Aus der Fakultät für Medizin
der Universität Regensburg
PD Dr. med. H.-Robert Springorum
Orthopädie und Unfallchirurgie

Effects of an 8-Week Long Home-Based Training Program for Patients with Bicondylar Total Knee Arthroplasty

Inaugural - Dissertation
zur Erlangung des Doktorgrades
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Zusammenfassung

HINTERGRUND

Die Implantation eines künstlichen Kniegelenks ist eine, der am häufigsten durchgeführten Operationen in Deutschland. Die Rehabilitation nach operativer Versorgung hat große Bedeutung, um eine gute Kniefunktion und Lebensqualität zurückzuerhalten. Die Studienlage bezüglich des richtigen Zeitpunktes und der Art der sportlichen Aktivität nach einer Endoprothesenversorgung ist jedoch nicht eindeutig. Strukturierte Trainingsprogramme für zu Hause können gegebenenfalls die sportliche Aktivität der Patienten nach Entlassung verbessern.

FRAGESTELLUNG

Ziel der vorliegenden Studie war es, die Auswirkungen eines 8-wöchigen Heimtrainingsprogrammes auf die Beinkraft, Gleichgewichtsfähigkeit, Ausdauerleistungsfähigkeit, Gangmechanik und Lebensqualität zu untersuchen.

METHODEN

Insgesamt wurden 26 Studienteilnehmer (15 Frauen, 11 Männer, Alter: 57-77 Jahre) mit bikondylärer Knietotalendoprothese zu einer Trainingsgruppe oder Kontrollgruppe randomisiert zugeteilt. Die Trainingsgruppe (13 TeilnehmerInnen) absolvierte ein 8-wöchiges Heimtrainingsprogramm mit Kräftigungs-, Beweglichkeits- und Gleichgewichtsübungen. Dies wurde mit Live-online Terminen und jederzeit abrufbaren Videos unterstützt. Die Gleichgewichtsfähigkeit wurde mit dem Y-Balance Test und die Beinkraft mit dem IsoMed2000 gemessen. Die Ganganalyse wurde mit inertialen Messeinheiten durchgeführt. Ein Fahrrad Ergometer Test wurde verwendet, um die Ausdauerleistungsfähigkeit zu testen. Lebensqualität und Kniegelenksfunktion wurden mit Oxford Knee Score, Lower Extremity Functional Score, WHO-BREF und Oxford Happiness Score erhoben. Datenerhebung für die Interventions- und Kontrollgruppe fand vor und nach dem Trainingsprogramm statt. Die Ergebnisse wurden mit zweifacher ANOVA ausgewertet.

ERGEBNISSE

Es konnte keine statistisch signifikante Verbesserung in keinem der durchgeführten Tests für die Interventionsgruppe beobachtet werden ($p > .05$). Die

Kontrollgruppe zeigte nach den acht Wochen in der Ganganalyse eine leicht verbesserte Knie Flexion ($p = .048$). Unabhängig von der Trainingsintervention, verbesserten sich über die Zeit das Gewicht, der BMI, das Gleichgewicht, die Herzfrequenz, die Ganggeschwindigkeit, die Schrittlänge des operierten Beines, sowie Lower Extremity Functional Score und Oxford Happiness Score ($p < .05$). Es trat ein signifikanter Haupteffekt der Gruppe für die maximale Herzfrequenz und Gleichgewichtsparameter ($p < .05$) auf.

ZUSAMMENFASSUNG

Insgesamt konnte diese Studie kein besseres Ergebnis für die Interventionsgruppe für objektiv und subjektiv erhobene Daten feststellen. In zukünftigen Studien sollte daher mehr Telerehabilitations-Technologie implementiert und evaluiert werden, um den Langzeittherapieerfolg bei Patienten mit totaler Knieendoprothese zu optimieren.

Abstract

BACKGROUND

Total knee replacement is one of the most frequently performed surgeries in Germany. Rehabilitation after the surgery is an essential part to attain good quality of life and regain good knee function. There is limited evidence on the right time to return to sport and scientific discussion on the recommendations on the type of physical activity. However, home-based training programs may help to optimize physical activity after discharge.

RESEARCH QUESTION/PURPOSE

The purposes of this study were to determine, whether 8 weeks of home-based rehabilitation induces an increase in muscle strength, results in better balance ability, increased cardiorespiratory fitness, transformed gait mechanics and better quality of life.

METHODS

Twenty-six individuals (15 women, 11 men, age range: 57-77 years) with bicondylar TKA were randomized to an intervention group, which completed an 8-week home-based exercise program, or a control group, which received standard rehabilitation. The training program included strength, mobility and balance exercises accompanied by online live-training sessions and on-demand training videos. To assess balance, this study used the Y-balance test. Lower limb muscle strength was measured using the IsoMed2000 machine. Gait was analyzed with inertial measurement units. A bicycle ergometer test was performed, and quality of life and functional parameters were assessed with the Oxford Knee Score, Lower Extremity Functional Score, WHO-BREF and Oxford Happiness Score. The assessment time points were before the start and after completion of the training program. The outcomes were evaluated using a two-way ANOVA.

RESULTS

The training group showed no significantly better outcomes in any of the tests performed ($p > .05$). The control group had slightly better knee flexion ($p = .048$) in the gait analysis. Independently of the training program, weight, BMI, balance, heart rate, gait speed, step length of the operated leg, Lower Extremity Functional

Score and Oxford Happiness Score improved over time ($p < .05$). A main group effect was found for maximum heart rate and balance scores ($p < .05$).

CONCLUSION

This study showed no better objective and subjective outcomes for the intervention group after an 8-week home-based training program compared to the control group undergoing usual rehabilitation. More tele-health technology should be implemented in future prospective studies to optimize long-term rehabilitation success.

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List of Abbreviations

AAOS .... American Academy of Orthopedic Surgeons

ACL .... Anterior Cruciate Ligament

ACR.. American College of Rheumatology

BMI .... Body Mass Index

BORG... Borg Rating of Perceived Exertion Scale

CG .... Control Group

CS .... Composite Score

DGOOC...... Deutsche Gesellschaft für Orthopädie und Orthopädische Chirurgie

EKA .... European Knee Associates

EPRD .... Endoprothesenregister Deutschland

EULAR .... European League against Rheumatism

GRFs .... Ground Reaction Forces

HR .... Heart Rate

IG .... Intervention Group

IMU .... Inertial Measurement Unit

KOA.. Knee Osteoarthritis

LCL .... Lateral Collateral Ligament

LCS .... Low Contact Stress

LEFS .... Lower Extremity Functional Scale

LSI .... Limb Symmetry Index

MCL .... Medial Collateral Ligament

MKA .... Mean Knee Angle

MRI.. Magnetic Resonance Imaging

NSAIDs .... Non-Steroidal Anti-Inflammatory Drugs

OARSI ....Osteoarthritis Research Society International

OHQ ....Oxford Happiness Questionnaire

OKS... Oxford Knee Score

PAL ....Physical Activity Level

PCL .... Posterior Cruciate Ligament

PFJR .... Patellofemoral Joint Replacement

PMMA ....Polymethylmethacrylate

PROMS ....Patient Reported Outcome Measures

PRP..Platelet-Rich Plasma

QOL..Quality of Life

RKA ....Range of Knee Angle

RPM .... Revolutions per Minute

TKA .... Total Knee Arthroplasty

TS... Training Session

UKA... Unicondylar Knee Arthroplasty

UKR.. Unicompartmental Knee Replacement

VAS ....Visual Analogue Scale

WHOQOL-BREF ....World Health Organization Quality of Life Short Version Instrument

YBT .... Y-Balance Test

1. Introduction

The incidence of degenerative chronic diseases is predicted to rise with the aging population and the increasing prevalence of obesity. Knee osteoarthritis (KOA), also called gonarthrosis, is one of the most common chronic diseases and a leading cause of pain and disability worldwide (1). The disease does not only lead to pain and functional limitations but affects psychological well-being as well (2, 3).

Effective conservative treatment options to stop the progress are limited. Especially in end-stage KOA, surgical treatments, particularly total knee arthroplasty (TKA), are used to reduce pain (4, 5). As Figure 1 shows, the number of knee arthroplasty procedures in German hospitals has risen considerably between 2015 and 2021. In 2021 a total of 172 011 knee replacement surgeries were undertaken in Germany, with most procedures in the age groups of 70-75 years (29 784) and 65-70 years (27 448) (6). These numbers reflect the worldwide upward trend of total knee replacements, as for example in the United States it is predicted that primary TKA will increase 85% by 2030 to a number of 1.26 million procedures per year (7).

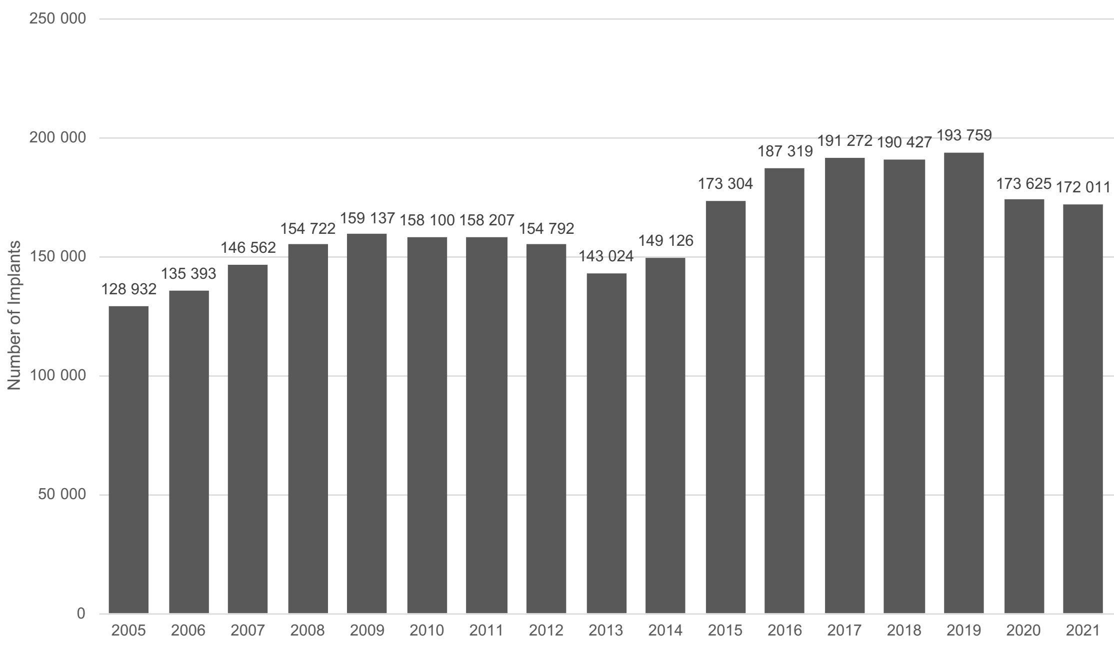

Figure 1. Number of implantations of knee prostheses in German hospitals between 2005 and 2021. Based on Statista (8)

Despite the positive outcome for most patients who undergo TKA, studies have proven that some patients are unsatisfied after surgical treatment. A systematic review revealed that 10 - 34% of patients still suffer long-term pain after TKA (9). Further, patients present themselves with muscle strength deficiencies, in particular quadriceps and hamstring dysfunction, and reduced function in daily activities after the surgery (10-13). The discontent after invasive treatment emphasizes the importance of rehabilitation programs, which are crucial for postoperative success. These programs should include interventions and procedures that focus on pain relief, improved function, and a higher quality of life (QOL) compared to the preoperative situation. However, literature shows no clear guideline on the starting timepoint and recommended type of rehabilitation program after TKA (10).

Another important aspect of patients' satisfaction after TKA is their ability to return to sport activities which they used to do before the deterioration of gonarthrosis. Especially in areas close to the mountains the question concerning return to winter sport activities is constantly rising. Empirical evidence shows that there is a wide range (34% - 88%) of patients who actually return to sport after TKA surgery (14, 15). Biomechanical studies indicate that low impact sports (e.g., swimming and biking) can be generally advised. However, it is still frequently debated among experts if and when to recommend high impact sport activities like skiing (14, 16-18). Authors have advised to assess the effects of these sport activities in future studies (19).

Therefore, the aim for this study was to further investigate the effects of two different rehabilitation programs after TKA. The initial goal was to compare an on-slope ski training to a ski specific home training program for patients with TKA. The next chapter outlines the theoretical background and gives an overview over recent literature on the topic followed by the aim of the thesis.

2. Theoretical Background

The following section of this paper moves on to describe the theoretical background for this research study. Firstly, the anatomical structures of the knee joint and the articular cartilage will be introduced. Secondly, the pathogenesis and treatment of gonarthrosis will be explained. Thirdly, an overview of TKA as a therapeutic option for gonarthrosis will be presented and the rehabilitation process for patients with TKA will be outlined. Lastly, results of current literature about skiing with TKA will be summarized.

2.1. The human knee joint

The human knee joint is the largest joint in the human body. It is a tri-compartmental gliding hinge joint composed of three bony structures, namely the tibia, femur, and patella (20). These bone components articulate together and compose the lateral femorotibial joint, the medial femorotibial joint and the patellofemoral joint (20). The human knee joint can move in three different planes (sagittal, frontal, and transversal) and has six degrees of freedom (20). The translational movements are anterior-posterior, medial-lateral and inferosuperior displacement. The rotations are flexion-extension, abduction-adduction, and internal-external rotation (20).

2.1.1. Bone articular components

The femoral condyles and the proximal tibia form the femorotibial joint. The geometry of the articular surfaces is decisive for the biomechanics of the knee (21). The femoral condyles are convex in the sagittal and frontal plane. At the front lies the facies patellaris and in the back the fossa intercondylaris between the condyles (22). The figure below depicts all bones and ligaments articulating in the human knee joint (see Figure 2). The medial and lateral condyle of the tibia form the distal joint surface and are separated by the eminentia intercondylaris. The medial surface is concave in the frontal and sagittal plane whereas the lateral condyle is only concave in the frontal plane but convex in the sagittal plane (21). These anatomical conditions are crucial for the kinematic behavior of the knee while moving.

The patella is a triangular sesamoid bone which articulates with the femur anteriorly. At the distal end the Lig. patellae proprium has its origin whereas the M. quadriceps femoris tendon inserts at the proximal area of the patella (22). The joint capsule forms several bursae (e.g. suprapatellar bursa, infrapatellar bursa, prepatellar bursa) which reduce friction in the joint (22). The patellofemoral joint functions as stabilizer during load and increases the leverage of the patella ligament and, in particular, the quadriceps femoris (21).

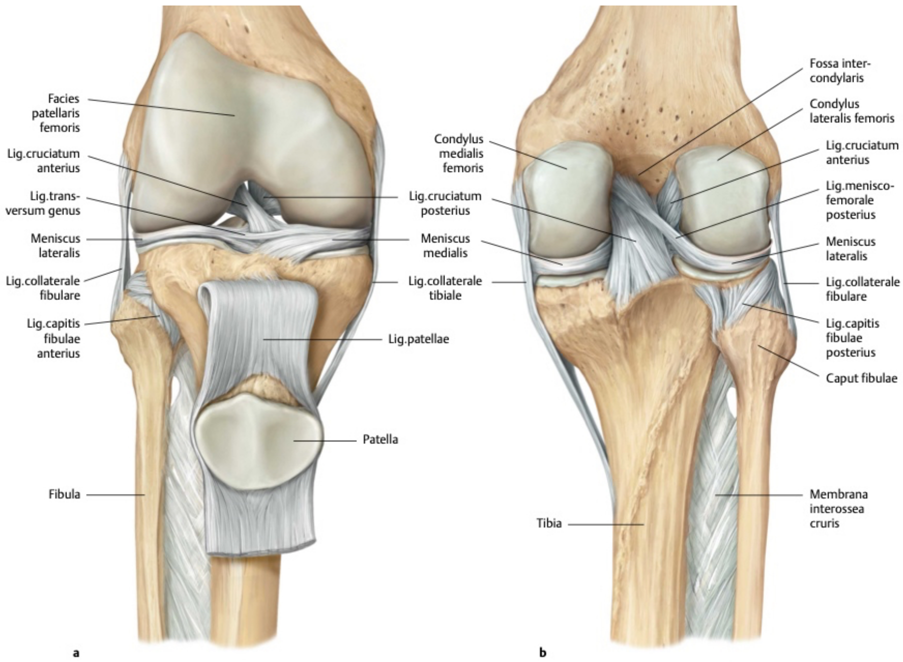

Figure 2. The human knee joint. (a) ventral, (b) dorsal view. (22)

2.1.2. Articular capsule of the knee joint

The knee joint capsule surrounds the knee. It is a fibrous cover wrapping the distal femur and proximal end of the tibia. The capsule is divided in an outer fibrous membrane and an inner synovial membrane, which produces synovial fluid (22). This fluid lubricates the joint and helps reduce friction of the bones. The capsule also provides nutrients to the joint (22). The fibrous outer layer of the capsule primarily functions as stabilizer by holding the bony components of the joint in the right position (22).

2.1.3. The menisci

The menisci (medial and lateral) are made of fibrocartilaginous tissue and are located between the femoral condyles and the tibia (21). They enlarge the articular surface providing better geometric conformity between the incongruent articular surfaces. This leads to more stability of the knee joint (21).

Moreover, they function as shock absorbers allowing for even distribution of load during movements. Further, the menisci contribute to knee joint lubrication and nutrition as well as to proprioceptive perception (23). The medial meniscus has a semicircular shape whereas the lateral meniscus is almost circular (21). On the ventral side both menisci are connected by the transverse ligament. The medial meniscus is further connected to the medial collateral ligament (MCL), whereas the lateral meniscus is more mobile and therefore less injury-prone (21). Figure 3 shows the menisci and the surrounding ligaments.

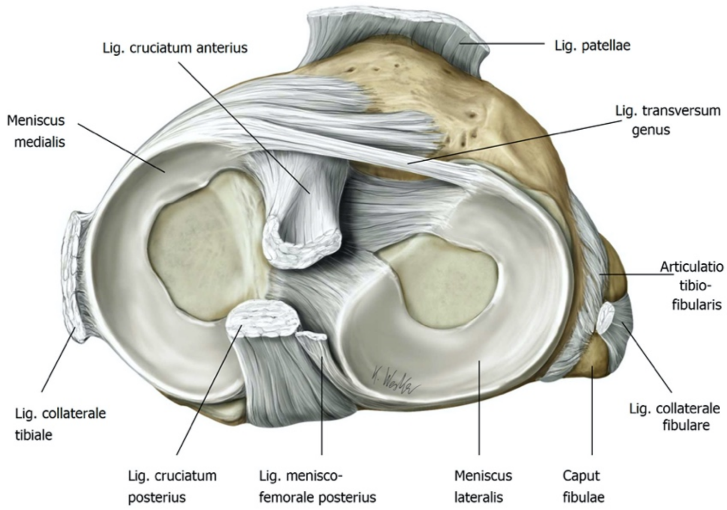

Figure 3. Menisci of the human knee. Right tibial plateau, proximal view. (24)

2.1.4. The ligaments

The knee is primary stabilized by ligaments. According to their anatomical position, ligaments of the knee joint can be divided into collateral, ventral, and dorsal ligaments (25). Additionally, the ventral and posterior cruciate ligaments stabilize the knee (25). To ensure stability of the knee joint in the whole range of motion and prevent joint dislocation adequate interaction of all ligaments is critical (25).

The MCL has its origin at the epicondylus femoris medialis and inserts at the medial condyle of the tibia (22). The MCL prevents excessive valgus stress during external rotation and provides medial stability to the knee (21). It is tight during extension and external rotation and loosens during flexion and internal rotation

(21). The lateral collateral ligament (LCL) originates cranial of the epicondylus femoris lateralis and runs to the lateral part of the head of the fibula (22). The LCL restricts varus stress during internal rotation. It is also taut during extension and loosens during flexion (21).

The cruciate ligaments play a central role as articular stabilizers. They do not only prevent translational movement in anterior-posterior direction but have mechano-receptors and therefore proprioceptive function as well (21). The posterior cruciate ligament (PCL) reaches from the posterior intercondylar area of the tibia to the lateral part of the medial condyle. The main function of the PCL "is to pre-vent posterior translation of the tibia" (21) . The anterior cruciate ligament (ACL) stretches from the anterior part of the tibia to the posterior lateral condyle of the femur (see Figure 2). The ACL's main function is to restrict anterior translation of the tibia, especially in flexion (21).

2.1.5. Muscles

The muscles, acting on the knee joint, function as secondary stabilizers. On the one hand, they enable the knee to move in all six degrees of freedom. On the other hand, they control and stabilize knee motion through their proprioceptive function (26). In the following, the main muscles for each direction of motion are outlined and illustrated in Figure 4.

The primary extensor of the knee joint is the quadriceps femoris (rectus femoris, vastus lateralis, vastus medialis, vastus intermedius) (22). The rectus femoris is the only biarticular muscle of the above-mentioned muscles acting on the knee (22). The biceps femoris (biarticular), semitendinosus (monoarticular) and the semimembranosus (monoarticular) build the hamstring group and are the main flexors of the knee joint (22). Knee flexion is supported by the M. gracilis and M. sartorius. The biarticular gastrocnemius is able to plantarflex the ankle joint and to flex the knee (22). The biceps femoris is the main lateral rotator supported by the M. tensor fasciae latae, whereas the M. semimembranosus, M. semitendi-nosus, M. sartorius and M. gracilis are important for medial rotation (22). Moreover, the knee is laterally stabilized by the tensor fasciae latae and iliotibial band (22).

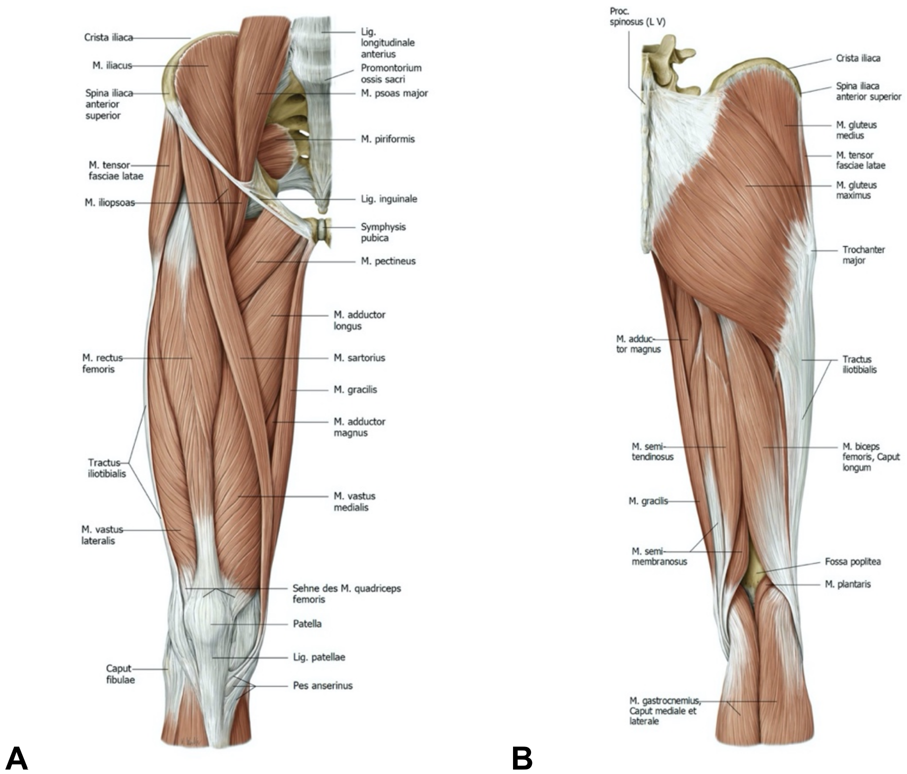

Figure 4. Muscles acting on the knee joint: (A) ventral, (B) dorsal.(24)

2.1.6. Cartilage

Cartilage is an important tissue consisting of dense collagen fibers and ground substance (27). In the human body three types of cartilage can be found (28). The hyaline cartilage is the most widespread type and can be found, e.g., on the articular bone structures, in the trachea, and nose of the human body (28). The elastic cartilage has more collagenous and elastic fibers and can be found, for instance, in the lobe of the ear (28). The fibrocartilage is found in areas like the intervertebral disks, where it functions as shock absorbers (28). Comprising both collagen I and II, fibrocartilage is tougher than the other cartilage types (27).

All articular surfaces are covered with hyaline cartilage (21). This lowers friction forces during sliding and rotating (27). Due to the high loads during motion on the cartilage, it has no perfusion itself (27). It is primarily supplied by surrounding tissue and the synovial fluid. According to Aigner et al. (29) the articular cartilage has four morphological zones, namely the superficial, transitional, deep, and calcified cartilage layer (see Figure 5). The superficial layer is mainly composed of small, flat chondrocytes which produce mainly collagen. The fibrils are arranged parallel resulting in a high tensile and shear strength. Destruction of this layer promotes the development of osteoarthritis (27).

