According to Bourne et al. 'dissatisfied primary total knee arthroplasty patients were older, lived alone, were more often a reassessment rather than a new patient referral at decision date for surgery, less likely to have less than 90° preoperative flexion, have extreme pain on the WOMAC pain score while lying or sitting, have a lower 1-year WOMAC, have a lower WOMAC change score, not be willing to have surgery again, and had expectations which were not met' {Bourne 2010 #23}.

To meet patient expectations it is important to achieve patient satisfaction after TKA. In this context it is important for the orthopaedic surgeon to discuss expectations before TKA to ensure that they are realistic. For example a low preoperative WOMAC should be discussed with the patient as this is a risk factor for patient dissatisfaction. {Bourne 2010 #23}

Bullens et al. describe the patient's opinion about the outcome as the most important target as 'the patient is the most prominent participant'. It is shown in medical research that patients can supply a reliable judgment of their health condition and the effects of treatment. In their study they found only a 'poor correlation between the objective physician-assessed knee score and the subjective patient-assessed satisfaction'. From here one comes to the suggestion that priorities of surgeons and patients are different.
For surgeons aspects like motion, stability and alignment are important. For patients the major target is 'the functionality of the knee as a whole'.
Follow-up studies reported a survivorship between 90% - 99% at 10 years. Thereby the endpoint of survivorship is defined as a revision or radiological failure. Revision is not a sensitive definition of failure but it is a sensitive definition of a low reoperation rate. Bullens et al. used patients' satisfaction as an 'endpoint in survival analysis'. {Bullens 2001 #98}{Amadio 1993 #99}

Hence, patients' satisfaction – this includes showing realistic targets before surgical intervention – is one of the most important issues to prevent revision.

5.2.6 Limitations of the study

The following limitations of this study have to be taken into account:

The preoperative patellar tracking could already have been changed because of severe gonarthrosis.

The patellar kinematics were measured without 'muscle tone and through passive range of motion'. But the data can be used for further clinical investigations as it was collected intraoperatively and they were 'not influenced by possible asymmetrical pull of the attached quadriceps tendon'.

There was no investigation for flexion angles between 0° and 30°. Hence, it was not possible to analyse a potential impact of the tibiofemoral 'screw home mechanism' (SHM) nor its influence on 'axial component alignment and patellofemoral kinematics'. This would be interesting as it takes place at early flexion angles. The SHM plays a key role in knee stability for standing upright.

The patella was not resurfaced. It should be kept in mind that this could affect patellar tracking compared to resurfaced patellae after TKA. {Keshmiri 2015 #72}

Regarding the clinical questionnaires it must be noted that they are always dependent on the personal opinion of the patient. To objectify, the HAKEMP-90 was collected as it gives an estimation of personal tendency.

5.2.7 Conclusion

After TKA there are differences in patellar kinematics compared to the preoperative arthritic knee, which the orthopaedic surgeon should be aware of. By means of a CT free navigation system the changes can be shown intraoperatively.

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6. Literature

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7. Index of figures and tables

Tables:

8. Appendix

Questionnaires:

Terminplan für

Präoperative Untersuchung am:

3. postop Tag:
7. postop Tag:
28. postop Tag:

Patientendaten (Stammdatenetikett)

oder

Name, Vorname, Geburtsdatum:

Fragebogen Patellatracking

1. Patientennummer:
2. Name:
3. Telefonnummer:
4. Geschlecht: 1 männlich 2 weiblich
5. Geburtstag tt.mm.jjjj
6. Alter 2010:
7. Gewicht kg
8. Körpergröße cm
9. Seite: 1 rechts 2 links
10. Grunderkrankung
    1 Idiopathische Arthrose 2 posttraumatische Arthrose

10. Bewegungsausmaß OP-Seite passiv: E/F

11. Bewegungsausmaß Gegenseite passiv: E/F

Besonderheiten:

12. Gerades Bein heben möglich(OP-Seite): 1 ja 2 nein

13. Visuelle Analogscala/ Numerische Rating Scala : ___ von 10

Patellar Score (Feller)