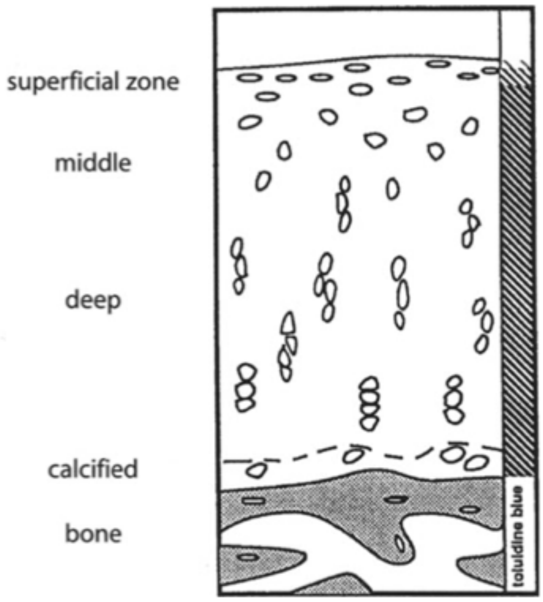

Figure 5. Morphological structure of normal adult human articular cartilage. (29)

2.2. Osteoarthritis of the knee joint

Osteoarthritis of the knee joint describes a chronic degenerative process with degradation of the hyaline cartilage and subsequent damage of the osseus joint surface. In Germany gonarthrosis is a very common disease of the elderly with prevalence ranging from 27% - 90% among people above 60 years depending on radiological or clinical criteria (30).

The International Osteoarthritis Research Society (OARSI) defines osteoarthritis as

> *"[…] a disorder involving movable joints characterized by cell stress and extracellular matrix degradation initiated by micro- and macro-injury that activates maladaptive repair responses including pro-inflammatory pathways of innate immunity. The disease manifests first as a molecular derangement (abnormal joint tissue metabolism) followed by anatomic, and/or physiologic derangements (characterized by cartilage degradation, bone remodelling, osteophyte formation, joint inflammation, and loss of normal joint function), that can culminate in illness." (31)*

The definition above explains that osteoarthritis not only affects the articular cartilage but is a multifactorial process leading to structural changes in the whole joint. This definition is fully applicable to the knee joint as well, and explains a group of various pathological conditions with homogenous presentation (32). In the following, the pathological aspects, diagnostics, and therapeutic options for osteoarthritis will be outlined.

2.2.1. Pathogenesis

On the right-hand side of Figure 6 the various pathological aspects involved in the development of osteoarthritis are depicted. Evidence highlights mechanisms like bone remodelling, subchondral sclerosis, osteophyte formation, meniscal damage and cartilage degradation as the leading cause for the aggravation of joint arthritis (33).

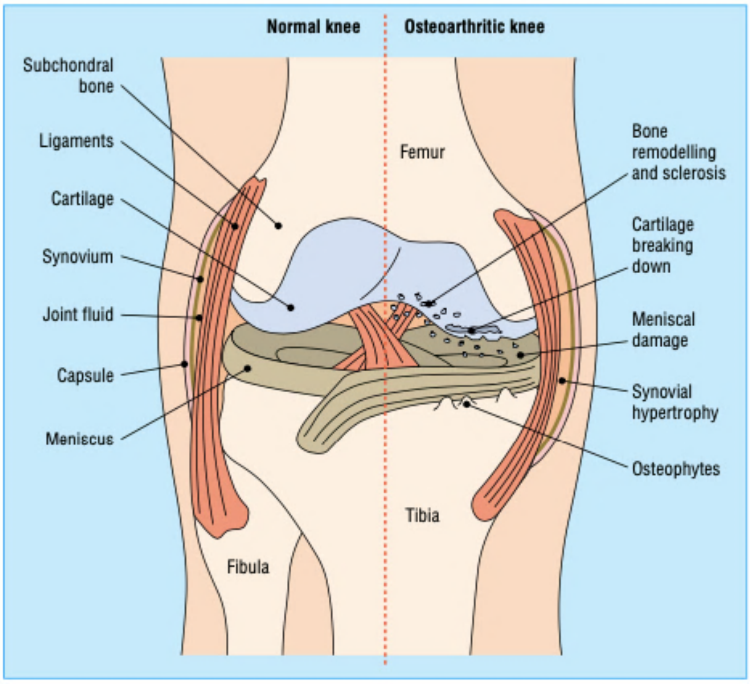

Figure 6. Joint tissue involvement in osteoarthritis. (33)

Generally KOA can be differentiated in primary and secondary gonarthrosis (32). Primary gonarthrosis describes the idiopathic wearing of the knee joint often accompanied by biological poor bone structure. The cause often remains unclear. However, certain risk factors facilitate the development of KOA. Risk factors for KOA can be categorized in systemic and local factors (1, 34).

It is well documented that systemic risk factors may contribute to the development of primary arthrosis. Systematic risk factors may include age, gender, race, genetics, obesity, osteoporosis, and nutrition (1). Whereas local factors refer to changes on joint level and are often causes for secondary gonarthrosis (1). Injuries of the knee joint, e.g., meniscus lesions, ligament ruptures or fractures, earlier can increase the chance of the development of osteoarthritis (1). Axial malalignment like genu valgus/ varus/ recurvatum/ antecurvatum or joint shape irregularities can likewise trigger osteoarthritis (1). Further, modifiable factors, like obesity and inactivity can trigger exacerbation of cartilage breakdown (1). In addition, secondary risk factors can be other diseases causing joint inflammation, like rheumatoid arthritis (1).

The starting point for the development of gonarthrosis is one or more mechanical and/or biochemical trigger that affects the cartilage and leads to an imbalance between the load and load-bearing capacity (32). In the case of primary gonarthrosis, the tolerance threshold is often exceeded by the aforementioned risk factors, e.g., age, obesity, genetics. For secondary gonarthrosis, the immediate causes may include, for example, trauma, infection, metabolic disorders (32). The disorder of cartilage homeostasis leads to consequential cartilage damage and may be induced both mechanically and biochemically. Pap et al. (32) describe three processes that occur in the progression of clinical manifestation of gonarthrosis:

(a) *Reaction of the synovia*: Destruction of the cartilage leads to abrasive particles which induce the release of proinflammatory enzymes leading to a synovial irritation. The synovitis induces more cartilage depleting proteases resulting in further destruction of the matrix (32).

(b) *Reaction of the subchondral bone:* Due to the cartilage destruction the subchondral bone is mechanically subject to more load. The increased load leads to bone remodeling resulting in stiffer and less perfused subchondral structures. The exposed subchondral areas are more exposed for microfractures with the risk of advancing into necrotic cyst (32).

(c) *Neuromuscular joint malfunction:* Joint destruction leads to an increased stimulation of intraarticular mechanoreceptors. This increased afferent information causes a reflective inhibition of efferent pathways, especially those stimulating the motoneurons of the M. quadriceps femoris. It is assumed, that it is primarily the receptors of the involved structures in joint destruction, like the synovia, that are affected. It results in less strength of the stabilizing muscles leading to reduced load-bearing capacity, balance, and gait difficulties. Through the resulting incorrect loading of the joint the progression of the disease is reinforced (32).

These explanations demonstrate that the pathogenesis of cartilage breakdown in OA is multifactorial. Mechanical as well as biological changes in the cartilage homeostasis contribute to the progression of the disease.

2.2.2. Diagnosis

According to the German guidelines for gonarthrosis, KOA should be diagnosed through physical examination and imaging techniques, particularly x-ray (29). Typical clinical signs are joint pain worsening during activity, morning stiffness or stiffness after rest, swelling, reduced range of motion and crepitus. Symptoms can deteriorate under stress to acute joint inflammation with signs like red skin, overheating and joint effusion (33). This condition is called activated arthrosis. Radiologically, arthrosis is typically classified according to Kellgren and Lawrence (35). Table 1 shows the radiologic classification of the stages of osteoarthritis described by Kellgren and Lawrence.

Table 1. Radiologic classification of osteoarthritis. Based on Kellgren and Lawrence. Modified from Fraitzl (36)

Stage	**Description**
0	No arthrotic signs
1	Initial osteophytes (e.g. at the eminentia intercondylaris or patella)
2	Definite detection of osteophytes, without joint space narrowing, no deformity
3	Moderate osteophytes, joint space narrowing, sclerosis of subchondral bone
4	Large osteophytes and joint space narrowing, clear sclerosis and deformation of osseous structures, cysts

Figure 7 depicts anterioposterior and lateral radiographs with typical signs of progressive osteoarthritis for instance joint space narrowing, osteophytes and subchondral cysts and sclerosis.

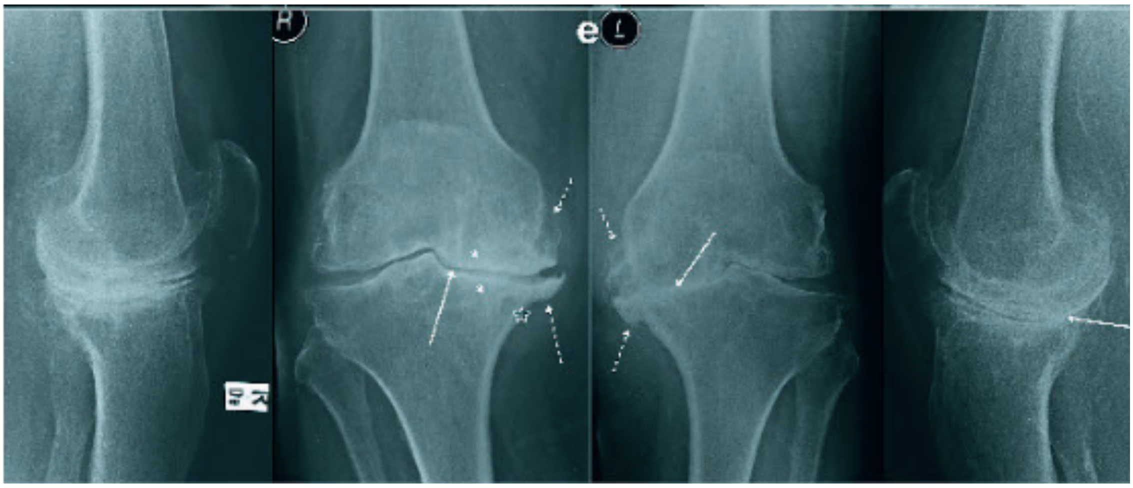

Figure 7. Progressive osteoarthritis Stage 3-4 (Kellgren-Lawrence). Joint space narrowing (arrows), osteophytes (dotted arrows), subchondral sclerosis (*), subchondral cyst (star). Modified from Schütz (37)

2.2.3. Therapy

Gonarthrosis can be treated conservatively or with surgical intervention. Both options will be discussed in the following section. Regardless of the treatment option the overall aim of osteoarthritis therapy is the reduction of disease progression, the improvement of joint mobility and function, pain relief and an overall improvement of the patients' QOL (33).

<u>Conservative treatment:</u>

Various treatment guidelines have been developed by different societies to standardize the therapy for patients with osteoarthritis. Figure 8 depicts conservative therapy recommendations by the American Academy of Orthopedic Surgeons (AAOS), American College of Rheumatology (ACR), European League against Rheumatism (EULAR) and OARSI for knee and hip osteoarthritis (5). A level of evidence of 1 out of 4 and a level of agreement higher than 8.5 out of 10 is shown as strongly recommended. Treatment options which have moderate to limited evidence are only recommended in certain conditions.

All four organizations strongly recommend that primary therapy should include nonpharmacologic treatment focusing on the patients' education (5). Additionally, regular exercise and weight loss should be advised in the case of overweight patients as obesity is one of the major factors causing knee problems (5). A randomized clinical trial of an intensive diet and exercise program with overweight and obese KOA patients revealed a reduction of knee pain, a reduction of knee compression force and increased knee function for the group following a diet and exercise program for 18 months (38). The literature review by Raposo et al. (39) shows that aerobic training, strength exercising as well as Pilates have a positive effect especially in regard to pain and strength improvement for patients with KOA. Further, the review revealed that aquatic exercise programs are comparable to land-based training programs. For treatment options such as balance training, yoga, tai chi, acupuncture, and cognitive behavior therapy the experts do not follow a clear line yet. Transcutaneous electrical nerve stimulation has not been recommended by any of them.

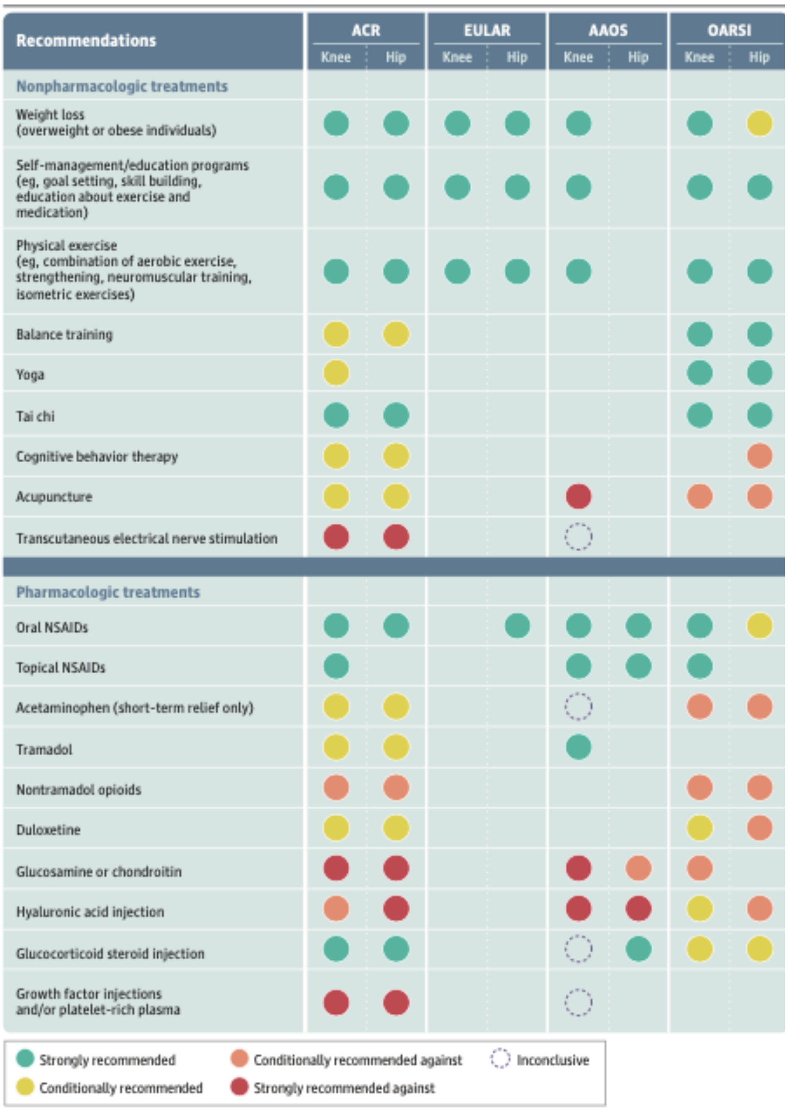

Figure 8. Osteoarthritis treatment guidelines. (5)

The treatment options above aim to provide long-term benefits for patients whereas for immediate symptom management pharmaceuticals can be used.

Pharmacological therapy includes analgesics, non-steroidal anti-inflammatory drugs (NSAID) and corticosteroids (30). As at the date of this paper, opioids have only been partly recommended by the professional societies (30). When prescribing NSAIDs a patient’s comorbidities should be considered as they increase the risk of gastrointestinal bleeding, ulceration and decreased renal blood flow (30). If necessary, medication should be complemented by proton pump inhibitors (30).

For acute aggravation of pain, supportive treatment options like intra-articular corticosteroid injection are available (30). Although studies have shown a pain reduction and increased joint mobility (40-42), in the overview by Katz et al. (5), only the ACR has strongly recommended glucocorticoid steroid injection in their guidelines for KOA so far. Nevertheless, the German guideline for gonarthrosis likewise shows a 100% consensus that intra-articular corticosteroid injections can be applied for short term pain relief (30). Other documented interventional treatment options are hyaluronic acid injection and the injection of platelet-rich plasma (PRP), however, opinions differ regarding their recommendation (5). The lack of well-designed studies about the positive effects of PRP has led the German experts to the opinion that a general recommendation cannot yet be given (30).

Additional steps involved in conservative therapy are physiotherapy as well as physical treatment methods (e.g., heat and cold therapy or transcutaneous electrical nerve stimulation) (30). Similarly, the supply of medical aids, such as adjustable footwear or knee braces to correct alignment deformities, can be a component of conservative therapy (30).

Surgical treatment:

If conservative treatment options fail or do not bring the desired effect, surgical methods have to be taken into consideration. According to the German Society for Orthopedics and Orthopedic Surgery (DGOOC) guidelines the main criteria for surgical treatment are as follows (43):

- knee pain lasting at least 3-6 months
- radiological confirmation of osteoarthritis
- failure of conservative treatment

- impact on patient's QOL
- relevant subjective level of suffering due to the knee disease

Depending on the manifestation, the underlying mechanisms and the severity of OA, different surgical techniques are individually applied. Surgical strategies can be divided into joint preserving methods and joint replacement operations.

Arthroscopic treatments range from simple joint lavages to combinations with meniscal and/or cartilage smoothening and the removal of loose joint bodies. Arthroscopic debridement is particularly suitable for early stage gonarthrosis to remove mechanical irritations in the knee joint (36). Furthermore, different methods to repair cartilage are applied during arthroscopy of the knee. The strategies can be divided into palliation, repair, and restoration. For focal cartilage defects perforation and micro fracturing can induce marrow stimulation and trigger replacement cartilage production, thus leading to an improvement of symptoms (44). The German guideline explicitly mentions, however, that these methods are only applicable to early stage gonarthrosis. The evidence is still limited for the general use of cartilage perforation and micro fracturing for patients with osteoarthritis (30). To restore cartilage matrix autologous matrix induced chondrogenesis, auto chondral cell transplant or osteochondral autograft transfer can be applied (45). Despite promising outcomes in some studies (46-48), the evidence is still unsatisfactory and therefore German experts have not recommended these methods in their current guideline (30). Corrective osteotomy is a further method to primarily treat unicompartimental gonarthrosis due to a varus or valgus malalignment. The aim of the procedure is to realign the knee joint, reduce symptoms, improve function and delay the implantation of a knee prosthesis (36).

If the patient's osteoarthritis has advanced considerably and none of the above-mentioned treatment options led to an improvement, joint replacement options should be taken into consideration. Total knee replacement, partial knee replacement or unicompartimental surgery is indicated after a thorough risk-benefit analysis. They are the only curative treatment methods as the damaged bone structures are excised and replaced with a durable prosthesis. Total, unicompartimental and partial knee arthroplasty will be outlined in more detail in the following chapter. Arthrodesis is a further joint replacing surgery option, but it has lost its prevalence due to the good results of knee prostheses (30, 36).

2.3. Knee arthroplasty

Knee replacement surgery is an established and effective method used in patients with end-stage KOA for whom conservative therapy has been ineffective. Indications range from osteoarthritis to inflammatory arthritis, osteonecrosis, congenital joint abnormalities or tumors (49). The next chapter looks at this intervention more closely, beginning with a short historical summary. In the interest of completeness, different designs of knee arthroplasties are illustrated, putting emphasis on TKA which was applied in the study population.

2.3.1. From the past to the present

The history of knee arthroplasty can be traced back to the 1860s, when Verneuil used soft tissue between the bone ends to avoid ankylosis (50). In the following decades a variety of materials were tested to recover joint function (51, 52). The first real artificial joint was introduced by the German surgeon Gluck and was made out of ivory (53). However, all tissues used at the time were too soft to endure human body weight and infection was a major problem resulting in septic loosening. Roughly 100 years later, the first stainless steel prosthesis for total knee replacement was designed by Shiers (54). The design was lacking translational and rotational movement and was soon replaced by designs resulting in better knee function (55). However, the designs were still struggling with implant loosening. The introduction of low friction arthroplasty for the hip by John Charnley 1961 marks another important milestone in the development of artificial joints. Charnley was able to decrease the rate of implant loosening by using polymethylmethacrylate (PMMA) and by introducing the polyethylene metal bearing (56). Charnley pioneered this design and many following knee prostheses designs used the advances of implant fixation introduced by him (57-59). In 1972 one of the first unicompartmental knee prostheses was introduced showing a 70% satisfactory rate after 10 years follow-up (60). Negative effects like heat injury (61) and chemical toxicity (62) led to the development of uncemented, press-fit implants (63, 64). Ever since, research has been aiming to develop designs with materials that prolong prosthetic survival rates and enhance functional outcome (65). Currently available designs for knee joint replacement are depicted in Figure 9. There are unicompartimental designs (Aa: femorotibial or Ab: femoropatellar), TKA with preservation of the PCL (Ba: cruciate retaining) or replacement of the PCL (Bb: posterior stabilized), partially coupled (C: condylar constrained) or fully coupled (D: rotating hinge knee) prostheses (36, 66).

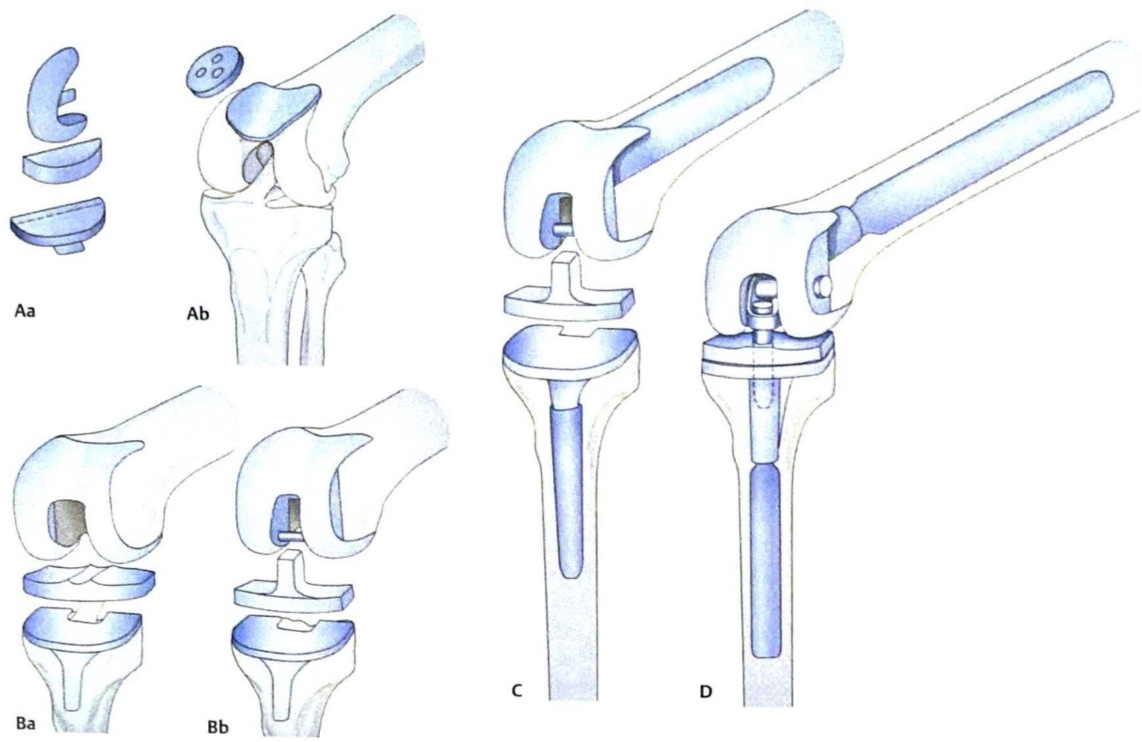

Figure 9. Knee replacement designs. (36)

Ongoing development of surgical techniques and the use of less invasive approaches are constantly driven forward to improve outcomes and shorten the rehabilitation phase after surgery. According to the German Arthroplasty Registry (EPRD) in 2020 111.365 primary knee arthroplasties were implanted in Germany (67). Figure 10 depicts the characteristics of the patients showing that roughly 60% of them were women. Further, it is noticeable that the mean body mass index (BMI) is about 30, which is considered obese by the World Health Organization (68). TKA still accounts for the majority of the surgical interventions (86.6%) compared to unicondylar knee arthroplasty (UKA) (13.2%) and other arthroplasties and with 94% of all knee replacements, cemented models are still the most common ones implanted (67).

	Proportion [%]	Age	m/f [%]	BMI
All primary knee arthroplasties	100.0	69	41 / 59	29.8
<45 years	0.7		38 / 62	32.0
45-54 years	7.7		42 / 58	32.5
55-64 years	27.8		46 / 54	31.4
65-74 years	33.4		40 / 60	30.1
75-84 years	27.9		37 / 63	27.9
85 years and older	2.6		35 / 65	26.3
Male	40.8	68	100 / 0	29.4
Female	59.2	69	0 / 100	30.1

Figure 10. Primary knee arthroplasties in Germany in 2020. (67)

2.3.2. Partial knee arthroplasty

In Germany around 13% of patients with knee replacements undergo partial joint arthroplasty (67). This includes either replacement of the patellofemoral joint (PFJR) or the medial or lateral tibiofemoral compartment, also called unicompartmental knee replacement (UKR) (see Figure 9). Partial knee prostheses are not presented in the patient selection of this study. Nevertheless, for the sake of completeness they will be shortly described in the following.

The PFJR is an alternative to TK indicated when the damage of cartilage is limited to the posterior face of the patella and the anterior groove in the femur. UKA is generally indicated when either the lateral or medial compartment is isolated involved. For the implantation of an UKA an intact ACL, intact collateral ligaments and a physiological alignment are essential conditions (66). Contraindications are for example an affected contralateral condyle, a worn out retropattelar surface, osteoporosis, severe clinical symptoms with axis malalignment and an extremely elevated BMI (66). The procedure requires a smaller incision compared to TKA and less overall tissue is affected. Therefore, patients undergoing UKR surgery can usually be discharged earlier and have a shorter recuperation time compared to TKA (69, 70). Further, research has shown lower morbidity and mortality for UKR compared to TKA (71) as well as better proprioception (72) and higher activity levels after surgery (73). Nevertheless, literature also shows higher revision rates for partial knee replacement (74, 75).

2.3.3. Total knee arthroplasty

TKA implies the resection of the diseased articular surfaces and replacing them with a femoral, tibial, and patellar prosthetic component (49). Most systems use a metal tibia tray and a polyethylene spacer which articulates with the femoral component. As mentioned above different designs with their respective advantages and disadvantages exist. The advantages of the PCL retention method are a greater range of motion, less stress on the implant resulting in lower failure rates and improved proprioception (49). On the other hand, PCL sacrificing models lead to a more reliable correction, are easier to balance and show decreased polyethylene wear (49). Nowadays, implants can be fixated with cement, cementless or in a hybrid technique where only one component is cemented (49).

The surgical procedures hinge on the prosthesis' design, tissue deformities and extent of malalignment. Generally speaking, the opening of the knee joint is carried out via a midline incision (76). Other opening approaches may be considered and should be chosen on a case-by-case basis (76). After opening the surgical area, the patella is everted and if PFJR is needed its posterior surface is removed and initially replaced by a trial implant before putting the final implant at the end of the surgery (49). Subsequently, the resection of the distal femur and proximal tibia depending on the prosthesis design is performed with help of manual instruments (49). Having regard to the symmetric and physiologic tension of the ligamentous apparatus the extent of bone resection is measured and ligamentous release might be necessary (49). Prior to the final implant the surgeon tests the biomechanics with a trial implant. Finally, the new prosthesis is implanted followed by a thorough wound closure.

Absolute contraindications for TKA include active remote infection, infection in the knee joint or any acute cardiovascular event (43). Relative contraindications are for example chronic ischemia in the lower extremities, BMI ≥ 40, skeletal immaturity or any neurologic disease affecting the extensor mechanism (43, 49). Some complications of TKA include periprosthetic fractures, prosthetic joint infection, aseptic loosening, instability, stiffness, vascular injury or peroneal nerve palsy (76).

After surgery adequate pain management is vitally important. Further, thrombosis prophylaxis is indicated. Mobilization starts on the surgery day through the aid of a trained physiotherapist. The hospitalization length is dependent on local standards and other comorbidities of the patient but usually ranges from zero to five days. Since a successful outcome is strongly influenced by the postoperative rehabilitation program and noting that no clear guidelines exist (77), it is of vital importance to provide the patient with a well-structured postoperative training program. “[Programs should include] range of motion exercises, gait training, quadriceps strengthening, and training activities of daily living […].” (49). The next chapter addresses a variety of aspects concerning the rehabilitation process for people with TKA in more detail.

2.4. Rehabilitation of patients with total knee arthroplasty

Rehabilitation's main goal after TKA surgery is reintegration into society. For preservation of life quality, social participation, and a self-determined lifestyle it is vitally important that patients are able to complete daily tasks and activities after the operation. Rehabilitation starts with postoperative management during the hospital stay and continues after discharge (49). Orthopedic inpatient rehabilitation after knee or hip arthroplasty in Germany is multidisciplinary and usually lasts for 3-4 weeks (78). As the effects often do not last in the long term it is necessary to inform the patients about recommendable aftercare treatment options after the inpatient rehabilitation (79). In this chapter special focus is placed on the benefits of rehabilitation programs after the release from inpatient rehabilitation on gait performance, strength and balance, and the psychological well-being with TKA. Lastly, a short literature review about the recommendations concerning returning to sport after TKA surgery is provided.

2.4.1. Effects of TKA on physical performance and psychological well-being

> *"A well-structured [physical therapy] program that includes range of motion exercise, gait training, quadriceps strengthening, and training in activities of daily living is an important component of the rehabilitation process."* (49)

As outlined in the recent up2date guideline, rehabilitation after TKA is a multidimensional process. In the following the different aspects of important components of rehabilitation after TKA will be further elaborated on.

Gait mechanics

To enable daily tasks post-surgery, mobility must be guaranteed. Major prerequisites are a good ability to balance and intact ability to walk. Normal gait is a rhythmic and alternating movement, resulting in a forward walking with a specific movement pattern. A gait cycle is defined as the time between contact to contact of one foot (80). It is divided into two phases, the stance, and the swing phase. These phases are further divided into 8 sub-phases (see Figure 11). The swing phase covers 40% of the total gait cycle and describes the phase when the limb is lifted off the floor, whilst the stance phase comprises 60% and marks the period of time the foot is in contact with the floor (81). Step length is defined as the distance measured between the posterior contact of the previous footfall to the heel contact of the opposing footfall (81). Whereas stride length is the distance between two successive points of initial contact of the same foot (81). Step width is described as the side-to-side distance between the heel centers (81). Other important temporal-spatial parameters to describe the gait mechanics are gait speed, often expressed in m/min and cadence (steps/time).

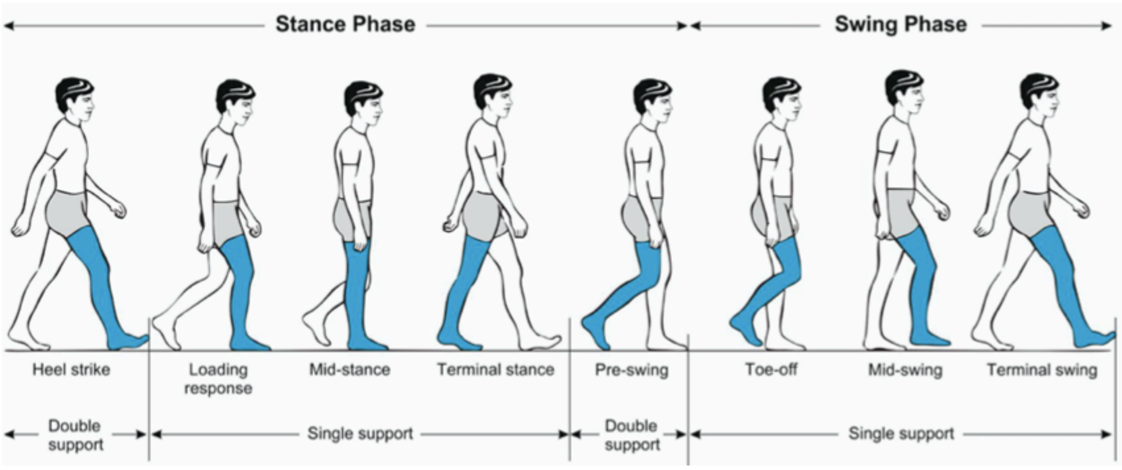

Figure 11. Human gait cycle. (80)

Depending on the gait phase the range of motion of joints, torque demands, and muscle activities of the lower limb and core vary. Figure 12 depicts the range of motion and torque moments for the knee joint during one gait cycle. The activated muscle groups of the lower limb can be assigned to the different gait phases. Prior research shows that KOA leads to pathological gait characteristics with greater knee stiffness (82, 83). Perry et al. (84) report that patients with gonarthrosis mostly reveal abnormalities in the sagittal plane. Reasons for insufficient flexion and excessive extension range from M. quadriceps femoris weakness, pain, or spasticity to exceeding plantarflexion of the upper ankle joint or weakness of the hip flexors. Causes for exceeding flexion and insufficient extension are weakness of the M. soleus, inappropriate activity of the ischiocrural muscles and flexion contraction of the knee joint (84). Even after operative treatment with knee replacement, studies show that gait mechanics stay pathological (85). Patients show a decreased range of motion compared to the non-operated leg, especially looking at the flexion during the loading phase (86). Papagiannis et al. (87) reported in their literature review slower walking speed, less knee flexion excursion during stance and lower peak knee flexion during the swing phase for patients after TKA surgery. A stiff gait pattern with less knee flexion excursion increases the risk of TKA of the other limb (88). These studies reveal the importance of a rehabilitation program focusing on quadriceps strength in order to improve gait mechanics after TKA surgery. A specific walking-skill program for instance revealed a better performance in a 6-minute walking test even after 9 months post-surgery compared to usual physiotherapy (89). The question that arises is, whether a structured home training program beginning 6 to 24 months post-surgery can contribute to better quadriceps strength and consequently improve the gait kinematics over the long term.

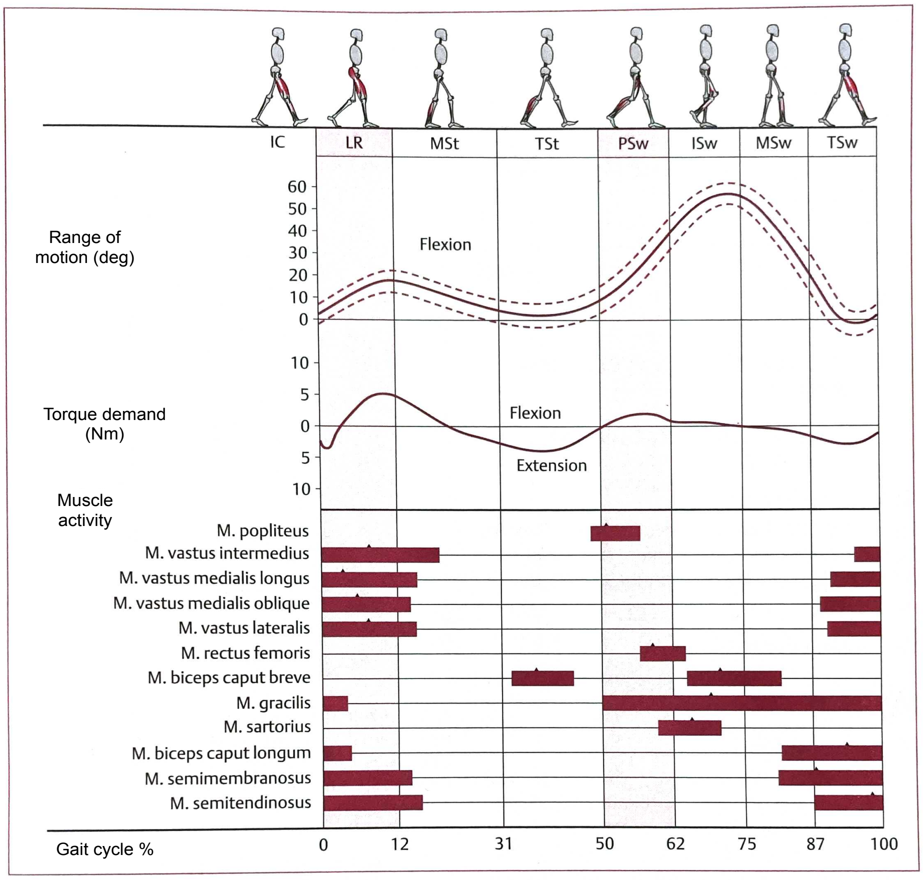

Figure 12. Normal range of motion, torsional moment, and muscle activity of the knee joint during one gait cycle. Abbreviations: IC= initial contact, LR= loading response, MSt= mid stance, TSt=terminal stance, PSw= pre-swing, ISw= initial swing, MSw= mid swing, TSw= terminal swing. Modified from Götz-Neumann (81)

Strength and balance

In order to not only return to daily activities but to be able to take part in sporting activities as well, it is important to reach good levels of balance and strength post-surgery. Research has shown that patients often show quadriceps muscle weakness after TKA surgery (90-92). Even 6 to 13 years post-surgery the strength deficit persists and patients maintain lower gait performances compared to healthy individuals (93). These deficits are not only present at the extensors but have been identified for the hamstring muscle group as well (13). It has been previously reported that high intensity strength training before knee replacement leads to better postural control shortly after TKA (94). Further, an 8-week maximal strength training post-surgery resulted in higher strength improvements in both legs after TKA compared to standard rehabilitation. The differences were also present after a 12-month follow-up (95). A study conducted with elderly women revealed increased muscle mass and mobility benefits after a 12-week elastic resistance exercise program post-surgery (96). Similarly, LaStayo et al. (97) provide evidence that patients benefit from a strength training intervention even four years after surgery. Nevertheless, a systematic review on progressive resistance training before and after TKA is inconclusive as the results were too heterogeneous (98). The inconsistency in results demonstrates the need of further studies to verify the effects of strength training after TKA. The question therefore arises as to how strength level and postural control can be improved long after TKA to speed up recovery and regain full participation in everyday life.

Balance is an important factor for the QOL and the knee function after primary TKA. As it is strongly linked to the strength status and gait performance of the lower limb this study also addresses possible effects of balance exercises after the surgery. Fernandes et al. (99) reported improved balance and higher QOL six months after TKA surgery. Nevertheless, their study also pointed out, that the balance levels for TKA patients are still lower compared to healthy individuals (99). Other authors point out that specific training after the surgery further improves balance levels and can enhance patients' knee function as well as their QOL (100, 101).

Psychological well-being

Literature shows that people with osteoarthritis have a higher chance of developing depressive symptoms compared to people without osteoarthritis (3). With these possible effects of osteoarthritis in mind, it seems reasonable to take a holistic view on the rehabilitation process for TKA patients. Therefore, more and more studies include not only the physical transformation processes but look at the psychological impacts of TKA surgery as well (99, 102, 103). A popular and validated tool to assess QOL is the World Health Organization Quality of Life short version instrument (WHOQOL-BREF) (104, 105). The WHOQOL-group defined QOL in their position paper on the assessment of QOL as one's:

> *"individual[…] perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns."(105)*

Previous research showed that knee replacement delivers significant improvements in health related QOL (106-109). However, there is also evidence that not all patients are satisfied after the treatment (107, 110). In particular, comorbidities, advanced age, lengthy wait for surgery and high BMI seem to be associated with lower QOL after surgery (110, 111). The question arises whether subjective QOL after TKA can be improved through a structured exercise program. For this reason, this study includes two questionnaires assessing the psychological well-being (see p.55).

2.4.2. Return to sport

Patients with osteoarthritis do not only increase in numbers with the aging population but also want to stay more active into their old age (18, 112). With this trend in society, clinicians are confronted with higher expectations regarding sport activities after TKA. However, the question on how much sport and what kind of sport activities are recommendable is not easily answered and the number of patients returning to sport activities varies. Reliable guidelines on the timepoint and kind of sporting activities are lacking, and most recommendations are based on expert opinions or clinical experience (18, 112, 113). Most experts differentiate between sports activities with low impact (e.g. swimming, bicycling, aquafit, walking, etc.) and those with high impact (e.g. skiing, running, dancing, tennis etc.) when providing advice regarding the return to sport (73, 114).

A meta-analysis by Witjes et al. (112) revealed highly variable return to sport rates ranging from 36% to 89%. After TKA 94% returned to low-impact sport, 64% to intermediate- impact sport and only 43% returned to high impact sport. The average time point of returning to sports activities was 13 weeks post-surgery (112). A recent systematic review from 2022 analyzes 6 articles on return to sports after TKA supporting the timepoint to return to sport of 13 weeks postoperatively (19). The authors recommend low-impact sports without prior experience, moderate-impact sports only with prior experience, but found no consensus for high impact sporting activities (19). Members of the European Knee Associates (EKA) recommend an increasing number of sports depending on the time point after surgery. After six months postoperatively 21 out of 47 sports are advised, leaving 20 disciplines with no final consensus and squash as not recommendable (18). Prognostic indicators for returning to leisure activity that have been identified are young age, low BMI and male sex (19, 115). Further, research suggests that moderate activity is recommendable as it raises osteointegration and prevents prosthetic loosening (116). Taken together, the studies presented thus far provide no final clarification on returning to sport after TKA.

2.4.3. Home-based rehabilitation

The previous sections underline the importance of additional training after the hospital release to ensure patients' contentment after the intervention. Since the COVID-19 pandemic the demand for home-based training possibilities has increased enormously raising the question whether long-term rehabilitation success can be reached through unsupervised training. After UKR patients show no significantly higher leg extension power after supervised progressive strength training combined with home training compared to patients who only trained at home. Consequently, the authors suggest that simple exercises at home can be recommended to improve muscle strength after knee replacement (117). Similar results have been found by Jakobsen et al. (118) for patients with TKA, who suggest including exercises with elastic bands or patients' own body weight instead of strength exercises in machines in early rehabilitation. The literature review by

Bravi et al. (119) underlines the fact that unsupervised rehabilitation has no drawbacks in regard to mobility, pain or function after TKA compared to supervised training. These results go along with the findings by Han et al. (120) that reveal a home exercise program is equally efficient to usual outpatient care. With these results in mind this paper addresses the specific effects a home training program including balance, strength, and mobility exercises, has compared to usual therapy and daily routine. Focus will be put on a subgroup completing a regular ski training guided by the objective to broaden scientific evidence on returning to sport after TKA.

2.5. Skiing with total knee arthroplasty

As described in chapter 2.4.2 literature shows no clear consensus concerning post-operative return to sport. However, in regions situated in the mountains or close to the mountains the demand for so called high-risk activities is generally higher than in other regions. Furthermore, due to the aging population and better medical care people are more active in old age (18, 102, 112), posing a challenge in respect of giving evidence-based recommendations on the timepoint of returning to different sporting activities after a surgery. Located at the bottom of Zugspitze, the highest mountain of Germany, surgeons in the Endogap Clinic for Joint Replacement are regularly confronted with the question of whether skiing after joint replacement is possible and if it can be recommended. In the following, basic biomechanics of skiing will be outlined and an overview of literature data regarding returning to the slopes after TKA will be provided.

2.5.1. Biomechanical introduction to skiing

Alpine skiing is a technically complex outdoor sport as the individual must adapt constantly to changing snow conditions, slope, and terrain. Ski performance is further influenced by kinetic and kinematic factors like "trajectory of the skis and/or center of mass, turning radius and speed, ground reaction forces (GRFs), aerodynamic drag and frictional forces, as well as energy dissipation" (121). Additionally, skiing technique has an impact on biomechanical parameters (120). Forces during alpine skiing reach up to 3.5 - 10 times the bodyweight (122). An Austrian study has investigated biomechanical differences between parallel ski-steering with skidded turn, carving turns with less skidding and individual skiing technique in older recreational skiers. Looking at mean knee angle (MKA), range of knee angle (RKA) and GRFs, the authors found lower peak GRFs, lower RKA and greater MKA for parallel ski steering (123). To better understand joint moments and forces during skiing, Heinrich et al. (124) analyzed these parameters for the inside and outside leg separately. Extension moments in the hip and knee were almost identical for the inside and outside leg, whereas GRFs was circa 50% higher on the outside leg (124). The only study that has been looking at the force loading during skiing with TKA revealed no significant difference in joint loading between operated and non-operated limb (125). To date, there are no more studies that have investigated the effect of knee arthroplasty on skiing biomechanics and performance.

2.5.2. Return to skiing after TKA

Previous literature indicates that regular alpine skiing has positive health effects and contributes to a healthier lifestyle (126). Despite the positive effects, the current data situation concerning returning to alpine skiing after knee arthroplasty surgery is poor. Alpine skiing ranks among high impact sports (127) and is often discussed with patients after TKA surgery. Main concerns include prosthetic loosening and higher polyethylene wear leading to higher revision rates (128). As a correlation exists between polyethylene wear rate and enhanced activity, recommendations for returning to skiing remain controversial (129).

Previous research in patients with total hip replacement has shown, that regular alpine and/or cross-country skiing does not lead to higher loosening rates or negative effects of the prothesis components even after a five year follow-up (130). A study by Mont et al. (127) found out that from 33 patients engaged in high impact sports, skiing included, only one needed revision after four years. Even after a seven year follow-up no aseptic loosening can be observed in patients regularly participating in high impact sport (131). Implant loosening rate is also not predominantly found in patients who perform high -impact sports but can also be found after low or medium impact sport (132). These results may suggest that in terms of longevity and revision of TKA high impact sport activities may be possible. Nevertheless, to our knowledge only one comparable study has been exclusively investigating the loosening rates and polyethylene wear for alpine skiing and TKA (133). It was part of a multidisciplinary study conducted in Austria investigating the long-term effects of a 12-week skiing intervention in patients with TKA (114). In their pilot study in 2015 the authors observed symmetric joint loading and no increased pain perception after ten weeks skiing, therefore concluding that skiing may be possible after TKA for patients with good postoperative outcomes and with skiing experience (125). In the main study, one season later, quadriceps and hamstring strength improved significantly for the operated limb, whereas no effect on cardiorespiratory fitness was observed (134). These results are only partially consistent with the outcomes of a 12-week skiing intervention for elderly without TKA showing improvements in aerobic capacity as well as leg muscle power and strength (135). Additionally, skiing with TKA led to an increase in psychological well-being and higher physical activity, perceived knee function and exertion (136). Moreover, gait characteristics improved through a consistent skiing program leading to a more symmetric load distribution (137). In regard to clinical and radiological outcomes patients showed no signs of implant loosening or polyethylene wear 5.1 years after surgery (133). Within the framework of their study the authors recommend sports like alpine skiing in order to improve activity levels post-surgery and diminish muscle strength imbalances (134). However, in the prospective online survey by Thaler et al. (18) no consensus on return to skiing was made, but approximately 40% recommended skiing after six months and 37% recommended it only with prior experience. Other studies are consistent with the case by case decision process depending on patients skiing experience (16, 133). In the most recent study regarding this topic, Buckley et al. (138) evaluated under which conditions patients were allowed to restart downhill skiing, whether the recommendations were evidence based and if any complications appeared after skiing in a Canadian cohort. Forty-one orthopedic surgeons in Alberta completed the survey showing opinions from “would not allow skiing at all” (2%) to “unrestricted skiing” (25%). The rest only recommended skiing under certain limitations. The most common restrictions mentioned were reduction of speed and intensity (71%), returned range of motion and strength in the operated limb as a prerequisite (63%) and years of experience (56%). However, mostly these recommendations were not evidence based (78%), once again demonstrating the lack of data for profound instructions and the need to further monitor downhill skiing after TKA (138). Despite several reviews in the literature that address the question whether skiing after TKA is possible, none delivers a good database for profound advice. This study was therefore originally designed to broaden the knowledge about possible effects of regular leisure skiing in patients with knee replacement.

3. Aim of the study

The aim of this project was to examine the influence of an 8-week home training intervention compared to an 8-week skiing intervention for patients with knee joint replacement. Accordingly, this study was designed to assess the effects of a home training and ski training group versus a control group (CG) in order to investigate key benefits of those training programs. In this present study an isokinetic strength test, cardiorespiratory bicycle test, coordination test and gait analysis were conducted with TKA patients 6-24 months post-surgery. Additionally, pain behavior pre and post intervention was evaluated. For psychological parameters the Oxford Happiness Score and WHOQOL- BREF were chosen as they provide estimates for psychological well-being (see section 4.3.6). The following questions were addressed in this study:

Does an 8-week home training intervention improve

- muscle strength?
- body composition?
- cardiorespiratory fitness?
- balance?
- gait performance?
- psychological well-being and functional scores?

Based on the available data on this topic, it was hypothesized that the home training program has a positive effect on all categories mentioned above. As scientific evidence shows a positive effect of skiing on muscle strength and gait parameters, it was further hypothesized that an 8-week skiing intervention has positive effects on the strength level and reduces gait asymmetries after skiing and might also improve the remaining physical and psychological properties 6-24 months after surgery.

It was the aim of the present study to especially explore the effects and benefits of the two training programs and compare them regarding muscle strength, gait parameters, balance, cardiorespiratory fitness, pain, and psychological well-being. The study was conducted for the purpose of broadening scientific knowledge and specifying recommendations for returning to sports and especially returning to high impact sports, like alpine skiing, after TKA. The next section outlines the methodology used in the study and is followed by the results and discussion chapter.

4. Subjects and methods

4.1. Study design

The study was designed as a prospective cohort study. Data were collected from September 2020 until May 2021 at the Institute of Motion Analysis and Sports Medicine, Endogap Clinic for Joint Replacement, Garmisch-Partenkirchen, Germany. On the first appointment, the examiner obtained the medical history of the patient before starting with the different testing procedures. All measurements were conducted by one of the two main investigators. Functional testing included anthropometrics, gait analysis, assessment of coordination, strength measurement of the lower limbs, and a cardiorespiratory fitness test. The tests will be described in detail in the following sections. All patients were invited to a second functional testing appointment after eight weeks. Testing procedures on the follow-up appointment were identical.