Vor Implantation der Knietotalendoprothese

I. Vordere Knieschmerzen

keine	15
leichte	10
mäßige	5
starke	0

II. Quadrizepsstärke

gut	5
ausreichend	3
schwach	1

III. Fähigkeit, sich von einem Stuhl zu erheben

leicht (ohne Armunterstützung)	5
leicht (mit Armunterstützung)	3
mit Unterstützung	1
unfähig	0

IV. Treppensteigen

ein Fuß pro Stufe (ohne Unterstützung)	5
ein Fuß pro Stufe (mit Unterstützung)	4
zwei Füße pro Stufe (ohne Unterstützung)	3
zwei Füße pro Stufe (mit Unterstützung)	2

Summe: _____________

Womac Score

Wir möchten mit dem folgenden Fragebogen herausfinden, inwieweit Sie durch Ihr erkranktes Knie in Ihrer Lebensführung beeinträchtigt werden. Aus diesem Grund bitten wir Sie, alle Fragen zu beantworten, auch wenn sie sich nicht direkt auf Ihr Knie beziehen.

Dauer der Beschwerden am betroffenen Knie: Seit ca. ……………..…. Monaten/Jahren

Voroperationen am betroffenen Knie: ja☐ nein☐

wenn „ja", wann: Vor ca. ………………………… Monaten/Jahren

Anleitung:
Bitte beantworten Sie die folgenden Fragen, indem Sie das Kästchen ankreuzen, das für Sie am ehesten zutrifft.

A. Fragen zu Beschwerden und Schmerzen des betroffenen Knies

1.) Wie viel Schmerzen spüren Sie beim Gehen auf einer ebenen Fläche?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

2.) Wie viel Schmerzen bereitet es Ihnen, Treppen hinunter zu gehen?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

3.) Wie viel Schmerzen spüren Sie nachts im Bett?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

4.) Wie viel Schmerzen spüren Sie beim Sitzen oder Liegen?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

5.) Wie viel Schmerzen spüren Sie beim aufrechten Stehen?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

6.) Wie oft haben Sie während der vergangenen vier Wochen Schmerzmedikamente für Ihr erkranktes Knie einnehmen müssen?

	Nie	**<1x/ Woche**	**1-3x/Woche**	**4-6x / Woche**	**täglich**
Betroffenes Knie					

B. Fragen zum Steifheitsgrad des betroffenen Knies

Die folgenden Fragen beziehen sich auf den **Steifheitsgrad** (nicht Schmerzen), den Sie in Ihrem zu operierenden Knie während der vergangenen vier Wochen empfunden haben. (Steifheit wird als Bewegungseinschränkung und Bewegungsverlangsamung des Gelenks definiert.)

Wie schwerwiegend ist Ihre Steifheit nach:

7.) dem ersten Aufwachen am Morgen?

Keine	Gering	Mäßig	Steif	Sehr Steif

8.) dem Sitzen, Liegen oder Ruhen später am Tag?

Keine	Gering	Mäßig	Steif	Sehr Steif

C. Fragen zur Funktionalität des betroffenen Knies:

Die folgenden Fragen beziehen sich auf Ihre **körperliche Funktionsfähigkeit** (Ihre Fähigkeit, umher zu gehen und sich selbst zu versorgen).
Geben Sie bitte für jede Aktivität die Schwierigkeiten an, die Sie **wegen Ihres zu operierenden Knies** während der vergangenen vier Wochen empfunden haben.

Welche **Schwierigkeiten** haben Sie:	Keine	Geringe	Mäßige	Schwer	Sehr schwer
beim Treppen hinunter gehen					
beim Treppensteigen					
beim Aufstehen vom Sitzen					
beim Stehen					
beim Bücken zum Fußboden					
beim Gehen auf einer ebenen Fläche					
beim Ein- und Aussteigen aus dem Auto					
beim Einkaufen					
beim Socken Anziehen					
beim Aufstehen aus dem Bett					
beim Socken Ausziehen					
beim Liegen im Bett					
beim Ein- und Aussteigen in die und aus der Badewanne					
beim Sitzen					
beim Aufstehen von der Toilette					
bei schwerer Hausarbeit					
bei leichter Hausarbeit					

Welche der folgenden Antworten beschreiben am besten Ihr Aktivitätsniveau während der vergangenen vier Wochen?