4.2. Study population

All patients were recruited from the Endogap Clinic for Joint Replacement, Garmisch-Partenkirchen, Germany. Only patients with primary unilateral bicondylar TKA were included in the study. Patients were either treated with the Low Contact Stress (LCS) by Depuy Synthes, the ATTUNE^{TM} likewise by Depuy Synthes, or the Persona Knee by Zimmer Biomet.

Inclusion criteria were: (a) age > 55years, (b) 6 to 24 months post-surgery, (c) Oxford Knee Score (OKS) > 25. A total of 314 eligible patients were filtered from the patients' database. After critical review 150 people were excluded due to the following exclusion criteria: (a) other joint arthroplasties, (b) BMI greater than 38 kg/m^2, (c) any cardiovascular, psychiatric, or musculoskeletal diseases that would hinder the conduction of the tests. After critical review for inclusion and exclusion criteria 164 patients were considered eligible for a telephone interview. Patients were called by the main investigator and asked if they would agree to participate in the study. 76 patients, who met the eligibility criteria, agreed to participate in the study. The patients were randomized with Microsoft Excel (Version 16.38) for the home training intervention, skiing intervention or for the CG and were given an appointment for the first functional testing. Due to the ongoing COVID-19 pandemic and the fear of a possible infection 16 patients dropped out (n=11 home training intervention, n=5 CG) prior to the first testing day. Four patients of the home training intervention group cancelled due to a lack of time and two patients dropped out due to personal reasons. Eventually, 15 subjects from the home training IG were tested and took part in the training program. 13 subjects were reexamined on the follow-up appointment and were included in the analyses. Two patients did not show up for the reexamination due to a lack of time. 20 subjects from the CG underwent the first functional testing. However, the coincidence of the beginning of the second lockdown in Germany and follow-up tests lead to a drop out of six patients in the CG. They again feared an infection with the virus in the hospital setting. One patient cancelled the second diagnostic for personal, not health related, reasons. Eventually, 13 subjects could be included in the CG analyses (see Figure 13).

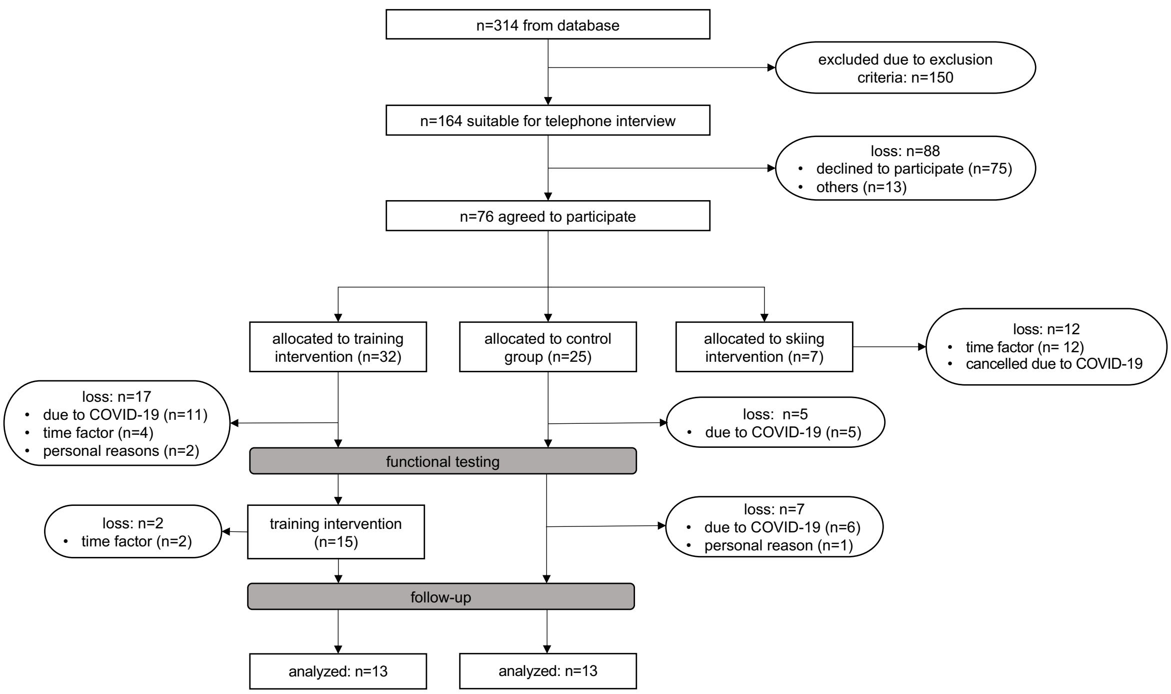

Figure 13. Participant flow diagram.

4.3. Research methods

On both investigation days, participants completed the following tests and measurements in the same order. First, an anamnesis was taken before starting with the coordination test, followed by the gait analysis. Afterwards participants' anthropometrics were measured. Second to last, lower limb strength level was assessed. Lastly, subjects performed a cycle ergometer test. In the following, all research methods are described in more detail.

4.3.1. Body composition

Body weight and skeletal muscle mass were measured by multifrequency bioelectrical impedance analysis (BIA) using the seca mBCA 515/514 (mBCA; seca Deutschland, Hamburg, Germany). This is a validated method for estimating body composition (139, 140) and has been used in patients with TKA (141). Body height was measured to the nearest 1mm using a measuring tape by XSens (MVN, Segmometer). BMI was calculated by dividing the weight in kilograms by the square of body height in meters. Waist circumference was measured at the midpoint between the lowest palpable rib and the top of the iliac crest (142).

4.3.2. Y-Balance Test

The Y-Balance Test (YBT) (Move2Perform, Evansville, IN, USA) is a coordination test to measure dynamic balance, which is important for daily movements such as walking or stair climbing. The YBT has been evaluated as a reliable and valid tool to measure balance in healthy adults, after knee surgery, or for injury prediction (143-146). It has also been shown to be valid for older individuals to assess the risk of falling (147, 148).

At first leg length was measured bilaterally in a supine position from the anterior superior iliac spine to the inferior distal surface of the medial malleolus as described in the test manual (149). The YBT was completed using a plastic Y-Balance Test kit (move2perform). All participants received a visual and verbal demonstration before starting the test. To eliminate stabilization from wearing shoes participants performed the test barefoot. The participants stood on the central plastic plate on one foot and reached with the free limb in all three directions (see Figure 14). Each subject performed one practice trial per leg prior to the final testing. Afterwards, they performed three test trials in each direction for both legs. Specifically, testing order was posteromedial, anterior, posterolateral. Three test trials were performed with one leg before changing sides. The reach distance was recorded to 0.5 cm at the edge of the reach indicator. A trial was invalid and repeated when the subject did not return the reach foot to the starting position under control, failed to maintain unilateral stance on the central platform, kicked the plate with the reaching foot, or lifted the heel on the central plate to gain more distance. A maximum of six attempts was allowed to obtain three successful trials for each direction.

Reach distance was normalized to limb lengths to allow better comparison between individuals and to previous publications. For data analysis the composite reach score was used (CS). The CS was calculated as the sum of the three greatest reach directions divided by three times limb length, multiplied by 100% (145). Limb symmetry index (LSI) was determined by dividing the operated leg data by the unoperated leg data. The results were multiplied by 100 (143).

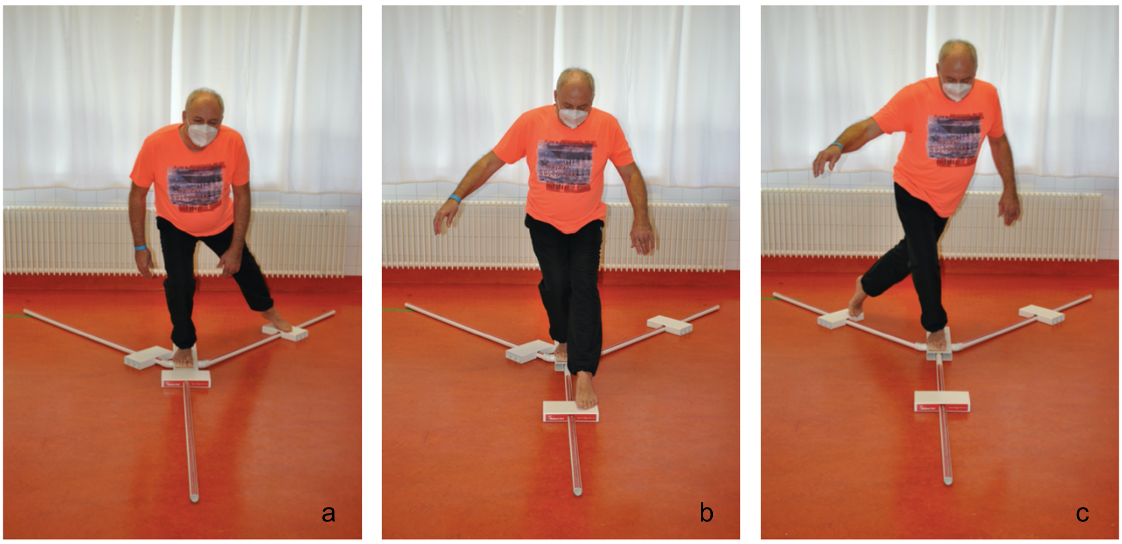

Figure 14. Y-balance test: posteromedial (a), anterior (b), posterolateral (c) reach direction.

4.3.3. Gait analysis

Gait variables were measured using the Xsens wireless inertial sensing device (MVN Awinda, XSens, Enschede, Netherlands). The inertial motion units combine a gyroscope, magnetometer, and accelerometer to assess the orientation and position of body segments. Figure 15 shows an inertial motion unit by Xsens. Studies have shown that inertial motion capture is suitable for clinical gait assessment as it has good between-rater, as well as within-rater reliability (150, 151). Further, it is a fast and easy method to determine important gait parameters, and can easily be integrated in ambulatory settings (152, 153).

Figure 15. Motion Tracker (MTw) by Xsens. (154)

Seven inertial measurement units (IMUs) (MTw Awinda, XSens, Enschede, Netherlands) were positioned on the subjects' lower body according to the Xsens protocol, namely two on the shoes, two on the lower legs, two on the upper legs and one at the pelvis (155). For exact placement position see Figure 16. Body height with shoes and shoe length were measured to 0.5 cm with a measuring tape (MVN, Segmometer). Following sensor placement, the calibration of each subject was conducted. All recordings were performed with the single-level scenario recommended by Xsens for measurements on a flat surface (155). For calibration the measured anthropometrics were entered in the MVN software. The calibration process was performed according to the manufacturer. Patients started in a neutral (N-pose) followed by a walk in the laboratory at a self-selected pace a few meters forth and back to N-pose. For the recording patients were told to walk on a predetermined flat area in the laboratory at a self-selected pace.

Location	Abbreviation	Optimal position
Foot	FOOT	Middle of bridge of foot
Lower leg	LLEG	Flat on the shin bone (medial surface of the tibia)
Upper leg	ULEG	Lateral side above knee
Pelvis	PELV	Flat on sacrum

Figure 16. Placement position of IMUs. Modified from XSens (155)

For analysis the "HD slow" reprocessing filter provided in the MVN analyze software (Version 2019.2.1) was applied to all recordings as it offers the best possible quality. Sample frequency was 100 Hz. Data was then imported to the Xsens gait report software 2.0.3. On average 8.00 steps were included in the gait report.

Various kinematic parameters are evaluated in the Xsens gait report. For the gait analysis in this study, general parameters (speed, cadence), spatial parameters (step length, step width), temporal parameters (stance, swing, and double support phase) and joint angles for the knee flexion during loading phase, foot strike and maximum knee flexion were used. Moreover, knee flexion excursion in the loading response phase was included in the analyses. For the knee flexion excursion, the maximum knee flexion during the loading phase for the third, fourth, and fifth step was evaluated bilateral in the MVN analyze software for each patient and the average of those was calculated. From the average of the peak flexion angle in the loading response phase, the knee flexion at foot strike values, given in the gait report provided by Xsens, were deducted. Figure 17 depicts the knee angle curves right and left of one patient in the Xsens analyze software.

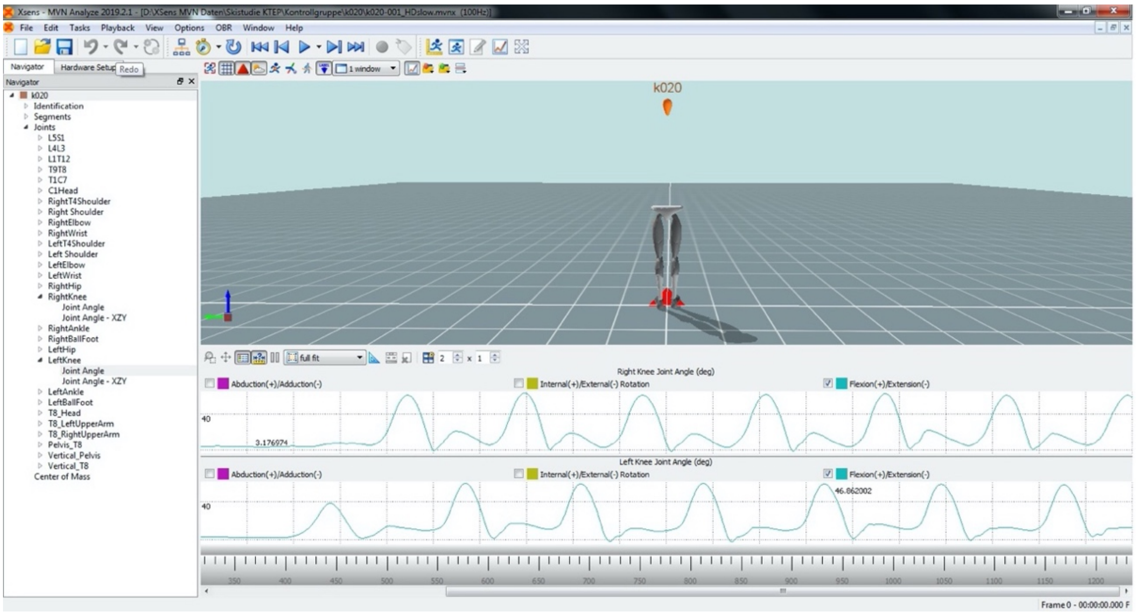

Figure 17. Knee angle curves MVN analyze software.

4.3.4. Lower limb strength measurement

Lower limb strength was measured using the isokinetic dynamometer IsoMed2000 (D. & R. Ferstl GmbH, Hemau, Germany). Isokinetic strength measurements can be used for diagnostic and therapeutic matters (16, 17). Literature shows that they are applicable to older individuals with osteoarthritis as well (156). The IsoMed2000 is a motor driven dynamometer used for testing and training of various joint movements and muscle groups. Leg press was selected as the test movement as this multi-joint exercise corresponds to the movement requirements during skiing. The test protocol based partly on the maximum concentric isokinetic strength test performed by Poetzelsberger et al., who examined the strength status of patients with knee prosthesis after a skiing intervention (134).

The subjects were positioned on the dynamometer with the backrest inclined 30° from an upright position. The torso was fixed with a seat belt and shoulder fastening pads. Hands were placed on the handlebars for further stabilization during testing (see Figure 18.). The range of motion was specified to a knee angle between 90° and 130° and adjusted individually for every patient using a goniometer. The speed of the footplate was set to 20mm/s. First, the acceleration of the foot plate was set to intermediate. However, first tests showed that the cohort's neuronal control of the leg muscles was too slow. It was therefore decided to change the acceleration to very slow and to keep the soft deceleration.

Figure 18. Experimental setup. Patients position on the IsoMed2000.

The strength test protocol consisted of three testing conditions. Muscle strength was measured with both legs, and with each limb separately. The order of testing (operated versus non-operated leg) was randomized. Subjects started with the same leg on both testing days.

Prior to every testing condition the patients completed 15 submaximal isokinetic contractions for familiarization and warm-up. The testing conditions consisted of five repetitions of which the first two were at submaximal and the following three of maximum effort. Between testing conditions patients had a one-minute rest break. Patients were instructed to push as fast and powerful in both movement directions (flexion and extension) and throughout the whole movement range. Strong verbal encouragement was given by the investigator for each testing condition. The maximum concentric and eccentric strength determined as the best trial of the three maximal efforts was used for analysis. Strength is reported as torque in Newton meters (Nm). Values for operated and non-operated limb were compared.

4.3.5. VO_2 peak test

The cardiopulmonary exercise test was performed on a stationary cycle ergometer (ergo premium 8i, daum electronic GmbH, Fürth, Germany). The metabolic response was measured with the JAEGER oxycon mobile device (Erich Jaeger, Viasys Healthcare, Germany), which was proven to be reliable and valid to measure oxygen uptake (157). Before each test gas and flow were calibrated. During the bicycle test heart rate (HR) was recorded with a wrist computer (Suunto Spartan Ultra, Suunto, Vantaa, Finland) and the compatible HR belt (Suunto Smart Sensor, Suunto, Vantaa, Finland). Patients started with a 2-min warm-up at 20 Watt followed by a continuous ramp protocol, where workload was increased by 25 Watt every two minutes. The tests were supervised by a sports medicine physician and sports scientist. Patients were instructed to maintain a pedalling rate of 60 to 70 revolutions per minute (RPM). The test was ended when patients reached their personal exhaustion or could not maintain a cadence above 60rpm.

Peak HR (beats/min), maximum work in watts (Wmax), maximum work normalized to body weight (Wmax/kg), absolute and normalized peak oxygen uptake (VO_2peak and VO_2peak/kg) were determined. Perceived exertion was assessed with the Borg Rating of Perceived Exertion Scale (BORG) (6 = no exertion, 20 = maximum exertion) (158).

4.3.6. Questionnaires

Pain and functionality assessment

General knee pain was measured using a visual analogue scale (VAS), (0 = no pain, 10 = violent pain) for pain at rest and pain during or after physical activity on both testing days (159). Further, pain level for both knees was reported by the patients after the strength measurement and VO_2 peak test.

For patient reported outcome measures (PROMS) the OKS and Lower Extremity Functional Scale (LEFS) were used. The OKS is a questionnaire to assess the pain and functional disability of the limb undergoing joint replacement (160). It comprises, for instance, difficulties in standing up from a chair, climbing stairs or personal hygiene. The score ranges from 0 (most severe symptoms) to 48 (least symptoms). Literature underlines its specificity in regard to knee joint arthroplasty (161-163). It has been validated in a German cohort (162).

Additionally, the LEFS was used to estimate the ability to perform everyday tasks. It is a well-known questionnaire developed by Binkley at al. in 1999 to measure the lower extremity function (164). Higher LEFS scores indicate better lower extremity function status. The LEFS has been validated in a spectrum of lower extremity problems for instance sport injuries, knee arthroplasty or stroke related difficulties (165-167). In this study it was applied to identify any improvements through a training intervention after knee joint arthroplasty.

Psychological assessment

To assess psychological well-being after knee replacement and the impact of a training intervention patients completed the WHOQOL-BREF and the Oxford Happiness Questionnaire (OHQ). Both questionnaires are described in the following section and can be found in the annex.

QOL was assessed with the WHOQOL-BREF (168). It is a broad indicator for QOL including general health, physical, psychological, as well as environmental and social aspects. It does not only include items that are directly relevant in regard to joint replacement, such as pain or physical function, but it also covers aspects like home environment, transportation, and further dependencies of one’s individual life. It has been demonstrated that the WHOQOL-BREF is an appropriate tool to measure the impact of joint surgery on the psychological well-being (104, 110). The questionnaire includes 26 items providing four domain scores. Question one queries the overall perception of one’s QOL and question two the overall perception of one’s health. The domain scores were determined by calculating the mean score of all items in one domain multiplied by four. The scores were then computed to a 0 - 100 scale. The higher the score the better the QOL (169).

Additionally, the OHQ was used to assess the overall happiness of the participants. The questionnaire was developed by Hills and Argyle in 2002 from the lengthy Oxford Happiness Inventory (170). It consists of 29 items, which all can be answered on a uniform six-point Likert scale (1= totally disagree, 6= totally agree). Items marked with R in the questionnaire were scored in reverse (1 changed to 6, 2 changed to 5, etc.). All numbers from the 29 questions were added up and divided by 29.

4.4. Home training intervention

The IG completed an 8-week standardized physical exercise program, specifically designed for patients with TKA and adapted to be easily implemented at home. On the first testing day the investigator held an educational session with the patients to instruct the training procedures and clarify questions. Additionally, they were supplied with a booklet with detailed descriptions and picture sequences of the exercises. Further, participants were able to train with uploaded YouTube videos for each training block. At the beginning of each training block a "Live-online" training session (TS) was held for all participants via ZOOM (Zoom, Version: 5.4.6), where the main investigator was able to give real time feedback and monitor the proper execution of the exercises.

The participants performed three TSs per week over a period of eight weeks. The difficulty of each exercise was increased after week three and week six (see Figure 19). Participants received an elastic training band for week seven to eight to increase exercise intensity with extra resistance. The program consisted of a five to ten minute warm-up mobilization part. It was followed by the strengthening part, focusing on the knee stabilizing muscles (quadriceps femoris, hamstrings, hip flexor and extensor, and triceps surae) but also including core strengthening exercises to improve posture. Thirdly, balance exercises were included to improve single leg stance. Proprioceptive work with foam mats or towels were included. Exercises partly derived from a recommended program by the Endogap Clinic, but were adapted and complemented to be especially suitable for TKA patients (171). Additional complexity with the use of an elastic resistance band was added in week seven. The whole program is annexed.

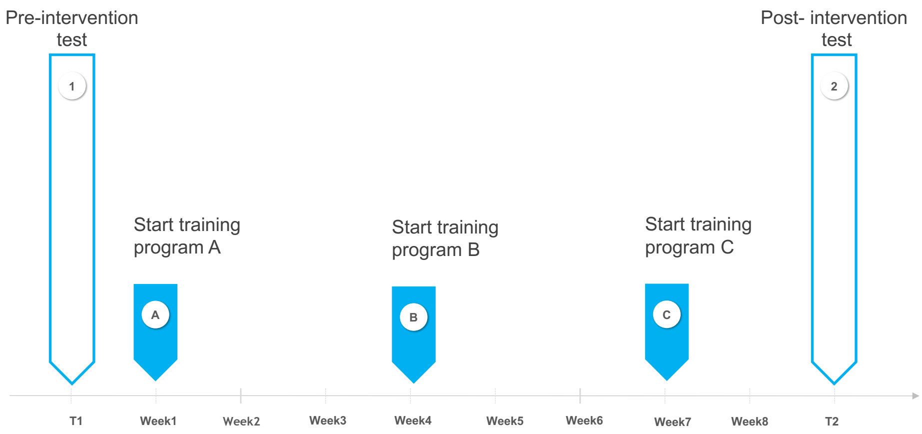

Figure 19. Timeline home training intervention.

Participants were contacted regularly by phone or e-mail to monitor compliance to the program and discuss possible variations, if patients had difficulties with a specific exercise. Further, a logbook was used to monitor physical activity. Training intensity was assessed with the BORG scale according to participants' perception of exertion (158).

4.5. Skiing intervention

The skiing intervention was planned to take place in the winter season 2020/2021, starting 11th of January 2021. Due to the COVID-19 pandemic, ski lifts could not be opened and sport activities in groups were not allowed by the government. It was therefore decided to cancel the skiing intervention and only focus on the effects of the home training intervention.

4.6. Control condition

Patients from the CG subjected themselves to the same testing procedures at the institute. Between test days patients from the CG underwent their usual rehabilitation program without additional exercises. Their activity was monitored by a personal training diary.

4.7. Ethics

The study protocol was approved by the ethics committee of the Bavarian State Medical Association with the identification number 19099 and was conducted in accordance with the principles of the Declaration of Helsinki. Each patient received detailed information about the study. Written informed consent to ethics committee guidelines was obtained from all participants.

4.8. Statistical analysis

Prior and after the study statistical method consulting was obtained at the University of Regensburg. An a priori sample size calculation using G*Power version 3.1.9.6 was conducted. The partial eta effect size was $\eta p^2 = 0.16$, considered to be large according to Cohen's criteria (172). With a significance level of $\alpha = .05$ and power T = .80, a minimum sample size of n = 40 participants for an ANOVA with repeated measures between factors was calculated. Normal distribution was tested using visual inspection and the Shapiro Wilk test. As simulation studies have shown, the ANOVA with repeated measures is relatively robust against violation of normal distribution, especially if no other assumptions are violated (173, 174). All data are therefore reported as mean and standard deviation unless otherwise noted. A two-way mixed ANOVA was used to test group (CG/IG) and time (pre/post) effects for all dependent variables. Homogeneity of error variances was calculated with the Levene's test. The homogeneity of covariances was assessed by the Box's test. The effect size partial eta-squared (ηp^2) was considered small ($\eta p^2 > 0.01$), medium ($\eta p^2 > 0.06$), and large ($\eta p^2 > 0.14$) (172). For all analyses, a p-value $p < .05$ was considered to be statistically significant. To avoid αn error after multiple testing correction models can be calculated. However, for this study it was decided to continue with a p-value of $p < .05$ (175). All statistical calculations were performed using SPSS version 29.0 software (IBM Corp, Armonk, NY, USA). A post hoc power analysis for a mixed ANOVA calculation using G*Power version 3.1.9.6 revealed that based on an $\alpha = .05$, the effect size observed in the present study for group x time interaction ($\eta p^2 = 0.16$), and the sample size (n = 26) the obtained statistical power was T = .69.