- ◻ Bettlägerig oder im Rollstuhl
- ◻ Minimale Beweglichkeit im Haus
- ◻ Büroarbeit, sitzende Arbeit oder leichte Hausarbeit
- ◻ Schwere Hausarbeit wie Staubsaugen oder Fußböden reinigen, Gartenarbeit
- ◻ Bis zu 25 kg gehoben oder mäßig fordernde Sportarten wie mehr als 5 km Gehen oder Radfahren ausgeübt
- ◻ Oft mehr als 25 kg gehoben oder dynamische Sportarten wie Tennis oder Joggen ausgeübt

Knee Society Score

A: Knee Score

Schmerz	Keiner			50
	Leicht oder gelegentlich			45
	Nur beim Treppensteigen			40
	Bei Gehen oder Treppensteigen			30
	Mittelmäßig: gelegentlich			20
	Ständig			10
	Starke Schmerzen			0
Beweglichkeit	(5° = 1 Punkt) -> max. 25 Punkte für 125°			25
Stabilität (Max. Bewegung in jeder Position)	Anterior-posterior	< 5 mm		10
		5-10 mm		5
		> 10 mm		0
	Medio-lateral	< 5°		15
		6-9°		10
		10-14°		5
		> 15°		0
Flexionskontrakur	140° - max. Beugung	5° - 10°		- 2
		10° - 15°		- 5
		16° - 20°		- 10
		>20°		- 15
Extensionsdefizit		<10°		- 5
		10° - 20°		- 10
		>20°		- 15
Alignment	Physiologische Beinsachse (Varus-/ Valgusfehlstellung)	0° - 4°		0
		5° - 10°		- 6
		11° - 15°		- 13
		>15°		- 20
Gesamt Knee Score				

B. Function Score

Gehen	unbegrenzt		50
	> 1000 Meter		40
	500 – 1000 Meter		30
	<500 Meter		20
	Nur im Haus		10
	Überhaupt nicht		0
Treppengehen	Normal rauf und runter		50
	Normal rauf, runter mit Geländer		40
	Rauf und runter mit Geländer		30
	Rauf mit Geländer, runter nicht möglich		15
	Überhaupt nicht		0
Gehhilfen	1 Gehstock		- 5
	2 Gehstöcke		- 10
	Krücken oder Gehgestell		- 20
Gesamt Function Score			

Persönlichkeitsfragebogen
HAKEMP-90 PB-Nr.:_____

1. Wenn ich etwas Wertvolles verloren habe und jede Suche vergeblich war, dann

a. kann ich mich schlecht auf etwas anderes konzentrieren □
b. denke ich nicht mehr lange darüber nach □

2. Wenn ich weiß, dass etwas bald erledigt werden muss, dann

a. muss ich mir oft einen Ruck geben, um den Anfang zu kriegen □
b. fällt es mir leicht, es schnell hinter mich zu bringen □

3. Wenn ich vier Wochen lang an einer Sache gearbeitet habe und dann doch alles misslungen ist, dann

a. dauert es lange, bis ich mich damit abfinde □
b. denke ich nicht mehr lange darüber nach □

4. Wenn ich nichts Besonderes vorhabe und Langeweile habe, dann

a. kann ich mich manchmal nicht entscheiden, was ich tun soll □
b. habe ich meist rasch eine neue Beschäftigung □

5. Wenn ich bei einem Wettkampf öfter hintereinander verloren habe, dann

a. denke ich bald nicht mehr daran □
b. geht mir das noch eine ganze Weile durch den Kopf □

6. Wenn ich ein schwieriges Problem angehen will, dann

a. kommt mir die Sache vorher wie ein Berg vor □
b. überlege ich, wie ich die Sache auf eine einigermaßen angenehme Weise hinter mich bringen kann □

7. Wenn mir ein neues Gerät versehentlich auf den Boden gefallen ist und nicht mehrzu reparieren ist, dann

a. finde ich mich rasch mit der Sache ab □
b. komme ich nicht so schnell darüber hinweg □

8. Wenn ich ein schwieriges Problem lösen muss, dann

a. lege ich meist sofort los □
b. gehen mir zuerst andere Dinge durch den Kopf, bevor ich mich richtig an die Aufgabe heranmache □

9. Wenn ich jemanden, mit dem ich etwas Wichtiges besprechen muss, wiederholt nicht zu Hause antreffe, dann

a. geht mir das oft durch den Kopf, auch wenn ich mich schon mit etwas anderem beschäftige □
b. blende ich das aus, bis die nächste Gelegenheit kommt, ihn zu treffen □

10. Wenn ich vor der Frage stehe, was ich in einigen freien Stunden tun soll, dann

a. überlege ich manchmal eine Weile, bis ich mich entscheiden kann □
b. entscheide ich mich meist ohne Schwierigkeit für eine der möglichen Beschäftigungen □

11. Wenn ich nach einem Einkauf zu Hause merke, dass ich zu viel bezahlt habe, aber das Geld nicht mehr zurückbekomme, dann

a. fällt es mir schwer, mich auf etwas anderes zu konzentrieren □
b. fällt es mir leicht, die Sache auszublenden □

12. Wenn ich eigentlich zu Hause arbeiten müsste, dann

a. fällt es mir oft schwer, mich an die Arbeit zu machen □
b. fange ich meist ohne weiteres an □

13. Wenn meine Arbeit als völlig unzureichend bezeichnet wird, dann

a. lasse ich mich davon nicht lange beirren □
b. bin ich zuerst wie gelähmt □

14. Wenn ich sehr viele wichtige Dinge zu erledigen habe, dann

a. überlege ich oft, wo ich anfangen soll □
b. fällt es mir leicht, einen Plan zu machen und ihn auszuführen □

15. Wenn ich mich verfahre (z.B. mit dem Auto, mit dem Bus usw.) und eine wichtige Verabredung verpasse, dann

a. kann ich mich zuerst schlecht aufraffen, irgendetwas anderes anzupacken □
b. lasse ich die Sache zuerst mal auf sich beruhen und wende mich ohne Schwierigkeiten anderen Dingen zu □

16. Wenn ich zu zwei Dingen große Lust habe, die ich aber nicht beide machen kann, dann

a. beginne ich schnell mit einer Sache und denke gar nicht mehr an die andere □
b. fällt es mir nicht so leicht, von einer der beiden Sachen ganz Abstand zu nehmen □

17. Wenn mir etwas ganz Wichtiges immer wieder nicht gelingen will, dann

a. verliere ich allmählich den Mut □
b. vergesse ich es zunächst einmal und beschäftige mich mit anderen Dingen □

18. Wenn ich etwas Wichtiges, aber Unangenehmes zu erledigen habe, dann

a. lege ich meist sofort los □
b. kann es eine Weile dauern, bis ich mich dazu aufraffe □

19. Wenn mich etwas traurig macht, dann

a. fällt es mir schwer, irgendetwas anderes zu tun □
b. fällt es mir leicht, mich durch andere Dinge abzulenken □

20. Wenn ich vorhabe, eine umfassende Arbeit zu erledigen, dann

a. denke ich manchmal zu lange nach, womit ich anfangen soll □
b. habe ich keine Probleme loszulegen □

21. Wenn einmal sehr viele Dinge an einem Tag misslingen, dann

a. weiß ich manchmal nichts mit mir anzufangen □
b. bleibe ich fast genauso tatkräftig, als wäre nichts passiert □

22. Wenn ich vor einer langweiligen Aufgabe stehe, dann

a. habe ich meist keine Probleme, mich an die Arbeit zu machen □
b. bin ich manchmal wie gelähmt □