5. Results

In this section answers will be given to the question whether an 8-week home training program has positive effects on the rehabilitation process of patients with bicondylar knee prosthesis. Firstly, descriptive analyses will be presented followed by the effects on body composition, strength level, balance, cardiorespiratory fitness, gait parameters and QOL.

5.1. Descriptive data

A study flow diagram of patients enrolled in the study has been presented in chapter 4.2. In total, 13 patients were included in the CG and 13 patients in the IG. In Table 2 patients' baseline demographics and clinical characteristics are presented. The average age of participants in the CG was 62.92 ± 5.63 years and in the IG 62.31 ± 4.25 years. There were fewer women (CG: 38.5%, IG: 46.2%) than men (CG: 61.5%, IG: 53.8%) in both test groups. On average patients in the CG were included in the study 10.62 ± 5.01 months after surgery and patients in the IG after 15.00 ± 4.45 months. In both groups 46.2% were operated on the left knee, 53.8% on the right knee. On average patients reported no to mild pain during rest and mild pain during moving.

As shown in Figure 20 and Figure 21 the LCS knee implant was primarily used for total knee replacement, followed by the Persona implant. In the CG no patient received an Attune implant. Most patients were operated in the hybrid technique cementing only one component. Only two implants in the CG were fully cemented. Four patients in the CG and two patients in the IG received a cementless prosthesis.

Table 2. Baseline characteristics.

	Control group N=13		Intervention group N=13	
Variable	Mean	SD	Mean	SD
Age (years)	62.92	5.63	62.31	4.25
Sex*				
Female	8	61.50%	7	53.80%
Male	5	38.50%	6	46.20%
Weight (kg)	82.24	17.67	84.19	14.91
Height (m)	1.69	0.08	1.69	0.07
BMI (kg/m^2)	28.55	4.71	29.3	4.49
Operation side*				
Left	6	46.20%	6	46.20%
Right	7	53.80%	7	53.80%
Time post-surgery (months)	10.62	5.01	15	4.45
Time T1 to T2 (weeks)	8.85	0.8	8.76	0.61
VAS resting	1.31	1.11	0.69	1.7
VAS moving	2.23	1.3	2.46	1.71

Note. SD= standard deviation, VAS= visual analogue scale, BMI= body mass index, T1= pre-intervention, T2= post-intervention, values represent mean +/- SD or *number of cases (absolute and percentage).

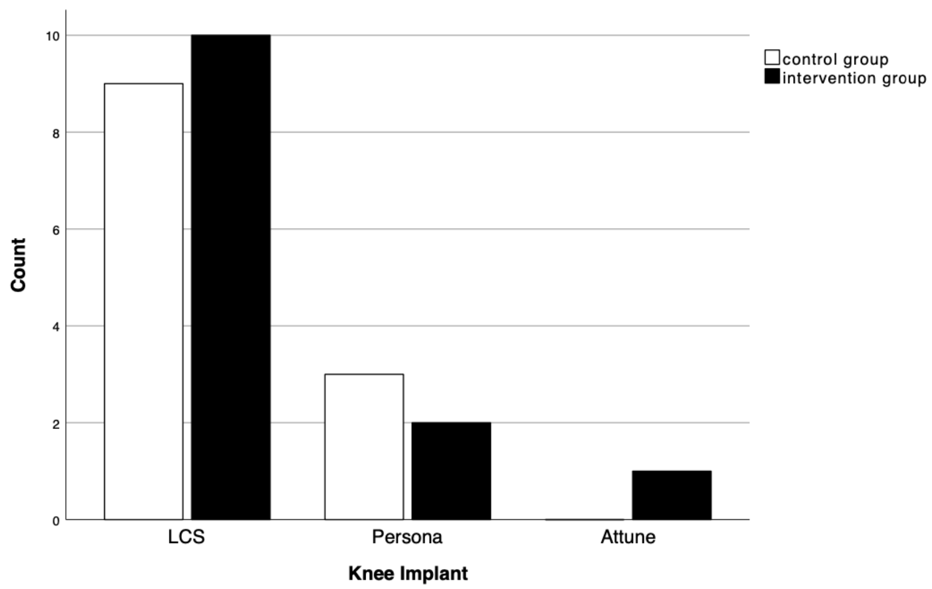

Figure 20. Knee implant type.

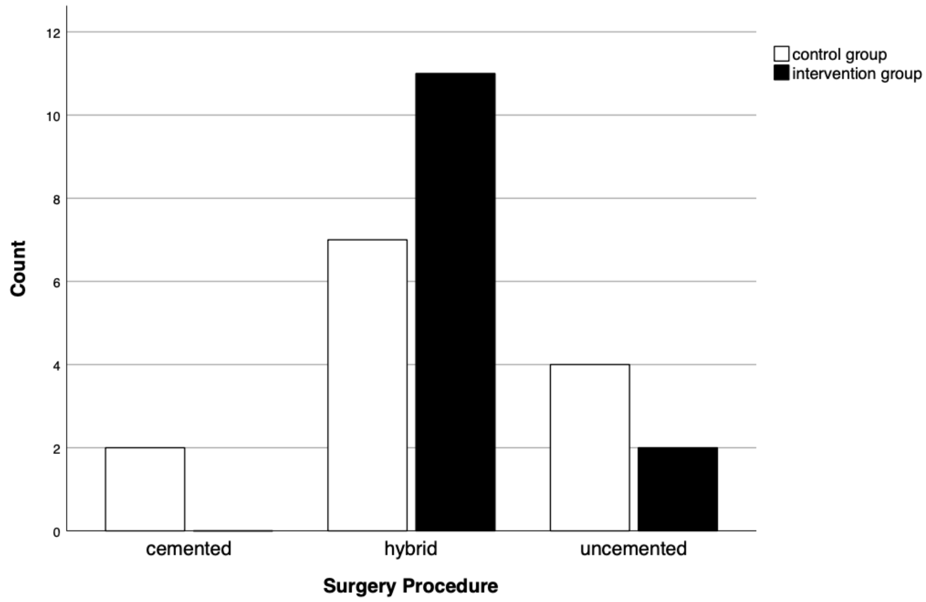

Figure 21. Surgery procedure.

Table 3 and Table 4 depict values of the training diary. One patient in the CG did not fill out the training diary and not all patients reported BORG after TSs and physical activity level (PAL). The average number of specific TSs completed in the IG was 22.77 ± 10.88. The average BORG scale after the specific TSs was between “somewhat exhausting” and “exhausting” (14.03 ± 1.63) (158). On average study subjects reported mild pain after the home training intervention (2.66 ± 2.04). The total number of TSs was similar in the CG and IG, but showed a vast SD. In total the training time in minutes per week was 399.44 min/week in the CG and 110.77 min/week in the IG. Overall, both groups revealed a similar subjective physical activity level (CG: PAL= 1.72 ± 0.20, IG: PAL=1.68 ± 0.14). Further analysis shows, that both groups were active in a variety of sporting activities. Table 4 depicts the sum of TSs in each sport activity patients reported in their diary. Closer inspection of the table shows that the CG completed more TS in endurance activities (see sum walking, biking, swimming) although the proportional distribution for walking and biking was almost identical (biking: CG: 27%, IG: 34%; walking: CG: 31%, IG: 31%). Moreover, the CG had 49 additional rehab session, whereas the IG underwent no extra session at a rehabilitation unit.

Table 3. Training diary.

Variables	Control group N	Control group Mean	Control group SD	Intervention group N	Intervention group Mean	Intervention group SD
TS IG	0			13	22.77	10.88
BORG TS IG	0			13	14.03	1.63
VAS TS IG	0			12	2.66	2.04
Additional TS	0			13	16.38	14.14
TS total	12	38.83	12.47	13	39.15	23.13
BORG TS	12	15.97	12.45	9	12.65	4.90
Total training time (min)	12	2796.11	2019.87	13	775.38	483.72
Total training time (min/week)	12	399.44	288.55	13	110.77	69.10
PAL	11	1.72	0.20	10	1.68	0.14

Note. SD= standard deviation, TS= training sessions, IG= intervention group, VAS= visual analogue scale, PAL= physical activity level.

Table 4. Sport activities.

Type of sport activity	Control group (N=12) Sum TS	Control group (N=12) Percentage	Intervention group (N=13) Sum TS	Intervention group (N=13) Percentage
Hiking	34	7%	9	4%
Biking	124	27%	72	34%
Swimming	25	5%	0	0%
Nordic walking	20	4%	21	10%
Rehabilitation unit	46	10%	0	0%
Walking	145	31%	65	31%
Aqua jogging	11	2%	0	0%
Physiotherapy	13	3%	21	10%
Golf	13	3%	0	0%
Fitness	27	6%	23	11%
Cross-trainer	8	2%	0	0%
Cross-country	0	0%	1	0%

Note. TS= training session.

5.2. Body composition

Firstly, anthropometric data and the effects after training on the body composition will be presented. Table 5 depicts anthropometric variables as mean ± standard deviation before (T1) and after (T2) the intervention for both groups.

There was homogeneity of error variances for all anthropometric variables, as assessed by Levene's test ($p > .05$). Anthropometric data showed homogeneity of covariances, as assessed by Box's test ($p > .05$), except for the muscle mass variable ($p = .003$) and the difference in muscle mass between operated and non-operated limb ($p < .001$). Table 6 shows the results for the mixed ANOVAs. No statistically significant interaction between time and group for anthropometrics data was found. There was no significant main effect for group for any anthropometric variable. A significant main effect for time was found for weight ($F (1,24) = 4.81$, $p = .038$, $\eta p^2 = 0.17$) and BMI ($F (1,24) = 5.88$, $p = .023$, $\eta p^2 = 0.20$), suggesting a reduction in body weight over time independently from the home training intervention. The effect size, calculated as ηp^2, was 0.17 and 0.20 respectively, indicating a large effect.

Table 5. Mean and SD of anthropometric data.

	Control Group (N=13)				Intervention Group (N=13)			
	T1		T2		T1		T2	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Weight (kg)	82.24	17.67	81.70	17.60	84.19	14.91	83.38	14.92
BMI (kg/m^2)	28.55	4.71	28.37	4.74	29.30	4.49	29.00	4.31
Waist Circumference (cm)	97.77	17.41	99.85	17.24	97.23	11.86	97.23	11.63
Fatmass (kg%)	30.94	9.90	30.56	10.43	29.89	8.87	29.32	8.78
Muscle mass (kg)	24.07	6.65	23.89	6.50	25.67	6.85	25.00	5.84
Muscle mass OP leg (kg)	5.33	1.52	5.34	1.51	5.48	1.30	5.37	1.29
Muscle mass NOP leg (kg)	5.12	1.30	5.09	1.29	5.51	1.38	5.45	1.38
Δ Muscle mass OP vs. NOP	0.21	0.51	0.25	0.58	-0.02	0.39	-0.08	0.63

Note. BMI= Body mass index, OP= operated, NOP= non-operated, SD= standard deviation, T1= pre-intervention, T2= post-intervention.

Table 6. Mixed ANOVAs for anthropometric data.

Variable		F	p	ηp2
Weight	Group	0.08	0.779	0.00
	Time	4.81	**0.038**	0.17
	Time*group	0.18	0.676	0.01
BMI	Group	0.15	0.702	0.01
	Time	5.88	**0.023**	0.20
	Time*group	0.41	0.528	0.02
Fat mass	Group	0.10	0.760	0.00
	Time	1.27	0.271	0.05
	Time*group	0.05	0.825	0.00
Waist circumference	Group	0.08	0.787	0.00
	Time	2.50	0.127	0.09
	Time*group	2.50	0.127	0.09
Muscle mass	Group	0.29	0.593	0.01
	Time	1.00	0.326	0.40
	Time*group	0.33	0.572	0.01
Muscle mass OP leg	Group	0.03	0.867	0.00
	Time	1.80	0.193	0.07
	Time*group	2.74	0.111	0.10
Muscle mass NOP leg	Group	0.51	0.480	0.02
	Time	2.39	0.135	0.09
	Time*group	0.14	0.717	0.01
Δ Muscle mass OP leg	Group	1.90	0.181	0.07
	Time	0.01	0.929	0.00
	Time*group	1.38	0.251	0.06

Note. ηp2= partial eta squared, OP= operated, NOP= non-operated, bold= statistically significant differences, dF= 1.

5.3. Strength

Next, the results of the isokinetic strength test will be presented. Table 8 gives an overview over both directions of movement for the trial with both legs, with the operated and with the non-operated leg respectively. Both groups subjectively exerted both legs to a similar level on both testing days (see Table 9). The perceived exertion was always comparable in the operated and non-operated limb.

There was homogeneity of the error variances for all strength parameters except extension of the operated limb ($p = .017$), as assessed by Levene's test ($p > .05$). There was homogeneity of covariances for all strength parameters, as assessed by Box's test ($p > .05$). The test showed no statistically significant interaction between effects of training and study group on any strength parameter. The analysis revealed no main effect for time nor group (see Table 7).

Table 7. Mixed ANOVAs for leg strength parameters.

Variable		F	p	ηp2
Flexion both	Group	0.03	0.861	0.00
	Time	1.53	0.228	0.06
	Time*group	0.18	0.667	0.01
Extension both	Group	0.06	0.815	0.00
	Time	1.50	0.233	0.06
	Time*group	0.01	0.936	0.00
Flexion OP	Group	0.19	0.668	0.01
	Time	1.77	0.197	0.07
	Time*group	3.25	0.085	0.12
Flexion NOP	Group	1.21	0.284	0.05
	Time	0.62	0.438	0.03
	Time*group	3.29	0.083	0.13
Extension OP	Group	0.05	0.829	0.00
	Time	3.59	0.071	0.14
	Time*group	1.58	0.221	0.06
Extension NOP	Group	0.06	0.814	0.00
	Time	0.49	0.489	0.02
	Time*group	1.25	0.274	0.05

Note. ηp2= partial eta squared, OP= operated, NOP= non-operated, bold= statistically significant differences, dF= 1.

Table 8. Mean and SD of strength values.

	Control Group						Intervention Group					
	T1			T2			T1			T2		
Variable	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Flexion both (Nm)	13	2555.92	880.61	12	2770.25	1026.90	13	2665.92	836.16	13	2775.69	963.51
Extension both (Nm)	13	2065.46	565.14	12	2168.58	739.95	13	2010.69	472.89	13	2116.62	758.69
Flexion OP (Nm)	13	1384.92	434.45	12	1569.00	484.37	13	1558.15	435.52	13	1528.69	405.26
Flexion NOP (Nm)	13	1460.92	516.01	12	1557.17	542.26	13	1838.23	605.20	13	1706.46	582.03
Extension OP (Nm)	13	1124.62	345.76	12	1147.92	370.31	13	1040.62	232.00	13	1174.85	316.17
Extension NOP (Nm)	13	1200.54	418.21	12	1181.67	369.91	13	1243.08	380.20	13	1257.31	448.70

Note. SD= standard deviation, Nm= Newton meter, OP= operated leg, NOP= non-operated leg, T1= pre- intervention, T2= post- intervention.

Table 9. Mean and SD of perceived rate of exertion.

	Control Group						Intervention Group					
	T1			T2			T1			T2		
Variable	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
BORG OP	13	16.00	1.29	11	15.55	1.29	13	15.00	2.31	12	15.42	1.62
BORG NOP	13	16.23	1.09	11	15.36	1.36	13	15.00	2.31	12	15.83	1.90

Note. OP= operated, NOP= non-operated, SD= standard deviation, T1= pre- intervention, T2= post-intervention.

5.4. Dynamic balance

Results for the Y-balance test are presented in the following. In Table 10 it can be seen that the CS for the operated and non-operated leg increased in both testing groups. The IG had the lowest leg symmetry index prior the start of the home training program, but symmetry approached levels of the CG after the intervention.

Table 10. Mean and SD of Y-Balance test results.

	Control Group (N=13)				Intervention Group (N=13)			
	T1		T2		T1		T2	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Leg length OP	89.46	6.06			89.00	6.09		
Leg length NOP	89.50	5.74			88.92	5.89		
CS OP	68.40	15.61	75.01	11.48	78.59	13.94	86.75	10.41
CS NOP	68.56	15.56	72.03	14.49	83.27	7.73	88.15	8.80
Δ CS	-0.16	7.42	2.98	6.62	-4.68	10.59	-1.39	4.85
LSI (%)	100.38	11.44	105.49	16.62	93.86	13.75	99.41	6.85

Note. CS= Composite score, LSI= Limb Symmetry Index, OP= operated, NOP= non-operated, SD= standard deviation, T1= pre-intervention, T2= post-intervention.

There was homogeneity of error variances for all balance parameters, as assessed by Levene's test ($p > .05$). Balance data showed homogeneity of covariances, as assessed by Box's test ($p > .05$). Table 11 shows the results for the mixed ANOVAs. No statistically significant interaction between time and group for balance data was found. There was a significant main effect for group for the CS of the operated leg ($F(1,24) = 5.20$, $p = .032$, $\eta p^2 = 0.18$) and of the non-operated leg ($F(1,24) = 11.80$, $p = .002$, $\eta p^2 = 0.33$), indicating that the training group showed higher values independently of the time of measurement. A significant main effect for time was also found for the CS of the operated ($F(1,24) = 18.50$, $p < .001$, $\eta p^2 = 0.44$) and CS of the non-operated limb ($F(1,24) = 6.86$, $p = .015$, $\eta p^2 = 0.22$). All significant results revealed a large effect size. This implies that the CSs for both legs increased independently of the home training intervention. (See Figure 22 and Figure 23)

Table 11. Mixed ANOVAs Y-Balance parameters.

Variable		F	p	ηp2
CS OP	Group	5.20	**0.032**	0.18
	Time	18.50	**<.001**	0.44
	Time*group	0.21	0.655	0.01
CS NOP	Group	11.80	**0.002**	0.33
	Time	6.86	**0.015**	0.22
	Time*group	0.20	0.661	0.01
Δ CS	Group	3.14	0.089	0.12
	Time	3.80	0.063	0.14
	Time*group	0.00	0.966	0.00
LSI%	Group	2.62	0.118	0.10
	Time	2.95	0.099	0.11
	Time*group	0.01	0.945	0.00

Note. ηp2= partial eta squared, CS= Composite Score, LSI= Limb Symmetry Index, OP= operated, NOP= non-operated, bold= statistically significant differences, dF= 1.

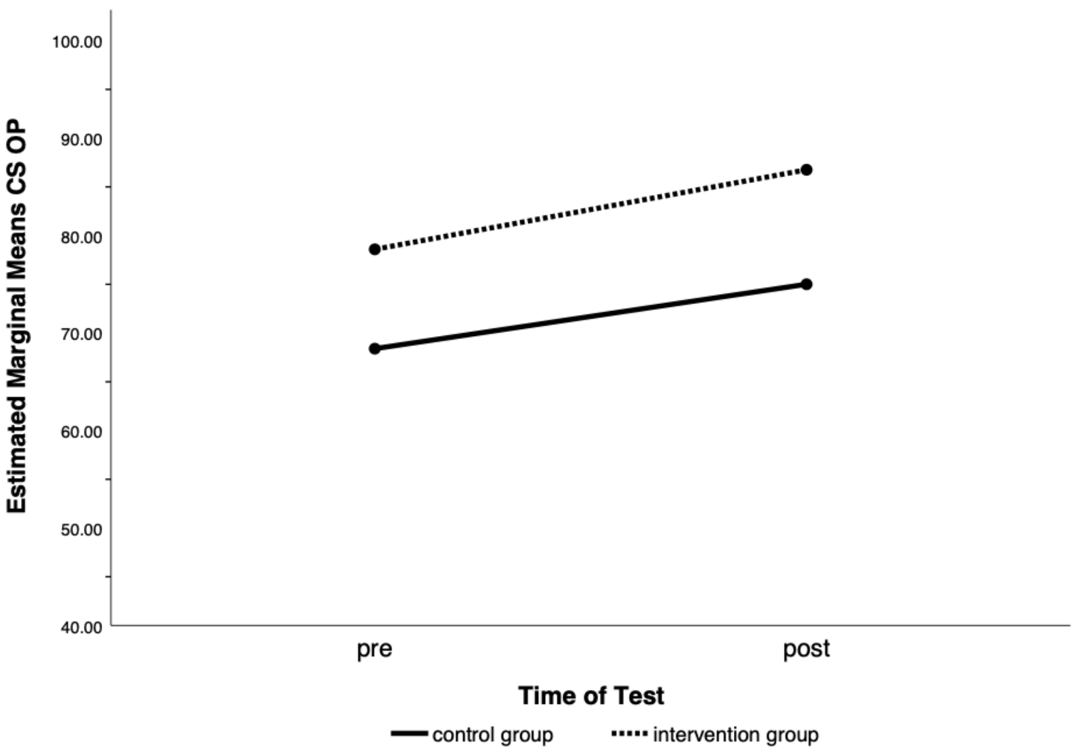

Figure 22. Main effects for CS OP.

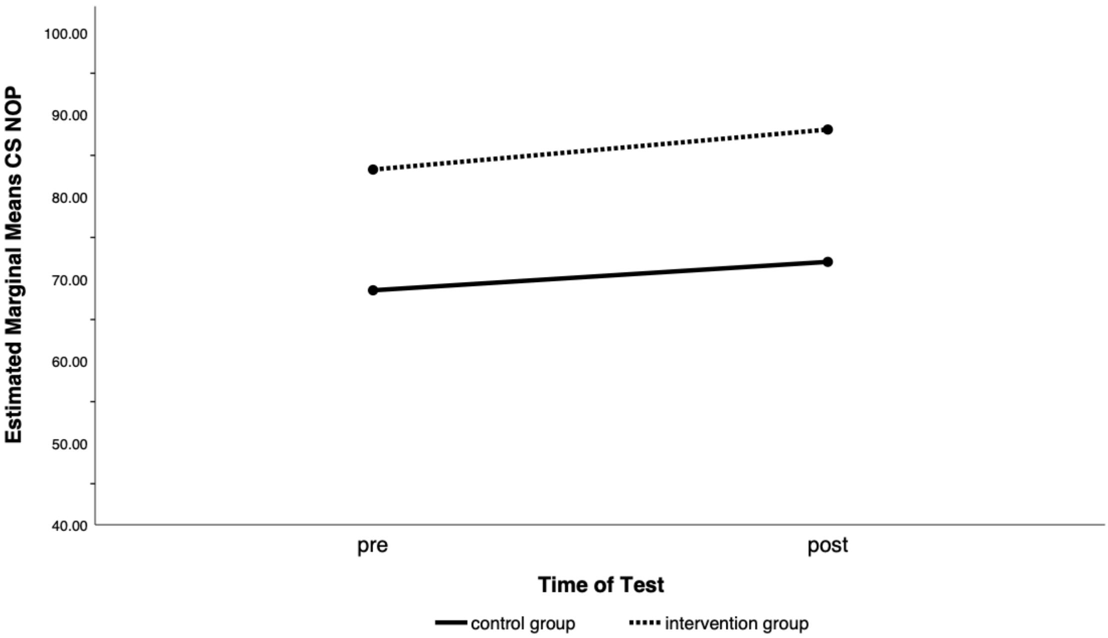

Figure 23. Main effects for CS NOP.

5.5. Cardiorespiratory fitness

For the analysis of the data from the cardiorespiratory fitness test only subjects who completed the bicycle test on both testing days were included. Four patients had to be excluded due to missing values. In total 11 patients were analyzed in both groups. In the CG one patient did not reach the VT2 on both testing days. In the IG one patient did not reach the VT2 on the post training testing day and one HR monitor was not working during the first testing day while the patient was reaching the VT1. Table 12 depicts mean and SD for all cardiorespiratory fitness test parameters. Both groups reached RER values > 1 on both testing days (CG: T1 RER = 1.15 ± 0.08, T2 RER = 1.16 ± 0.06; IG: T1 RER = 1.15 ± 0.06, T2 RER = 1.17 ± 0.11), indicating anaerobic respiration. Patients subjective perceived exhaustion level was "very hard" (17.36 - 17.91) on both testing days (see Table 12). According to criteria of maximal effort (176) the results display that patients performed the ergometer test until they reached their full physical capacity.