23. Wenn ich meinen ganzen Ehrgeiz darin gesetzt habe, eine bestimmte Arbeit gut zu verrichten und es geht schief, dann

a. kann ich die Sache auf sich beruhen lassen und mich anderen Dingen zuwenden □
b. fällt es mir schwer, überhaupt noch etwas zu tun □

24. Wenn ich unbedingt einer lästigen Pflicht nachgehen muss, dann

a. bringe ich die Sachen ohne Schwierigkeiten hinter mich □
b. fällt es mir schwer, damit anzufangen □

Post - OP Tage:

3. postoperativer Tag:

Datum:

VAS/NRS: ___von 10
gestrecktes Bein Heben möglich: 1 ja 2 nein
Beweglichkeit: Ext/Flex

7. postoperativer Tag:

Datum:

Reha-Klinik: Zeitraum:

VAS/NRS: ___von 10
gestrecktes Bein Heben möglich: 1 ja 2 nein
Beweglichkeit: Ext/Flex

28. postoperativer Tag:

Datum:

VAS/NRS: ___von 10
gestrecktes Bein Heben möglich: 1 ja 2 nein
Beweglichkeit: Ext/Flex

Patellar Score (Feller)

Nach Implantation der Knietotalendoprothese

I. Vordere Knieschmerzen

keine	15
leichte	10
mäßige	5
starke	0

II. Quadrizepsstärke

gut	5
ausreichend	3
schwach	1

III. Fähigkeit, sich von einem Stuhl zu erheben

leicht (ohne Armunterstützung)	5
leicht (mit Armunterstützung)	3
mit Unterstützung	1
unfähig	0

IV. Treppensteigen

ein Fuß pro Stufe (ohne Unterstützung)	5
ein Fuß pro Stufe (mit Unterstützung)	4
zwei Füße pro Stufe (ohne Unterstützung)	3
zwei Füße pro Stufe (mit Unterstützung)	2

Summe: _____________

Womac Score

Wir möchten mit dem folgenden Fragebogen herausfinden, inwieweit Sie durch Ihr erkranktes Knie in Ihrer Lebensführung beeinträchtigt werden. Aus diesem Grund bitten wir Sie, alle Fragen zu beantworten, auch wenn sie sich nicht direkt auf Ihr Knie beziehen.

Anleitung:
Bitte beantworten Sie die folgenden Fragen, indem Sie das Kästchen ankreuzen, dass für Sie am ehesten zutrifft.

A. Fragen zu Beschwerden und Schmerzen des betroffenen Knies

1.) Wie viel Schmerzen spüren Sie beim Gehen auf einer ebenen Fläche?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

2.) Wie viel Schmerzen bereitet es Ihnen, Treppen hinunter zu gehen?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

3.) Wie viel Schmerzen spüren Sie nachts im Bett?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

4.) Wie viel Schmerzen spüren Sie beim Sitzen oder Liegen?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

5.)Wie viel Schmerzen spüren Sie beim aufrechten Stehen?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

6.) Wie oft haben Sie während der vergangenen vier Wochen Schmerzmedikamente für Ihre erkranktes Knie einnehmen müssen?

	Nie	<1x/ Woche	1-3x/Woche	4-6x / Woche	täglich

Betroffenes Knie					

B. Fragen zum Steifheitsgrad des betroffenen Knies

Die folgenden Fragen beziehen sich auf den **Steifheitsgrad** (nicht Schmerzen), den Sie in Ihrem zu operierenden Knie während der vergangenen vier Wochen empfunden haben. (Steifheit wird als Bewegungseinschränkung und Bewegungsverlangsamung des Gelenks definiert.)

Wie schwerwiegend ist Ihre Steifheit nach:

7.) dem ersten Aufwachen am Morgen?

Keine	Gering	Mäßig	Steif	Sehr Steif

8.) dem Sitzen, Liegen oder Ruhen später am Tag?

Keine	Gering	Mäßig	Steif	Sehr Steif

C. Fragen zur Funktionalität des betroffenen Knies:

Die folgenden Fragen beziehen sich auf Ihre **körperliche Funktionsfähigkeit** (Ihre Fähigkeit, umher zu gehen und sich selbst zu versorgen).
Geben Sie bitte für jede Aktivität die Schwierigkeiten an, die Sie **wegen Ihres zu operierenden Knies** während der vergangenen vier Wochen empfunden haben.

Welche **Schwierigkeiten** haben Sie:	Keine	Geringe	Mäßige	Schwer	Sehr schwer
beim Treppen hinunter gehen					
beim Treppensteigen					
beim Aufstehen vom Sitzen					
beim Stehen					
beim Bücken zum Fußboden					
beim Gehen auf einer ebenen Fläche					
beim Ein- und Aussteigen aus dem Auto					
beim Einkaufen					
beim Socken Anziehen					
beim Aufstehen aus dem Bett					
beim Socken Ausziehen					
beim Liegen im Bett					

beim Ein- und Aussteigen in die und aus der Badewanne					
beim Sitzen					
beim Aufstehen von der Toilette					
bei schwerer Hausarbeit					
bei leichter Hausarbeit					

Welche der folgenden Antworten beschreiben am besten Ihr Aktivitätsniveau während der vergangenen vier Wochen?

- □ Bettlägerig oder im Rollstuhl
- □ Minimale Beweglichkeit im Haus
- □ Büroarbeit, sitzende Arbeit oder leichte Hausarbeit
- □ Schwere Hausarbeit wie Staubsaugen oder Fußböden reinigen, Gartenarbeit, Fließbandarbeit oder leichte Fitnessübungen wie Spazieren gehen
- □ Bis zu 25 kg gehoben oder mäßig fordernde Sportarten wie mehr als 5 km Gehen oder Radfahren ausgeübt
- □ Oft mehr als 25 kg gehoben oder dynamische Sportarten wie Tennis oder Joggen ausgeübt

Knee Society Score

A: Knee Score

Schmerz	Keiner			50
	Leicht oder gelegentlich			45
	Nur beim Treppensteigen			40
	Bei Gehen oder Treppensteigen			30
	Mittelmäßig: gelegentlich			20
	Ständig			10
	Starke Schmerzen			0
Beweglichkeit	(5° = 1 Punkt) -> max. 25 Punkte für 125°			25
Stabilität (Max. Bewegung in jeder Position)	Anterior-posterior	< 5 mm		10
		5-10 mm		5
		> 10 mm		0
	Medio-lateral	< 5°		15
		6-9°		10
		10-14°		5
		> 15°		0
Flexionskontrakur	140° - max. Beugung	5° - 10°		- 2
		10° - 15°		- 5
		16° - 20°		- 10
		>20°		- 15
Extensionsdefizit		<10°		- 5
		10° - 20°		- 10
		>20°		- 15
Alignment		0° - 4°		0

	Physiologische Beinsachse (Varus-/ Valgusfehlstellung)	5° - 10°		- 6
		11° - 15°		- 13
		>15°		- 20
Gesamt Knee Score				

B. Function Score

Gehen	unbegrenzt		50
	> 1000 Meter		40
	500 – 1000 Meter		30
	<500 Meter		20
	Nur im Haus		10
	Überhaupt nicht		0
Treppengehen	Normal rauf und runter		50
	Normal rauf, runter mit Geländer		40
	Rauf und runter mit Geländer		30
	Rauf mit Geländer, runter nicht möglich		15
	Überhaupt nicht		0
Gehhilfen	1 Gehstock		- 5
	2 Gehstöcke		- 10
	Krücken oder Gehgestell		- 20
Gesamt Function Score			

28 Tage postoperativ:

Datum:

VAS/NRS: ___von 10
gestrecktes Bein Heben möglich: 1 ja 2 nein
Beweglichkeit: Ext/Flex

Womac Score

Wir möchten mit dem folgenden Fragebogen herausfinden, inwieweit Sie durch Ihr erkranktes Knie in Ihrer Lebensführung beeinträchtigt werden. Aus diesem Grund bitten wir Sie, alle Fragen zu beantworten, auch wenn sie sich nicht direkt auf Ihr Knie beziehen.