Figure 24 and Figure 25 demonstrate the reasons for termination of the cycling test for the first and second testing day, respectively. Remarkably, peripheral exhaustion decreased for the IG from 72.7% to 36.4%, whereas for the CG peripheral exhaustion increased from 45.5% to 63.6%.

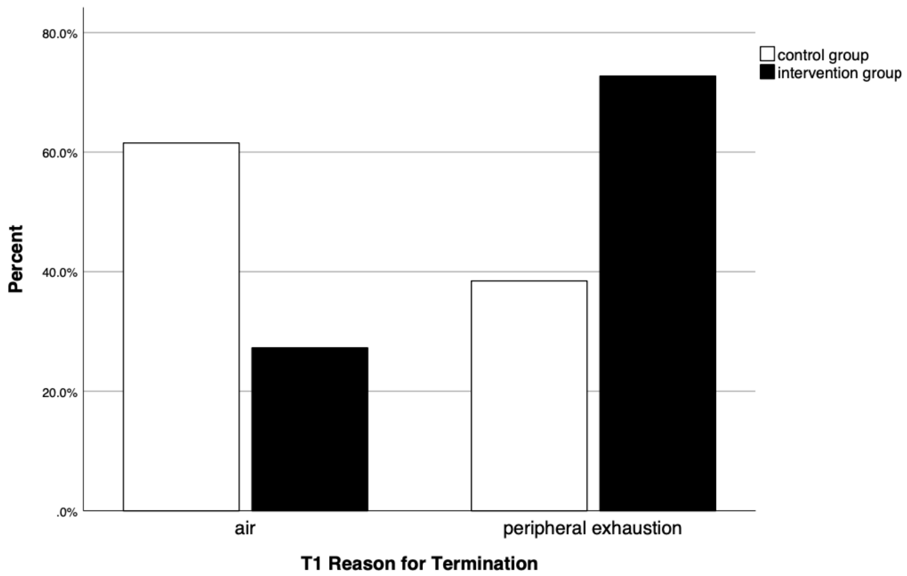

Figure 24. Reason for termination T1.

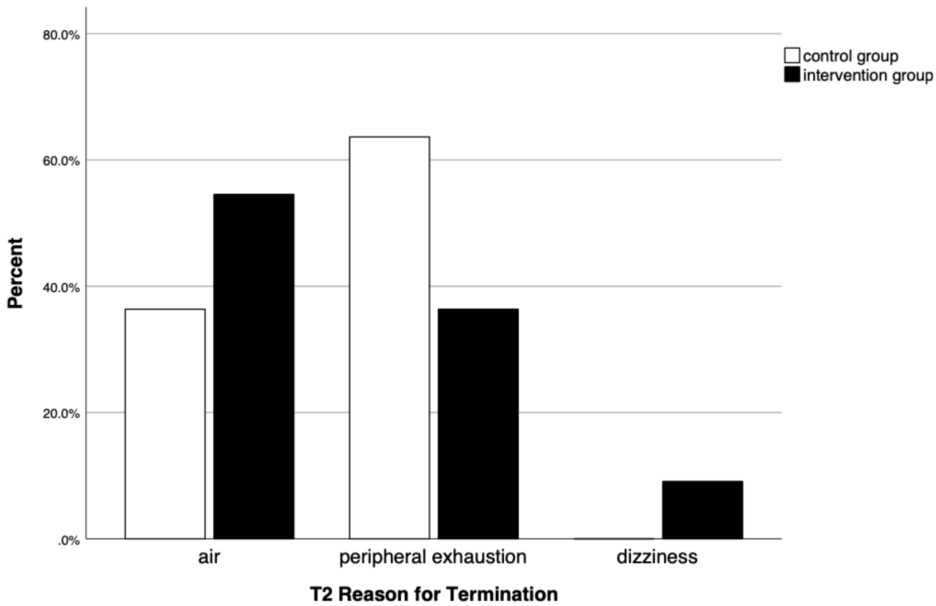

Figure 25. Reason for termination T2.

There was homogeneity of error variances for all cardiorespiratory fitness variables, as assessed by Levene's test ($p > .05$). The data showed homogeneity of covariances, as assessed by Box's test, except for the RER variable ($p = .046$). Table 13 shows the results for the mixed ANOVAs. No statistically significant interaction between time and group for cardiorespiratory fitness was found. There was a significant group main effect for maximal HR ($F(1,20) = 5.00$, $p = .0037$, $\eta p^2 = 0.20$), showing that the IG revealed higher HRs independent from the time of measuring. A significant main effect for time was found for HR at rest ($F(1,20) = 13.59$, $p = .001$, $\eta p^2 = 0.41$) and maximal HR ($F(1,20) = 10.29$, $p = .004$, $\eta p^2 = 0.34$), revealing significantly higher HRs for both groups on the second testing day. All effect sizes were above 0.14, indicating large effects.

Table 12. Mean and SD for cardiorespiratory fitness test parameters.

	Control Group						Intervention Group					
	T1			T2			T1			T2		
Variable	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
HR rest (bpm)	11	78.73	11.88	11	88.45	20.59	11	81.18	17.38	11	87.27	15.42
HR max (bpm)	11	140.64	13.76	11	146.00	15.83	11	154.18	13.35	11	158.36	13.01
VO_2 (ml/min/kgKG)	11	24.37	6.85	11	25.43	5.96	11	26.31	7.44	11	25.44	7.18
VT1 (h:min:sec)	11	00:04:09	00:02:38	11	00:03:36	00:01:46	11	00:03:58	00:02:43	11	00:03:51	00:02:15
Watt at VT1	11	76.73	32.92	11	69.73	22.16	11	74.45	34.27	11	72.91	27.61
HR VT1 (bpm)	11	106.18	11.04	11	108.27	17.68	10	114.00	17.65	11	117.73	16.06
VT2 (h:min:sec)	10	00:06:59	00:03:45	10	00:08:00	00:03:57	11	00:08:19	00:03:28	10	00:09:17	00:03:34
Watt at VT2	10	112.50	47.20	10	124.10	49.69	11	129.09	44.19	10	141.60	45.19
HR VT2 (bpm)	10	124.50	16.45	10	133.20	18.02	10	139.50	15.77	10	148.20	12.80
P max (W/kg)	11	1.73	0.54	11	1.80	0.51	11	1.85	0.60	11	1.88	0.59
RER	11	1.15	0.08	11	1.16	0.06	11	1.15	0.06	11	1.17	0.11
BORG max	11	17.36	1.91	11	17.36	1.21	11	17.09	1.97	11	17.91	1.14

Note. SD= standard deviation, HR= heart rate, VO_2= maximal oxygen uptake, VT1= first ventilatory threshold, VT2= second ventilatory threshold, RER = respiratory exchange ratio, Pmax= maximal power, BORG= perceived rate of exertion.

Table 13. Mixed ANOVAs cardiorespiratory fitness parameters.

Variable		F	p	ηp2
HR rest	Group	0.01	0.926	0.00
	Time	13.59	**0.001**	0.41
	Time*group	0.72	0.407	0.04
HR max	Group	5.00	**0.037**	0.20
	Time	10.29	**0.004**	0.34
	Time*group	0.16	0.695	0.01
VO_2	Group	0.11	0.741	0.01
	Time	0.04	0.843	0.00
	Time*group	3.90	0.062	0.16
RER	Group	0.00	0.988	0.00
	Time	0.84	0.371	0.04
	Time*group	0.22	0.641	0.01
P max	Group	0.18	0.674	0.01
	Time	1.79	0.196	0.08
	Time*group	0.20	0.661	0.01

Note. ηp2= partial eta squared, HR= heart rate, VO2= maximal oxygen uptake, RER= respiratory exchange ratio, P max= maximal power, bold= statistically significant differences, dF= 1.

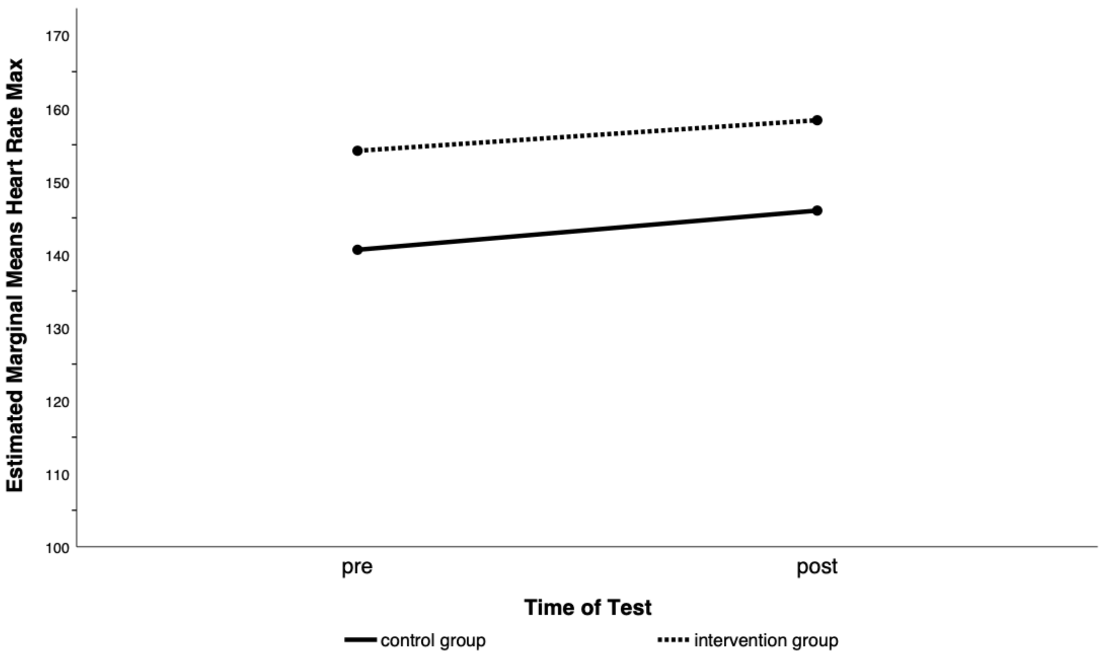

Figure 26. Main effects for maximal heart rate.

5.6. Gait analysis

For the statistical analysis for the gait parameters 13 patients were included in the CG and 12 patients in the IG. On average 8.00 steps were evaluated. Table 14 depicts the general, spatial, and temporal parameters as well as joint angles for knee flexion.

There was homogeneity of error variances for all gait variables, as assessed by Levene's test ($p > .05$). The data showed homogeneity of covariances, as assessed by Box's test ($p > .05$). Table 15 shows the results for the mixed ANOVAs. The analysis revealed a statistically significant interaction between time and group for knee excursion of the operated limb ($F(1,23) = 4.38$, $p = .048$, $\eta p^2 = 0.16$.). There was no significant group main effect for any gait parameter. A significant main effect for time was found for gait speed ($F(1,23) = 9.06$, $p = .006$, $\eta p^2 = 0.28$), cadence ($F(1,23) = 8.49$, $p = .008$, $\eta p^2 = 0.28$), and step length of the operated limb ($F(1,23) = 8.48$, $p = .008$, $\eta p^2 = 0.27$), revealing improvements over time independently of the group. The parameters revealed large effects for all significant results.

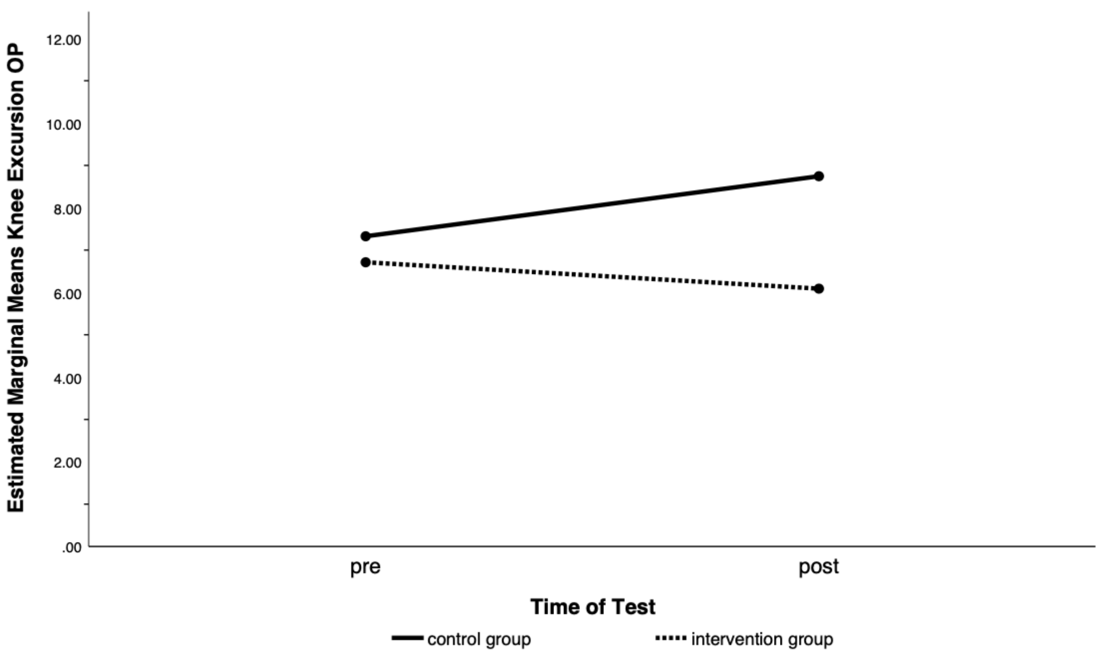

Figure 27. Interaction effect for knee excursion of the operated leg.

Table 14. Mean and SD for gait parameters.

		Control Group (N=13)				Intervention Group (N=12)			
		T1		T2		T1		T2	
Variable		Mean	SD	Mean	SD	Mean	SD	Mean	SD
General Parameters									
Speed (m/s)		1.07	0.16	1.10	0.17	1.06	0.19	1.13	0.16
Cadence (steps/min)		103.79	8.11	104.88	6.70	102.66	7.48	106.79	9.00
Spatial Parameters									
Step Length (cm)	OP	62.10	8.15	61.62	8.44	61.34	9.44	63.49	6.49
	NOP	62.08	8.04	64.11	10.24	61.43	8.40	64.00	6.47
	Δ	0.02	5.68	-2.49	7.85	-0.08	6.59	-0.51	3.75
Step Width (cm)	OP	7.62	3.52	6.89	3.45	7.51	3.24	7.51	3.34
	NOP	6.75	4.77	6.72	3.37	7.16	3.98	7.89	3.17
	Δ	0.25	0.78	0.17	0.72	0.35	0.83	-0.37	0.55
Temporal Parameters									
Stance Phase (%)	OP	57.67	1.73	56.82	2.08	58.24	2.54	56.92	4.86
	NOP	57.79	0.89	58.21	1.36	58.79	3.02	57.85	2.40
Swing Phase (%)	OP	42.31	1.88	42.23	1.86	41.77	2.53	42.20	6.26
	NOP	41.93	0.96	41.76	1.37	41.28	2.63	42.46	3.18
Double Support Phase (%)	OP	7.66	1.69	7.78	1.34	8.26	2.70	7.62	2.92
	NOP	7.80	1.55	8.18	1.72	8.52	2.77	7.46	2.85
Joint Angles									
Knee Flexion Loading (deg)	OP	13.60	4.22	14.09	3.65	12.20	5.99	13.51	5.82
	NOP	15.77	5.11	16.26	5.23	14.43	6.29	16.85	4.53
	Δ	-2.17	4.64	-2.18	3.91	-2.23	5.57	-3.34	7.10
Knee Flexion Foot Strike (deg)	OP	6.27	2.54	5.34	3.23	5.49	2.93	6.30	5.07
	NOP	6.28	3.42	5.67	3.29	4.98	3.03	5.27	4.32
	Δ	-0.01	3.54	-0.32	2.93	0.51	3.42	1.03	4.33
Knee Flexion Excursion (deg)	OP	7.33	3.19	8.74	2.75	6.71	5.77	6.09	5.85
	NOP	9.48	3.42	10.60	3.30	9.45	6.50	10.18	5.38
	Δ	-2.16	3.42	-1.85	2.75	-2.74	4.98	-4.09	4.56
Knee Flexion Maximum (deg)	OP	59.08	5.86	59.96	5.35	62.24	3.30	62.97	3.48
	NOP	59.08	7.17	61.17	7.31	61.56	4.71	62.81	3.38
	Δ	0.00	4.82	-1.20	3.66	0.68	3.97	0.16	4.01

Note. SD= standard deviation, T1= pre- intervention, T2= post-intervention, OP= operated, NOP= non-operated, Δ= difference OP vs. NOP.

Table 15. Mixed ANOVAs for gait parameters.

Variable		F	p	ηp2
Speed	Group	0.04	0.849	0.00
	Time	9.06	**0.006**	0.28
	Time*group	1.68	0.208	0.07
Cadence	Group	0.02	0.898	0.00
	Time	8.49	**0.008**	0.27
	Time*group	2.91	0.102	0.11
Step Length OP	Group	0.03	0.863	0.00
	Time	1.09	0.308	0.05
	Time*group	2.68	0.115	0.11
Step Length NOP	Group	0.01	0.908	0.00
	Time	8.48	**0.008**	0.27
	Time*group	0.12	0.737	0.01
Step Width OP	Group	0.04	0.844	0.00
	Time	0.63	0.435	0.03
	Time*group	0.63	0.436	0.03
Step Width NOP	Group	0.44	0.512	0.02
	Time	0.12	0.735	0.01
	Time*group	0.14	0.711	0.01
Knee Flexion Excursion OP	Group	0.86	0.362	0.04
	Time	0.67	0.423	0.03
	Time*group	4.38	**0.048**	0.16
Knee Flexion Excursion NOP	Group	0.02	0.904	0.00
	Time	3.61	0.070	0.14
	Time*group	0.16	0.691	0.01
Knee Flexion Foot Strike OP	Group	0.00	0.948	0.00
	Time	0.01	0.925	0.00
	Time*group	2.06	0.165	0.08
Knee Flexion Foot Strike NOP	Group	0.45	0.510	0.02
	Time	0.07	0.799	0.00
	Time*group	0.53	0.475	0.02

Note. ηp2= partial eta squared, OP= operated, NOP= non-operated, bold= statistically significant differences, dF= 1.

5.7. Self-reported quality of life and functional scores

Table 16 provides the summary descriptive statistics for the functional and quality of life questionnaires. The physical subcategory of the WHOQOL-BREF showed the lowest score compared to the other subcategories in both study groups and on both testing days (CG: T1 69.23 ± 12.42, T2 71.43 ± 12.71; IG: T1 72.53 ± 17.15, T2 73.63 ± 17.59).

There was homogeneity of error variances for all questionnaire variables, as assessed by Levene's test ($p > .05$). Self-reported quality of life and physical function data showed homogeneity of covariances, as assessed by Box's test. Table 17 shows the results for the mixed ANOVAs. No statistically significant interaction between time and group for neither QOL nor physical function was found. There was no significant main effect for group for any self-reported variable. A significant main effect for time was found for the LEFS score ($F (1,24) = 5.19$, $p = .03$, $\eta p^2 = 0.18$), indicating that the lower extremity function improved between testing days independently of the home training intervention. The analysis further showed an only just significant time effect for the Oxford Psychological Score ($F (1,24) = 4.30$, $p = .049$, $\eta p^2 = 0.15$), showing improvement in QOL in both groups over time. For both significant main effects, the effect size indicated a large effect (see Table 17).

Table 16. Mean and SD for physical function and quality of life questionnaires.

	Control Group (N=13)				Intervention Group (N=13)			
	T1		T2		T1		T2	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
OKS	36.54	5.56	36.85	6.11	38.00	7.85	40.38	6.41
LEFS	54.08	9.36	55.69	11.86	57.85	15.87	62.46	13.60
WHOQOL-BREF								
Overall QOL	3.77	0.60	3.92	0.64	4.00	0.71	4.00	0.71
Overall Health	3.69	0.63	3.54	0.66	3.38	0.87	3.69	0.63
Score Physical	69.23	12.42	71.43	12.71	72.53	17.15	73.63	17.59
Score Psychological	72.76	12.22	75.96	13.73	73.72	7.49	76.92	8.78
Score Social relationships	74.36	10.46	71.79	19.99	78.21	13.41	77.56	18.44
Score Environment	79.81	13.42	79.81	12.21	83.65	10.14	85.82	8.99
OHQ	4.57	0.44	4.79	0.53	4.54	0.66	4.67	0.59

Note. SD= standard deviation, OKS= Oxford Knee Score, LEFS= Lower Extremity Functional Score, QOL= Quality of Life, OHQ= Oxford Happiness Questionnaire.

Table 17. Mixed ANOVAs for physical function and quality of life questionnaires.

Variable		F	p	ηp2
OKS	Group	1.06	0.315	0.04
	Time	2.77	0.109	0.10
	Time*group	1.65	0.211	0.06
LEFS	Group	1.17	0.290	0.05
	Time	5.19	**0.032**	0.18
	Time*group	1.20	0.283	0.05
WHOQOL-BREF Overall QOL	Group	0.40	0.532	0.02
	Time	0.65	0.429	0.03
	Time*group	0.65	0.429	0.03
WHOQOL-BREF Overall Health	Group	0.09	0.762	0.00
	Time	0.44	0.515	0.02
	Time*group	3.93	0.059	0.14
Score Psychological	Group	0.07	0.795	0.00
	Time	2.16	0.154	0.08
	Time*group	0.00	1.000	0.00
Score Physiological	Group	0.24	0.632	0.01
	Time	0.81	0.377	0.03
	Time*group	0.09	0.767	0.00
Score Environment	Group	1.32	0.262	0.05
	Time	0.90	0.351	0.04
	Time*group	0.90	0.351	0.04
Score Social	Group	0.77	0.389	0.03
	Time	0.27	0.609	0.01
	Time*group	0.10	0.758	0.00
OHQ	Group	0.12	0.729	0.01
	Time	4.30	**0.049**	0.15
	Time*group	0.34	0.565	0.01

Note. OKS= Oxford Knee Score, LEFS= Lower Extremity Functional Score, QOL= Quality of Life, OHQ= Oxford Happiness Questionnaire, bold= statistically significant differences, dF= 1.

6. Discussion

6.1. Discussion of the main findings

In this study the effects of an 8-week home training intervention with patients in southern Germany after TKA surgery were investigated. Originally, this study was designed to assess the effects of a home training and ski training group versus a CG, in order to investigate key benefits of those training programs. Due to the SARS-CoV2 pandemic and the shut-down of all ski areas, the objective of the study was adapted, and focus was laid on the home training intervention in comparison to a CG. To date, no study has investigated a mere home training program after primary TKA from a German cohort. Therefore, one novel component of the present study was the focus on benefits of autonomous training for TKA patients. In this study it was found that, participation in an 8-week training program 6-24 months after TKA surgery was not associated with substantial increases in muscle mass, physical function, and quality of life. Consequently, none of the hypotheses were confirmed. These findings contrast the results of previous research and should be critically questioned (96, 118, 177, 178). Conversely, a previous meta-analysis by Alrawashdeh et al. (10) already highlighted the problem, that modified rehabilitation programs after TKA do not automatically lead to a systematic improvement. These results are in line with the results of the systematic review by Wylde et al. (179) which demonstrated no obvious advantage of a specific post discharge intervention. So far, research has been unable to determine the most effective starting point and duration of a rehabilitation program after TKA. Similar to the systematic review, the conceived post discharge intervention at the selected time point in the current study could not lead to an improved physical function.

In the following subsections the results of the individual tests and questionnaires will be discussed in more detail. In addition, limitations and methodological considerations of the study will be discussed. Finally, perspectives for future research will be outlined.

6.1.1. Body composition

The present study identified that postoperative exercise interventions using a home-based training program had no benefits on the body composition as well as on muscle mass outcomes. This result contradicts findings by Liao et al. (96) which demonstrated that resistance exercise for TKA patients improves lower leg muscle mass for the training group. Moreover, our results indicate, that the home training intervention does not contribute to an improvement of muscle mass in the operated limb (T1: 5.48 ± 1.30 kg, T2: 5.37 ± 1.29) as assessed with bioimpedance analysis. Other studies assessed muscle mass, for example by magnet resonance imaging (MRI) (97) or a x-ray absorptiometer (96). Nevertheless, BIA is a validated method to assess muscle mass and has already been used in TKA patients (141). Still, it might explain the different results and may be better used for screening objectives instead of exact muscle mass changes for scientific purposes.

The BMI of the examined cohort can be classified as pre-obese according to the WHO (28.37 ± 4.74 kg/m2 – 29.30 ± 4.49 kg/m2) (68). Nevertheless, it was observed that weight and BMI decreased significantly over time independently of the group (CG: 28.55 ± 4.71 vs. 28.37 ± 4.74, IG: 29.30 ± 4.49 vs. 29.00 ± 4.31). This can be viewed as an exceedingly positive trend as weight gain after TKA is associated with inferior outcomes (180). The trend contradicts, however, the findings of Coelho et al. (181), who investigated the weight development one year after TKA surgery. In their study patients did not show a significant weight loss post-surgery although functional scores have improved. In a study by Naylor et al. (182) the researchers tried to explore which patient factors are associated with weight gain and weight loss for patients who have undergone total knee or hip replacement. They showed that weight gain after joint replacement was associated with younger age and lower BMI prior to surgery, whereas the factors no ongoing joint issues and female sex lead to weight loss. In our study patients reported almost “no” to “mild” pain, which may have contributed to an overall more active lifestyle due to reduced knee pain after TKA surgery and therefore more movement and corresponding loss of weight. Our results concur with an Austrian study which observed a loss of weight after TKA with a follow-up median of 8.8 years (183). However, when comparing to the weight trend of the general population the change in BMI was almost directly comparable. Authors therefore recommend educating patients perioperatively about a healthy lifestyle postoperatively (183). Since obesity is a well-known modifiable risk factor for osteoarthritis (184, 185), the weight trend in the present study can be regarded as an important step towards prolonging aggravation of osteoarthritis in the nonsurgical limb and training interventions should be promoted to enhance this effect.

6.1.2. Strength

Interestingly, the findings of the isokinetic strength test of knee flexion and knee extension of the surgical and non-surgical limb suggest that patients 10-15 months (CG: 10.62 ± 5.01 months, IG: 15.00 ± 4.45 months) post-surgery show no difference in strength level between limbs. Moreover, no effect of the training program on knee extension or flexion is detectable. These results correspond to the findings of Jakobsen et al. (186), which demonstrated that seven weeks of progressive strength training in addition to physical rehabilitation was inferior to normal physical rehabilitation in regard to muscle strength. For the double-sided strength test, our cohort revealed a trend that strength level increases between testing points (CG: 8.85 ± 0.80 weeks, IG: 8.76 ± 0.61 weeks) independently of the training program. Yet, this trend was non-significant.

Previous research shows a decrease in leg muscle strength after TKA surgery that can remain years after surgery (92, 187-190). It therefore seems reasonable to focus on achieving good leg muscle strength after TKA to regain good physical function. Unlike our results, LaStayo et al. (97) showed an increase in knee extension strength after 12 weeks of training. In contrast to our methods, their intervention lasted four weeks longer which may be the reason for the significant difference. Additionally, their training program consisted of only eccentric exercises, whereas the training program in the current study comprised mainly concentric strength exercises. A few studies have already addressed the question whether TKA patients should perform eccentric strength training instead of conventional strength training (97, 103, 191). Results show eccentric training may be more effective to reduce quadriceps strength loss and to improve gait speed and endurance (97, 103). It should be highlighted, that starting point and duration substantially differed to the present study protocol. Suh et al. (102) began their intervention two weeks after surgery and patients performed 5 TSs for only two weeks. Despite the drastically different protocols, eccentric training led to greater outcomes than the training program used in the present study. This suggests that including specifically eccentric exercises might have had a bigger effect. However, research concerning eccentric training is still poor and future studies should further verify whether eccentric exercises do also lead to long-term positive effects.

The present study revealed a non-significant trend that knee extension improved in both limbs in the IG, especially in the operated limb (T1: 1040.62 ± 232.00 Nm, T2: 1174.85 ± 316.17 Nm). These results are in accordance with the significant improvement of knee extension strength by 43% after a 12-week high intensity training (95). However, it must be noted that patients started training 8 days post-operatively. Nevertheless, the positive results persisted to the 12 months post-surgery follow-up. As stated by the authors, for an early training start it is of high importance to supervise the training during the first weeks (95). This approach contradicts with the objective of the present study to provide an effective training program, which patients can do independently at home.

Knee extension is a movement that requires, in particular, the quadriceps muscles (95). Quadriceps strength is very important for everyday tasks like walking or stair climbing (94). Taking a closer look at the extension strength in the present examined cohort, it is recognizable that knee extension has improved the most in the operated limb of the IG (T1: 1040.62 ± 232.00 Nm, T2: 1174.85 ± 316.17 Nm, Δ= 12%). This result suggests there is a trend, that the operated limb can benefit from a training program as conducted in this study. Nevertheless, these results were not significant and rather disappointing drawing into question whether the intensity of training was correctly chosen. Prior research evaluating the training intensity for TKA patients observed inconsistent results as to whether high or low intensity programs are superior (192, 193). Authors reported that a high-intensity, progression-based training program after surgery showed no greater results than a low-intensity training (192). Apart from that, preoperative high-intensity strength training leads to faster functional recovery with reduced pain, better lower limb muscle strength and range of motion before surgery (192). The current investigation found no significant effect of low-intensity training.

Considering the optimal training mode, one should pay attention to recent studies examining a relatively new method of strength training with the blood-flow restriction method. Literature has reported interesting results (194-196). An 8-week home-based training with blood-flow restriction seems to improve knee extensor strength in the surgery leg by 55% and knee extensor strength symmetry reached almost 100% (98%) (196). Improvements lasted up to 14 months post- surgery (196). According to these data, it might be helpful to include methods such as blood-flow restriction in a home-based environment to further evaluate and confirm these findings.

In summary, there is an abundance of room to further progress in determining the optimal start point, intensity and type of strength training clinicians should recommend to their TKA patients 6-24 months after surgical intervention.

6.1.3. Dynamic balance

Authors have reported that the balance level after TKA is not comparable to healthy individuals six months after surgery (99), highlighting the importance of targeting these deficits. Hence it has been recommended to include not only strength but also balance exercises into training programs for older individuals (197). This is due to the fact that during TKA surgery, important structures for the function of mechanoreceptors in the knee, such as knee ligaments and cartilage, are removed resulting in a reduction in motor control (198, 199). This study therefore included static and dynamic balance exercises (see Appendix) and assessed the improvements in balance ability by the lower limb Y-balance test.

In this study, dynamic single leg stance test showed no significant time x group interaction. This is starkly different to the outcome of a meta-analysis examining the effects of balance training on balance ability after TKA. In this review, authors detected improvement in balance-specific performance and other parameters like functional outcome measures after balance specific training (200). Training duration in the reviewed studies varied between 4-32 weeks making it difficult to conclude whether training duration was a critical factor for non-significant results in our study.

Despite the ineffectiveness of the home training intervention, a positive trend in the IG was detectable. Participants revealed a lower CS (CS OP: 78.59 ± 13.94, CS NOP: 83.27 ± 7.73) in the operated limb but could reduce such leg asymmetry after the training program (CS OP: 86.75 ± 10.41, 88.15 ± 8.80) and were able to reach almost complete symmetry at the follow-up (LSI T1: 93.86 ± 13.75%, LSI T2: 99.41 ± 6.85%). The findings of this study also indicate that the training group had higher CSs independently of the time point of measurement. However, it is important to not only look at the value but, as mentioned above, to also include symmetry considerations. Interestingly, an increase in CS for both legs was found in both groups at follow-up. These findings suggest that balance asymmetry exists after TKA surgery but can be improved to attain symmetric values. Nevertheless, caution must be applied, as this study is unable to provide clear answers or explanations for the cause of the above-mentioned improvement.

Comparing the scores to results by Freund et al. (148), which examined a similar age group, the following was observed. 60-69 year-old individuals revealed CSs of right leg: 79.72 ± 10.06%, left leg: 80.5 ± 9.68%. Interestingly, the CSs of the CG in the current study were lower at all test points compared to the cohort of Freund et al. (148), while CS for the IG were constantly above the balance level of the 60-69 year-olds in Freund's study. However, their study only included female participants and they used a wooden test kit, whereas the original plastic version of the Y-balance test kit was used in the present study. These are only two factors which might explain the differences.

Recent results from another exercise intervention after TKA by Lee et al. (100) indicate that training improves not only the ability to balance but also the QOL and physical function too. In contrast to our results, the six week training intervention improved balance as assessed statically with a multifunction force plate and dynamically with the timed up and go test (100). Compared to the present study, the authors used different measurement outcomes to determine balance level which may explain the different results. In addition, it should be mentioned that the training program consisted of only specific progressive dynamic balance exercises, whereas the training in this study was designed as a holistic program to improve physical function and included strength and mobility tasks besides the balance exercises.

Preliminary work was undertaken to investigate whether preoperative balance training is effective for improving balance after TKA. Authors reported that implementing balance training before surgery leads to better balance and functional outcomes as measured with the Knee Injury and Osteoarthritis Outcome Score Function in Activities in Daily Living (201). This outcome is contrary to the findings presented in the present study including balance exercises post-operatively, raising the question whether it would have been more effective to start with the training intervention already prior to surgery. Despite the unexpected results in the present study, it is proven that strengthening the muscles in combination with balance and proprioception exercises is helpful in reducing falls in older individuals (202, 203). Therefore, a balance intervention after TKA seems also to be advisable.

6.1.4. Cardiorespiratory fitness

This intervention study did not detect any evidence for benefits of an 8-week long training intervention on cardiorespiratory fitness parameters determined by relative maximal VO_2, P max as well as HR. Nonetheless, the data suggests a significant change in resting HR and maximum HR in both groups independently of the training. Interestingly, resting HR increased just like maximum HR, in both groups. Additionally, the IG reached higher maximum HRs on both testing days. An attempt to integrate our results in the outcomes of previous research revealed that our cohort has had a higher relative peak VO_2 even before the intervention compared to patients with severe osteoarthritis before TKA surgery (19.4 ± 4.2) (204). When comparing to values of TKA patients prior to a skiing intervention, values are also slightly higher than in the IG and CG of the intervention study by Poetzelsberger et al. (134). In addition, relative peak VO_2 seems to be higher than in a comparable aged healthy group of subjects (205). This suggests that the cohort examined in this study has been relatively fit prior to the intervention compared to similar age-groups.

Our results are in accordance with other studies which used a 6-minute walking test to assess submaximal and maximal aerobic capacities (97, 186, 193, 206-208). The meta-analysis by Alrawashdeh et al. (10) revealed no significant differences in their combined results between groups after long rehabilitation programs. This provides support for the lacking time x group effects in the present study. A study by Casazza et al. (209) focused not only on fitness parameters but also included risk factors for cardiovascular diseases after TKA. In their study they suggest that long-term improvements such as the exercise capacity, leg strength and lipid profiles need more than 12 months to improve. Comorbidity scales post-TKA revealed a significant correlation with declining physical function and pain after TKA (210). These results imply that reducing comorbidities may lead to better outcome after TKA. However, additional research is needed to develop a training intervention, that leads to improvement of cardiovascular parameters.

6.1.5. Gait analysis

The main finding of the present study in regard to gait pattern is that there was an increase in gait speed, cadence, and step length of the NOP for both groups over time. In addition, and contrary to expectations, this study did not find a significant difference between the groups after the intervention except for knee flexion excursion for the operated leg. This finding was unexpected as results suggest a greater increase in the CG than in the IG.

Our findings show time from surgery influences the gait variables. The increase in gait velocity is consistent with results by Biggs et al. (211). However, comparing our results with normative values for adults (gait velocity: 1.20 - 1.50 m/sec, step length: 0.65 - 0.75 m, cadence: 105 - 130 l/min) it is interesting to note, that gait velocity, step length, and cadence are below norm values for both study groups at both testing days (212) (see Table 14). This trend was also reported in the study by Biggs et al. (211) as they definitively found an increase in gait speed, however, TKA patients could not reach the speed of the CG. Our results concerning step length are in line with other findings reported in unilateral total knee arthoplasty by Alnahdi et al. (213). TKA patients in their study revealed shorter step length one year after surgery (OP: 0.69 ± 0.06 m, NOP: 0.68 ± 0.06

m) compared to a CG (OP leg: 0.75 ± 0.06 m, NOP leg: 0.74 ± 0.07 m). Notably, step length in the present study remained below the values of the reported CG for both groups. It is therefore important that focus on the recovery of normal gait mechanics is part of long-term rehabilitation after knee arthroplasty (214).

Compared to other gait analyses (Braito et al.: 0.93 ± 0.15 m/s ; Suh et al.: 1.0 ± 0.2 m/s) our patients walked faster at all time points (103, 215). Strikingly, the temporal phases differed to other studies with a distinct shorter double support phase. After an early resistance training double support duration was 30.5 ± 5.7% for eccentric-concentric combination and 29.0 ± 3.5% for only concentric training, respectively (103). Similarly, Braito et al. (215) reported double support phases over 20% of the gait cycle for TKA and UKA. A note of caution should be made here since studies analyzed gait mechanics with different systems. A camera-based motion capture system was used by Braito et al. (215). According to Zhang et al. (152) camera-based motion capture systems show good concordance of angles in sagittal plane but caution should be applied when looking at other gait parameters. Nevertheless, Suh et al. (103) also applied inertial sensing devices as used in the present study to measure spatiotemporal variables. When regarding the method of collecting gait data, it should be stressed, that X-Sens is easy to use and therefore suitable for clinical practice, reliable especially in sagittal plane for walking and has good between-rater and within-rater reliability (150).

Moreover, we did not see a significant difference in knee flexion of the knees between operated and non-operated limb in both groups. These results are in line with the reported outcomes of Agarwal et al. (216) for TKA patients who detected 3.4% less flexion at heel strike and 11.4% less flexion during the loading response phase. Furthermore, operated knees could be extended by 3.7% less than the healthy limb (216). McClelland et al. (86) compared knee flexion in TKA patients with a healthy control and reported less knee flexion in operated knees ($p < .001$) for two different gait speeds. Authors explain this deficit with prolonged hamstring activity and reduced gluteal and quadriceps muscle function. In this study no deficit of muscle function in the operated leg compared to the contralateral leg was detectable (see Table 8), which may also explain the similar knee extension between limbs. The current investigation found a significant improvement for knee extension in the CG, but not in the group who underwent the training intervention. Unfortunately, this finding is rather difficult to interpret. It is possible that this result was influenced by the distinctly higher walking activity time in the CG which may have helped to adapt the muscles after TKA surgery in the time frame of the 8-week intervention better than through the combined resistance and mobility training program. Admittedly, the present study put focus on the sagittal plane. However, to complement the gait analysis and further evaluate gait patterns after TKA it would be interesting to include the frontal and transversal planes in future analyses as well.

Research has shown that lower quadriceps strength in the operated limb is related to worse gait pattern (217). As no significant strength deficit was detectable in our cohort it is not surprising that gait mechanics did not differ dramatically between surgical and non-surgical limbs. It should be duly noted that our analyses did not include joint moments. Joint moments may be an important indicator for load distribution within the joint and should be considered in future research, especially when analyzing the effects of high impact sport activities like skiing. Future in field setups could therefore include mobile insoles to reveal information about joint loading and pressure distribution during walking or other activities.

6.1.6. Self-reported quality of life and functional scores

Research has shown, that TKA does not always result in patient satisfaction, often reflected in the QOL patients report after surgery. A meta-analysis by Shan et al. (218) included 19 studies and could only report a satisfaction rate of 75% after five years. QOL includes various dimensions, particularly activity limitations, social limitations and psychological or emotional aspects (107). For this reason, it was decided to take account of the psychological factors after a training intervention with functional and psychological questionnaires.

This work has shown that an 8-week home-based intervention has no effect on functional scores measured with the OKS and LEFS. Prior research investigated the minimal important difference for the OKS when comparing two groups (five points) (219). In comparison, our results suggest only a difference of approximately four points after the intervention (CG: 36.85 ± 6.11 points, IG: 40.38 ± 6.41 points) leading to the conclusion that the difference between CG and IG should be classified as not meaningful. Patients reported an OKS of CG: 36.54 ± 5.56 points and IG: 38.00 ± 7.85 points before the intervention. These results reflect those of Abane et al. (220) which demonstrated as part of a randomized trial a mean OKS of 38.2 points (range: 21-48 points). In contrast to this, Jenny et al. (221) reported a considerably lower post-operative score (20.5 ± 5.69 points) in patients whose surgery took place more than one year earlier. However, it is important to bear in mind that studies were conducted with patients with various surgery methods and prothesis types which may explain the differences. Looking at the LEFS our cohort revealed higher scores both prior to and subsequent to the training as compared to other studies, for example by Turcotte et al. (52.2 ± 12.6 points) (222). The comparatively high baseline values in our study may be a possible explanation for the insignificant change over time.

In addition, no significant changes in QOL as assessed by the WHO-BREF and Oxford Questionnaire through the training program have been detected in the present study. These results contradict the findings in a randomized-controlled trial among healthy adults which showed a significant improvement (p= .001) of Oxford Happiness Inventory after an 8-week long physical exercise program (223). Still, comparing the results of the WHOQOL-BREF with a long-term follow-up in a cohort of 148 patients and follow-up time 11.3 ± 2.3 years, patients in the present study revealed higher QOL and higher overall health as well as higher scores in every subdomain after the training intervention (224). A possible inference that can be made from this finding is the possibility that regular movement leads to better QOL and need to be implemented in everyday life for patients with TKA in order to maintain the level of satisfaction throughout the years after surgery.

Despite the disappointing effect of the training program, this study has been able to demonstrate a significant improvement of LEFS independently of the group, indicating that knee function did improve over time without regard to the intervention. Additionally, analyses showed an improvement in the Oxford Happiness score in both groups over time. These results are consistent with data obtained in previous studies. Studies have been conducted to assess QOL after the surgery, of which many show an improved QOL after TKA without a specific training program (99, 225). Unlike the present study, Fernandes et al. (99) used the Western Ontario and McMaster Universities Osteoarthritis Index questionnaire (WOMAC) and the Short Form Health Survey (SF-36) to assess QOL. The results of Fernandes et al. (99) are in accordance with those obtained in a Saudi Arabian cohort (225). Overall, it can be determined, that this project was the first study that used the OHQ in patients with TKA. Most studies that have been conducted by now used a form of the Short Form Health Survey which might be a reason for the inconsistency in results.

6.2. Limitations and methodological considerations

Potential limitations should be considered within the study. First, the sample size in this present study was rather small. The limited statistical power due to the modest sample size (n= 26) may have contributed to a limited significance of the conducted statistical analyses. As the project was organized as a single-center study the patient selection may not be suitable as a representative sample of the entire population. Studies with a larger number of sample sizes would be required in order to confirm the trends observed in the current study. Moreover, due to the limited number of re-examined patients, it was decided to not investigate gender specific differences within the groups. Another aspect that must be mentioned is, that patients were operated on by several surgeons and different implants were included. However, again due to the small sample size it was decided to forego group specific analyses. Another potential limitation is the various time span after surgery between control (10.62 ± 5.01 months) and IG (15.00 ± 4.45 months). Patients in the IG have been on average included 4.38 months later than individuals in the CG. This may be considered as a methodological weak point and the question arises as to whether the inclusion time span of 6 to 24 months post-surgery might have been too big to detect significant results. As discussed above, the selected training mode might also have contributed to the unsatisfying results. One concern about the insignificant group x time effects was the reported training time per week in the CG (399.44 ± 288.55 min/week). This was on average more than three times more physical activity compared to the IG that completed 94.88% of the recommended TSs but were less active in activities such as walking, biking, or swimming (see Table 4). For future studies, standardizing the permitted activity for the CG should be considered. Regarding our measurement methods validation has been given in the methods section (see chapter 4). However, some limitations occurred during testing which should be taken into consideration when reviewing the results. During gait analysis all mobile devices in the testing room were switched off as IMU can be affected by ferromagnetic objects. However, other local magnetic field disturbances in the surrounding rooms may still have occurred (153). When implausible gait results appeared during measurement, we tried to limit incorrect measurements and repeated the calibration before rerunning the test. Despite the fact that eight weeks of physical exercise intervention have led to significant improvement in other studies, the intervention period may have been a limiting factor for the type of training used in this study and the reason for the non-significant results (95). It would be interesting to investigate, whether a longer intervention would lead to more noticeable results. Certainly, the original objective was to investigate the different effects of a home-based training compared to an on-field ski training as the demand in areas like southern Germany for returning to high impact sports has been rising. In future, it is advised that more clinics with a patient collective interested in mountain sports after TKA should be included. Due to the potential limitations mentioned above, the results are treated with care, and we are aware that they may only reveal a trend and the generalizability of the results may be comprised.

6.3. Research and clinical perspectives

Despite the aforementioned limitations, the findings of this study are still of special interest for clinicians and therapists who are in charge of patients with TKA. Asymmetrical movements after unilateral TKA can overload the contralateral limbs and stiff gait pattern during walking increases progression of osteoarthritis in the contralateral leg (88). The analysis of strength and gait undertaken here, has extended the knowledge of rehabilitation after TKA and suggests that symmetrical strength level also implies a better gait pattern. Regardless of a specific training intervention it still seems reasonable to advise the importance of post-discharge activity after TKA surgery. Considerably more work will need to be done to determine the optimal training method to regain and then maintain good physical function with a replaced knee. A reasonable approach would be to put more effort in comparing pre- and post-surgery interventions and to put emphasis on the exploration of other methods like eccentric training or training with blood flow restriction after TKA.

The planned objective of this project to compare an 8-week skiing intervention with a home training intervention for TKA patients could not be reached due to closed ski fields during the COVID-19 pandemic. Nevertheless, it remains an important research question, whether a regular ski training can improve the physical parameters for patients with knee replacement and especially whether it can improve patients' quality of life. In Austria researchers have shown in a small cohort, that recreational skiing is suitable for strengthening the quadriceps strength (134). Further investigations should verify these results and take psychological factors into consideration as well.

Particular in rural areas treatment options for rehabilitation programs are often limited. It has been proven that simple forms of strength training with e.g., elastic bands and one's own body weight is not inferior to machine-based strength training (118). On top of that, virtual physical training reduces health-care costs if implemented in the 12 weeks after surgery (226, 227). As telerehabilitation can be performed at any-time, it could increase patients' compliance. This may specifically be the case for employed patients (228). The flexible use of a home-based training program is reflected in the high implementation rate (94.88%) in the present study. Additionally, it has been proven that people who train with tele-health technology use 16.7% less pain killers (229). For these reasons, home based training programs with tele-health technologies have a high potential in remote areas to increase rehabilitation success and should therefore be considered as a rehabilitation alternative for TKA patients.

7. Conclusion

In summary, as of today only a few studies exist which have been analyzing a home-based training intervention in German TKA patients. It was the aim of this investigation to assess whether patients benefit from a training intervention after discharge. Contrary to the study hypotheses, this study has demonstrated that an 8-week home training intervention 6-24 months post-surgery is not effective at improving strength status or gait parameters. Furthermore, there were no observed differences in cardiovascular fitness or dynamic balance. However, over time an improvement in leg asymmetry was detected. Moreover, the home-based training did not affect functional or QOL scores. Further exploration with a larger cohort, best in a multi-center set-up, is needed to determine whether patients can benefit from an 8-week long training program after TKA. Special emphasis should be laid on the different resistance training methods.

The present findings still provide clinicians with useful information and home-based training should be further investigated as it may contribute greatly to a long-term success of rehabilitation and can be a very promising alternative to usual rehabilitation especially when thinking about increasing patients' compliance and economic efficiency. Research should focus on implementing telehealth technology in order to advance conventional TKA rehabilitation and in order to optimize the long-term rehabilitation success for patients after TKA surgery.

8. List of Figures

9. List of Tables

10. Bibliography

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Appendix

Home training program A

Heimtrainingsprogramm A

Woche 1 + Woche 2 + Woche 3

			Sätze	Wiederholungen/Zeit	Pause (sek)
Mobility	1.	Hüftkreisen	1	10 pro Richtung	
	2.	Fußwippen	1	20	
	3.	Uhr	1	10 pro Richtung	
	4.	Bogen seitlich	1	30 sek pro Seite	
	5.	Quadrizeps Dehnung	1	30 sek pro Seite	
	6.	Katzenbuckel	1	20	
Kräftigung	1.	Ausfallschritt	3	10 pro Bein	30
	2.	Muschel	3	20 pro Bein	30
	3.	Wandsitzen	3	60 sek halten	30
	4.	Brücke	3	20	30
	5.	Vierfüßlerstand	3	20	30
	6.	Bauchspannung	3	20	30
	7.	Bogen Bauchlage	3	20	30
Balance	1.	Bergab	3	10 pro Bein	30
	2.	Flasche kreisen	3	10 pro Bein	30
Cool-down				5min Körperwahrnehmung	

Training und Bewegungsanalyse bei Patienten mit Knieendoprothese

Mobilitätstraining

Mobilitätstraining („Mobility-Training“) verbessert das Zusammenspiel von Muskeln und Gelenken. Ziel der folgenden Übungen ist es, die Gelenke und Muskulatur mit passiven und aktiven Übungen in möglichst große Bewegungsgrade zu mobilisieren. Dadurch wird Muskel- und Fasziengewebe aktiviert und auf die darauf folgenden Kräftigungsübungen vorbereitet.