Anleitung:
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1.) Wie viel Schmerzen spüren Sie beim Gehen auf einer ebenen Fläche?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

2.) Wie viel Schmerzen bereitet es Ihnen, Treppen hinunter zu gehen?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

3.) Wie viel Schmerzen spüren Sie nachts im Bett?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

4.) Wie viel Schmerzen spüren Sie beim Sitzen oder Liegen?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

5.) Wie viel Schmerzen spüren Sie beim aufrechten Stehen?

	Keine	Geringe	Mäßige	Starke	Sehr starke
Betroffenes Knie					

6.) Wie oft haben Sie während der vergangenen vier Wochen Schmerzmedikamente für Ihr erkranktes Knie einnehmen müssen?

	Nie	**<1x/ Woche**	**1-3x/Woche**	**4-6x / Woche**	**täglich**
Betroffenes Knie					

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Die folgenden Fragen beziehen sich auf den **Steifheitsgrad** (nicht Schmerzen), den Sie in Ihrem zu operierenden Knie während der vergangenen vier Wochen empfunden haben. (Steifheit wird als Bewegungseinschränkung und Bewegungsverlangsamung des Gelenks definiert.)

Wie schwerwiegend ist Ihre Steifheit nach:

7.) dem ersten Aufwachen am Morgen?

Keine	Gering	Mäßig	Steif	Sehr Steif

8.) dem Sitzen, Liegen oder Ruhen später am Tag?

Keine	Gering	Mäßig	Steif	Sehr Steif

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Die folgenden Fragen beziehen sich auf Ihre **körperliche Funktionsfähigkeit** (Ihre Fähigkeit, umher zu gehen und sich selbst zu versorgen).
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Welche **Schwierigkeiten** haben Sie:	Keine	Geringe	Mäßige	Schwer	Sehr schwer
beim Treppen hinunter gehen					
beim Treppensteigen					
beim Aufstehen vom Sitzen					
beim Stehen					
beim Bücken zum Fußboden					
beim Gehen auf einer ebenen Fläche					
beim Ein- und Aussteigen aus dem Auto					
beim Einkaufen					
beim Socken Anziehen					
beim Aufstehen aus dem Bett					
beim Socken Ausziehen					
beim Liegen im Bett					
beim Ein- und Aussteigen in die und aus der Badewanne					
beim Sitzen					
beim Aufstehen von der Toilette					
bei schwerer Hausarbeit					
bei leichter Hausarbeit					

Welche der folgenden Antworten beschreiben am besten Ihr Aktivitätsniveau während der vergangenen vier Wochen?

- □ Bettlägerig oder im Rollstuhl
- □ Minimale Beweglichkeit im Haus
- □ Büroarbeit, sitzende Arbeit oder leichte Hausarbeit
- □ Schwere Hausarbeit wie Staubsaugen oder Fußböden reinigen, Gartenarbeit, Fließbandarbeit oder leichte Fitnessübungen wie Spazieren gehen
- □ Bis zu 25 kg gehoben oder mäßig fordernde Sportarten wie mehr als 5 km Gehen oder Radfahren ausgeübt
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Knee Society Score

A: Knee Score

Schmerz	Keiner			50
	Leicht oder gelegentlich			45
	Nur beim Treppensteigen			40
	Bei Gehen oder Treppensteigen			30
	Mittelmäßig: gelegentlich			20
	Ständig			10
	Starke Schmerzen			0
Beweglichkeit	(5° = 1 Punkt) -> max. 25 Punkte für 125°			25
Stabilität (Max. Bewegung in jeder Position)	Anterior-posterior	< 5 mm		10
		5-10 mm		5
		> 10 mm		0
	Medio-lateral	< 5°		15
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		10-14°		5
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		16° - 20°		- 10
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Extensionsdefizit		<10°		- 5
		10° - 20°		- 10
		>20°		- 15
Alignment	Physiologische Beinsachse (Varus-/ Valgusfehlstellung)	0° - 4°		0
		5° - 10°		- 6
		11° - 15°		- 13
		>15°		- 20
Gesamt Knee Score				

B. Function Score

Gehen	unbegrenzt		50
	> 1000 Meter		40
	500 – 1000 Meter		30
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	Überhaupt nicht		0
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	Rauf und runter mit Geländer		30
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Gehhilfen	1 Gehstock		- 5
	2 Gehstöcke		- 10
	Krücken oder Gehgestell		- 20
Gesamt Function Score			

9. Acknowledgements

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Furthermore my special thanks go to Dr. med. Armin Keshmiri to provide me the data, to support me with literature and ideas.

Finally, I would like to take this opportunity to thank my family and friends for their support and motivation throughout the entire studies period and this dissertation.

10. Curriculum vitae

Personal details:	
Surname:	Diwald
First names:	Stephanie Maria
Date of birth:	07/10/1988
Place of birth:	Altötting
School education:	
2008 – 2015:	Study of human medicine at the Universität Regensburg, final exam: state exam
1999 – 2008:	Secondary School: Maria-Ward-Gymnasium Altötting, final exam: A-Levels
1995 – 1999:	Primary school: Grundschule Altötting (Süd)
Internships:	
December 2014 – April 2015	Klinik für Chirurgie, Caritas-Krankenhaus St. Josef, Regensburg
September – December 2014	Klinik für Augenheilkunde, Universität Regensburg
July – September 2014	Department of Gastroenterology, Mater Misericordiae University Hospital, Dublin, Ireland

May – July 2014	Department of Diabetology, Ninewells Hospital, University of Dundee, UK
March 2013	Emergency department/surgery, Universidad de Ciencias Médicas Habana, Cuba
September 2013	Emergency department, St. Vincent´s University Hospital, Dublin, Ireland
March 2012	Department of children’s orthopaedics, Schön Klinik München Harlaching
September 2011	Department of anaesthesiology, St. Hedwig-Krankenhaus, Lehrkrankenhaus der Charité Berlin
March 2011	Department of diabetology/endocrinology, Bürgerhospital Klinikum Stuttgart
<u>Prizes:</u>	
March 2008	Special prize in ‘Jugend forscht’ in Biology on the topic ‘Observation of a neozoen throughout a year’
<u>Languages:</u>	German, English, Latin, French, Spanish

ERKLÄRUNG ZUM PROMOTIONSVERFAHREN

nach § 3 Abs. 3 und 4 der Promotionsordnung
der Fakultät für Medizin der Universität Regensburg

Name:	Diwald
Vorname:	Stephanie
geb. am:	07.10.1988
in:	Altötting

Ich erkläre,

- dass ich den **Doktorgrad der Medizin / ~~Zahnheilkunde~~*** nicht schon an einer Hochschule der Bundesrepublik Deutschland erworben habe
- das ich nicht an anderer Stelle zu einem Promotionsverfahren zum Erwerb des **medizinischen / ~~zahnmedizinischen~~ Doktorgrades*** zugelassen bin
- dass ich die **medizinische / ~~zahnmedizinische~~ Doktorprüfung*** nicht schon an einer Hochschule der Bundesrepublik Deutschland endgültig nicht bestanden habe

Außerdem erkläre ich,

- dass mir keine Tatsachen bekannt sind, die mich zur Führung eines akademischen Grades im Sinne des Gesetzes über die Führung akademischer Grade unwürdig erscheinen lassen
- dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Die aus anderen Quellen direkt oder indirekt übernommenen Daten und Konzepte sind unter Angabe der Quelle gekennzeichnet. Insbesondere habe ich nicht die entgeltliche Hilfe von Vermittlungs- bzw. Beratungsdiensten (Promotionsberater oder andere Personen) in Anspruch genommen. Niemand hat von mir unmittelbar oder mittelbar geldwerte Leistungen für Arbeit erhalten, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen. Die Arbeit wurde bisher weder im In- noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde vorgelegt.

Regensburg, den 21.3.16   Stephanie Diwald

(Ort, Datum)   (Unterschrift)

Die einmalige Rücknahme des Promotionsgesuches ist bis zur Bestellung der Gutachter zulässig.

* Nicht Zutreffendes bitte streichen