1. Hüftkreisen

Ausgangsposition
Beidbeiniger hüftbreiter Stand

Ausführung
Kreisen Sie mit den Hüften im Uhrzeigersinn. Hände auf den Hüften

Ziel
10 Wdh pro Richtung

2. Fußwippen

Ausgangsposition
Beidbeiniger Stand

Ausführung
Bewegen Sie ihr Körpergewicht von der Ferse auf die Ballen und wieder zurück

Ziel
20 Wdh

3. Uhr

Ausgangsposition
Beidbeiniger Stand,
Hände Richtung Decke

Ausführung
Oberkörper locker zur Seite schwingen und über die Mitte zurück in die Ausgangsposition führen

Ziel
10 Wdh pro Richtung

Training und Bewegungsanalyse bei Patienten mit Knieendoprothese

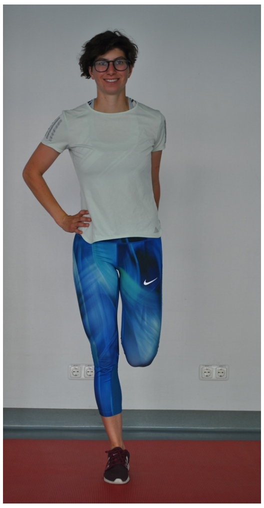
4. Bogen seitlich

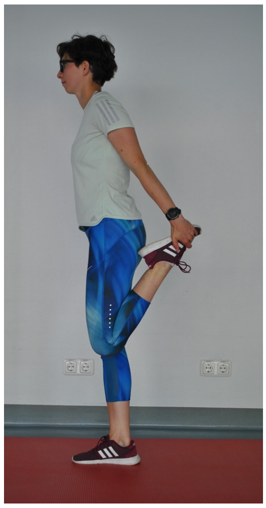
Ausgangsstellung
Stand, das vordere Bein überkreuzt das Standbein.

Ausführung
Die Arme werden in Richtung des vorderen Beines bewegt.

Ziel
30 sek halten pro Seite

5. Quadrizeps Dehnung





Ausgangsposition

Aus dem Stand greifen Sie mit der rechten Hand den rechten Fußrücken.

Ausführung

Ziehen Sie Ihren Fuß in Richtung Gesäß, so dass das Knie nach unten zeigt.

Ziel

30 sek pro Seite halten

Bauchmuskeln anspannen, damit das Becken nicht in eine Hohlkreuzposition ausweicht. **!**

6. Katzenbuckel

Ausgangsstellung

Vierfüßlerstand mit geradem Rücken. Die Ellbogen sind leicht gebeugt.

Ausführung

Der Rücken wird rund gemacht und dann langsam in die Gegenrichtung bewegt (Hohlkreuz mit leichter Bauchspannung).

Ziel

20 Wdh

Kräftigung

Die folgenden Kräftigungsübungen haben das Ziel die motorischen Kraftfähigkeiten zu verbessern. Dabei wurden Übungen gewählt ,die vor allem zur Verbesserung des Kraftniveaus der Beine und des Rumpfes führen. Alle Übungen werden fast ausschließlich mit dem eigenen Körpergewicht absolviert. Ab Woche 4 kommen Übungen mit geringen Zusatzlasten hinzu.

1. Ausfallschritt

Ausgangsstellung:
Ausfallschritt mit geradem Rücken, Arme locker seitlich hängenlassen

Ausführung:
Hinteres Knie absenken bis kurz über dem Boden. Arme werden gleichzeitig nach oben geführt.

Ziel:
3 Sätze
10 Wdh pro Bein
30 sek Pause zw. Sätzen

Knie sollte stabil nach vorne gerichtet sein, nicht nach innen/außen rotieren. !

2. Muschel

Ausgangsstellung:
Seitlage, beide Beine sind im Hüft- und Kniegelenk leicht angebeugt

Ausführung:
Das obere Knie wird in Richtung Decke geführt.

Ziel:
3 Sätze
20 Wdh pro Bein
30 sek Pause zw. Sätzen

Becken bleibt stabil und rotiert nicht nach vorne oder hinten. Beide Fersen halten Kontakt.

Training und Bewegungsanalyse bei Patienten mit Knieendoprothese
endogap Klinik für Gelenkersatz im Klinikum Garmisch-Partenkirchen

3. Wandsitzen

Ausgangsposition:
Sitzposition an einer Wand einnehmen. Der Kniewinkel sollte etwas mehr als 90 Grad betragen.

Ausführung:
Position halten.

Ziel:
3 Sätze
60 sek halten
30 sek Pause zwischen Sätzen

Gesamter Rücken hält Kontakt zur Wand. Fußsohle komplett am Boden.

4. Brücke

<u>Ausgangsstellung:</u>

Rückenlage, beide Beine hüftbreit angestellt

<u>Ausführung:</u>

Becken heben, sodass Oberschenkel und Oberkörper eine Linie bilden. Dann Becken langsam wieder senken.

<u>Ziel:</u>

3 Sätze

20 Wdh

30 sek Pause zw. Sätzen

> Becken sollte stets in einer aufgerichtete Position sein, damit kein Hohlkreuz entsteht. !

5. Vierfüßlerstand

<u>Ausgangsstellung</u>

Kniestand mit geradem Rücken. Die Hände werden auf Höhe der Schultern aufgestellt.

<u>Ausführung:</u>

Beide Knie werden ca 5cm über dem Boden angehoben. Position kurz (2-3sec) halten, Knie wieder aufstellen.

<u>Ziel:</u>

3 Sätze

20 Wdh

30 sek Pause zw. Sätzen

> Bauchspannung durchgehend halten. Füße hüftbreit. !

6. Bauchspannung

Ausgangsstellung:

Rückenlage, Beine 90Grad in der Luft gebeugt, Finger berühren den Hinterkopf.

Ausführung:

Schulterblätter vom Boden abheben. Spannung für ca. 2sec halten. Oberkörper wieder senken.

Ziel:

3 Sätze

20 Wdh

30 sek Pause zw. Sätzen

Nacken locker lassen. Anheben aus den Bauchmuskeln. !

Training und Bewegungsanalyse bei Patienten mit Knieendoprothese

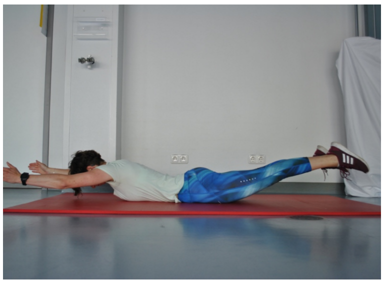
7. Bogen Bauchlage

Ausgangsstellung:

Bauchlage, Arme und Beine gestreckt

Ausführung:

Kontrolliertes Abheben und Senken von Armen und Beinen



Ziel:

3 Sätze

20 Wdh

30 sek Pause zw. Sätzen

Das Schambein wird Richtung Unterlage gedrückt, damit kein Hohlkreuz entsteht !

Balance

Die letzten zwei Übungen sollen die koordinativen Fähigkeiten schulen. Dabei wird vor allem durch Gleichgewichtsübungen die Tiefenmuskulatur und vielfältige Bereiche des Gehirns stimuliert. Es wird die Fähigkeit den Körper im Gleichgewicht zu halten, oder während Bewungen wieder ins Gleichgewicht zu bringen, trainiert. Somit kann durch ein Balance Training das Sturzrisiko gesenkt werden.

1. Bergab

Ausgangsstellung

Aufrechter Einbeinstand auf einer Erhöhung (Stufe).

Ausführung

Kontrolliertes Absenken und wieder Strecken des Standbeines von der Erhöhung.

Ziel

3 Sätze

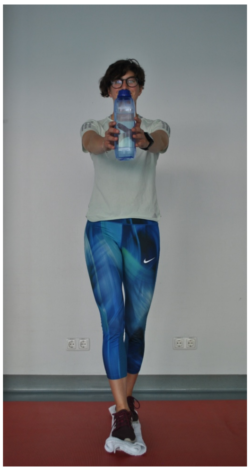
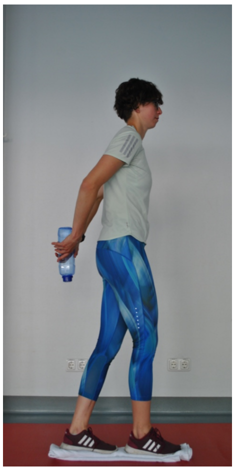
10 Wdh pro Bein

30 sek Pause zw. Sätzen

Knie nicht nach innen/außen rotieren. Oberkörper bleibt gerade und leicht nach vorne geneigt.

!

2. Flasche kreisen


Ausgangsposition

Sie stehen wie ein Seiltänzer auf einer unebenen Fläche (zB Handtuch).

Ausführung

Führen Sie einen schweren Gegenstand (zB Flasche) einmal um Ihren Oberkörper und halten Sie die Balance.

Ziel

3 Sätze

10 Wdh pro Bein

30 sek Pause zw. Sätzen

Home training program B

Training und Bewegungsanalyse bei Patienten mit Knieendoprothese

Heimtrainingsprogramm B

Woche 4 + Woche 5 + Woche 6

			Sätze	Wiederholungen/Zeit	Pause (sek)
Mobility	1.	Hüftkreisen	1	10 pro Richtung	
	2.	Kniekreisen	1	10 pro Richtung	
	3.	Fußwippen	1	10 pro Richtung	
	4.	Uhr	1	10 pro Richtung	
	5.	Bogen seitlich	1	30 sek pro Seite	
	6.	Katzenbuckel	1	20	
Kräftigung	1.	Ausfallschritt	3	10 pro Bein	30
	2.	Beinheben	3	20 pro Bein	30
	3.	Wandsitzen	3	60 sek halten	30
	4.	Brücke	3	20	30
	5.	Vierfüßlerstand	3	20	30
	6.	Maikäfer	3	20	30
	7.	Schnittlauch hacken	3	20	30
Balance	1.	Bergab	3	10 pro Bein	30
	2.	Balancieren	3	10 pro Bein	30
Cool-down				5min Körperwahrnehmung	

Viel Spaß!

1

Training und Bewegungsanalyse bei Patienten mit Knieendoprothese

Mobilitätstraining

Mobilitätstraining („Mobility-Training“) verbessert das Zusammenspiel von Muskeln und Gelenken. Ziel der folgenden Übungen ist es, die Gelenke und Muskulatur mit passiven und aktiven Übungen in möglichst große Bewegungsgrade zu mobilisieren. Dadurch wird Muskel- und Fasziengewebe aktiviert und auf die darauf folgenden Kräftigungsübungen vorbereitet.

2

1. Hüftkreisen

<u>Ausgangsposition</u>

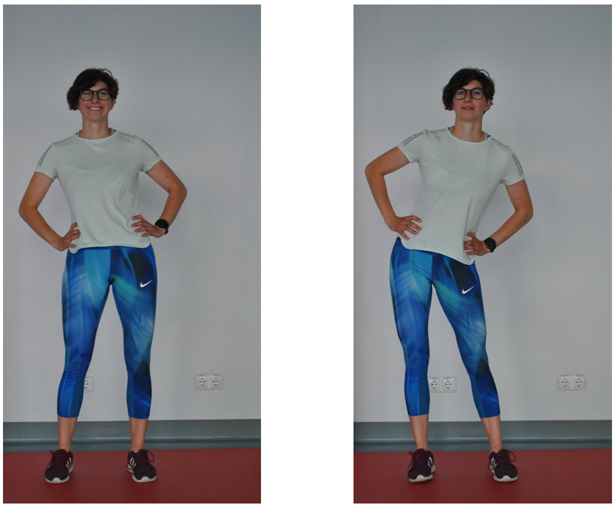
Beidbeiniger hüftbreiter Stand

<u>Ausführung</u>

Kreisen Sie mit den Hüften im Uhrzeigersinn. Hände auf den Hüften

<u>Ziel</u>

10 Wdh pro Richtung



Training und Bewegungsanalyse bei Patienten mit Knieendoprothese
endogap Klinik für Gelenkersatz im Klinikum Garmisch-Partenkirchen

2. Fußwippen

<u>Ausgangsposition</u>

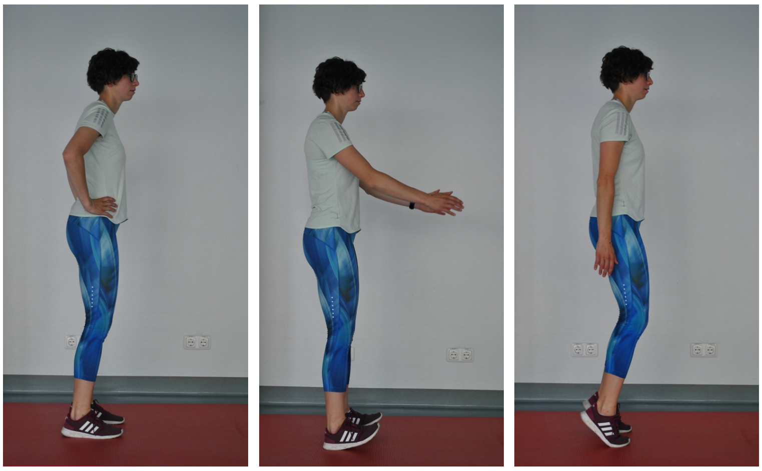
Beidbeiniger Stand

<u>Ausführung</u>

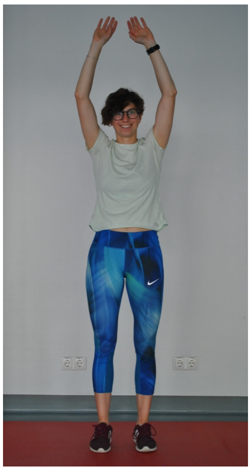
Bewegen Sie ihr Körpergewicht von der Ferse auf die Ballen und wieder zurück

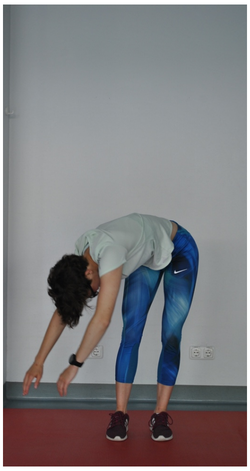
<u>Ziel</u>

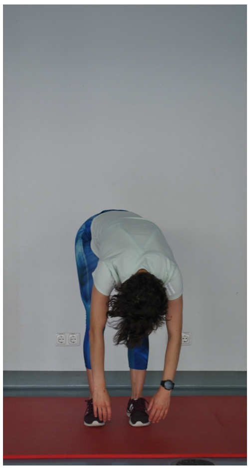
20 Wdh



3. Uhr







Ausgangsposition
Beidbeiniger Stand, Hände Richtung Decke

Ausführung
Oberkörper locker zur Seite schwingen und über die Mitte zurück in die Ausgangsposition führen

Ziel
10 Wdh pro Richtung

Training und Bewegungsanalyse bei Patienten mit Knieendoprothese

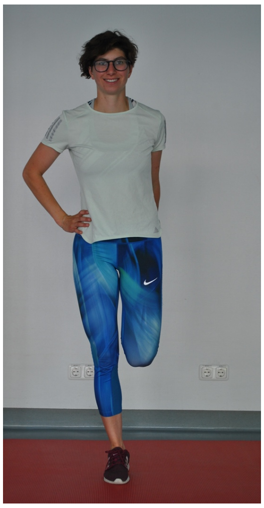
4. Bogen seitlich

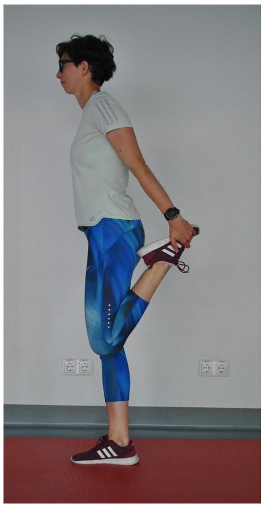
Ausgangsstellung
Stand, das vordere Bein überkreuzt das Standbein.

Ausführung
Die Arme werden in Richtung des vorderen Beines bewegt.

Ziel
30 sek halten pro Seite

5. Quadrizeps Dehnung





Ausgangsposition

Aus dem Stand greifen Sie mit der rechten Hand den rechten Fußrücken.

Ausführung

Ziehen Sie Ihren Fuß in Richtung Gesäß, so dass das Knie nach unten zeigt.

Ziel

30 sek pro Seite halten

> Bauchmuskeln anspannen, damit das Becken nicht in eine Hohlkreuzposition ausweicht.

Training und Bewegungsanalyse bei Patienten mit Knieendoprothese
endogap Klinik für Gelenkersatz im Klinikum Garmisch-Partenkirchen

6. Katzenbuckel

Ausgangsstellung

Vierfüßlerstand mit geradem Rücken. Die Ellbogen sind leicht gebeugt.

Ausführung

Der Rücken wird rund gemacht und dann langsam in die Gegenrichtung bewegt (Hohlkreuz mit leichter Bauchspannung).

Ziel

20 Wdh

Kräftigung

Die folgenden Kräftigungsübungen haben das Ziel die motorischen Kraftfähigkeiten zu verbessern. Dabei wurden Übungen gewählt ,die vor allem zur Verbesserung des Kraftniveaus der Beine und des Rumpfes führen. Alle Übungen werden fast ausschließlich mit dem eigenen Körpergewicht absolviert. Ab Woche 4 kommen Übungen mit geringen Zusatzlasten hinzu.

1. Ausfallschritt

<u>Ausgangsstellung:</u>
Ausfallschritt mit geradem Rücken, Arme auf die Hüften. Vorderfuß auf unebene Fläche stellen.

<u>Ausführung:</u>
Hinteres Knie absenken bis kurz über dem Boden. Arme werden gleichzeitig nach oben geführt.

<u>Ziel:</u>
3 Sätze
10 Wdh pro Bein
30 sek Pause zw. Sätzen

Knie sollte stabil nach vorne gerichtet sein, nicht nach innen/außen rotieren.

!

2. Beinheben

Ausgangsstellung:
Seitlage, unteres Bein im Hüft- und Kniegelenk leicht angebeugt, oberes gestreckt

Ausführung:
Das obere Bein wird in Richtung Decke geführt.

Ziel:
3 Sätze
20 Wdh pro Bein
30 sek Pause zw. Sätzen

Becken bleibt stabil und rotiert nicht nach vorne oder hinten. !

3. Wand sitzen

Ausgangsposition:
Sitzposition an einer Wand, Kniewinkel etwas mehr als 90 Grad

Ausführung:
Ein Bein anheben und Position halten.

Ziel:
3 Sätze
60 sek halten
30 sek Pause zw. Sätzen

Gesamter Rücken hält Kontakt zur Wand. Fußsohle Standbein komplett am Boden. !

4. Brücke

Ausgangsstellung:

Rückenlage, beide Beine hüftbreit angestellt. Ein Bein gestreckt anheben.

Ausführung:

Becken heben, sodass Oberschenkel und Oberkörper eine Linie bilden. Dann Becken langsam wieder senken.

Ziel:

3 Sätze

20 Wdh

30 sek Pause zw. Sätzen

> Becken sollte stets in einer aufgerichtete Position sein, damit kein Hohlkreuz entsteht. !

5. Vierfüßlerstand

Ausgangsstellung

Kniestand mit geradem Rücken, Hände auf Höhe der Schultern

Ausführung:

Beide Knie werden ca 5cm über dem Boden angehoben. Ein Bein nach hinten ausstrecken.

Ziel:

3 Sätze

20 Wdh

30 sek Pause zw. Sätzen

> Bauchspannung durchgehend halten. Hüfte stabil halten. !

6. Maikäfer


<u>Ausgangsstellung:</u>
Rückenlage, Beine 90Grad in der Luft gebeugt, Finger berühren den Hinterkopf.

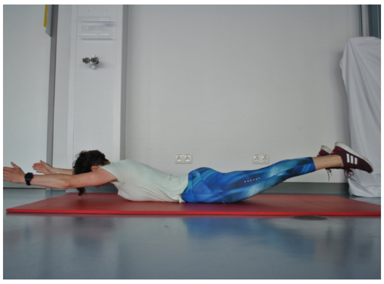
<u>Ausführung:</u>
Rechten Ellbogen in Richtung linkes Knie führen. Rechtes Bein ausstrecken.

<u>Ziel:</u>
3 Sätze
20 Wdh
30 sek Pause zw. Sätzen

Nacken locker lassen. Anheben aus den Bauchmuskeln.

!

7. Schnittlauch hacken




<u>Ausgangsstellung:</u>
Bauchlage, Arme und Beine gestreckt

<u>Ausführung:</u>
Gegengleich Arm und Bein anheben.

<u>Ziel:</u>
3 Sätze
20 Wdh
30 sek Pause zw. Sätzen

Das Schambein wird Richtung Unterlage gedrückt, damit kein Hohlkreuz entsteht

!

Balance

Die letzten zwei Übungen sollen die koordinativen Fähigkeiten schulen. Dabei wird vor allem durch Gleichgewichtsübungen die Tiefenmuskulatur und vielfältige Bereiche des Gehirns stimuliert. Es wird die Fähigkeit den Körper im Gleichgewicht zu halten, oder während Bewungen wieder ins Gleichgewicht zu bringen, trainiert. Somit kann durch ein Balance Training das Sturzrisiko gesenkt werden.

1. Bergab

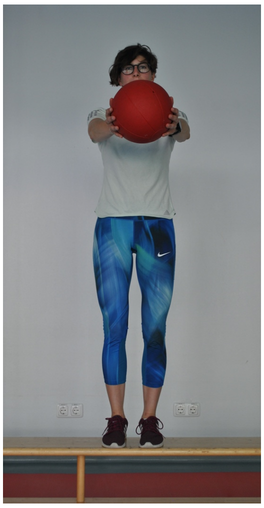
<u>Ausgangsstellung</u>
Aufrechter Einbeinstand auf einer Erhöhung (Stufe). Gegenstand waagrecht vor dem Körper halten.

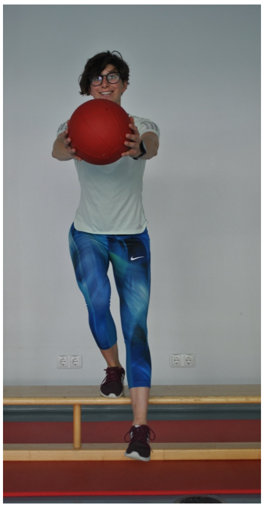
<u>Ausführung</u>
Kontrolliertes Absenken und wieder Strecken des Standbeines von der Erhöhung.

<u>Ziel</u>
3 Sätze
10 Wdh pro Bein
30 sek Pause zw. Sätzen

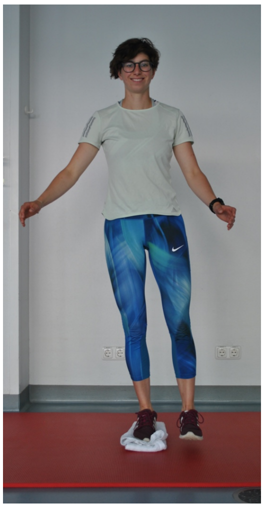
Knie nicht nach innen/außen rotieren. Oberkörper bleibt gerade und leicht nach vorne geneigt.

!





2. Balancieren



Ausgangsposition

Einbeinstand auf unebenen Untergrund (zB Handtuch).

Ausführung

Gleichgewicht halten.

Ziel

3 Sätze

30 sek pro Bein

30 sek Pause zw. Sätzen

Home training program C

Heimtrainingsprogramm C

Woche 7 + Woche 8

			Sätze	Wiederholungen/Zeit	Pause (sek)
Mobility	1.	Hüftkreisen	1	10 pro Richtung	
	2.	Kniekreisen	1	10 pro Richtung	
	3.	Fußwippen	1	10 pro Richtung	
	4.	Uhr	1	10 pro Richtung	
	5.	Bogen seitlich	1	30 sek pro Seite	
	6.	Katzenbuckel	1	20	
Kräftigung	1.	Ausfallschritt	3	10 pro Bein	30
	2.	Muschel	3	20 pro Bein	30
	3.	Wandsitzen	3	60 sek halten	30
	4.	Brücke	3	20	30
	5.	Vierfüßlerstand	3	20	30
	6.	Maikäfer	3	20	30
	7.	Bogen Bauchlage	3	20	30
Balance	1.	Bergab	3	10 pro Bein	30
	2.	Wadenheber	3	10 pro Bein	30
Cool-down				5min Körperwahrnehmung	

Viel Spaß!

1

Training und Bewegungsanalyse bei Patienten mit Knieendoprothese
endogap Klinik für Gelenkersatz im Klinikum Garmisch-Partenkirchen

Mobility

„Mobility-Training“ verbessert das Zusammenspiel von Muskeln und Gelenken. Ziel der folgenden Übungen ist es, die Gelenke und Muskulatur mit passiven und aktiven Übungen in möglichst große Bewegungsgrade zu mobilisieren. Dadurch wird Muskel- und Fasziengewebe aktiviert und auf die darauf folgenden Kräftigungsübungen vorbereitet.

2

1. Hüftkreisen

Ausgangsposition
Beidbeiniger hüftbreiter Stand, Hände auf den Hüften

Ausführung
Kreisen Sie mit den Hüften im Uhrzeigersinn.

Ziel
10 Wdh pro Richtung

2. Kniekreisen

Ausgangsposition
Beidbeiniger Stand.
Knie leicht gebeugt.

Ausführung
Mit den Knien einen Kreis nachfahren.

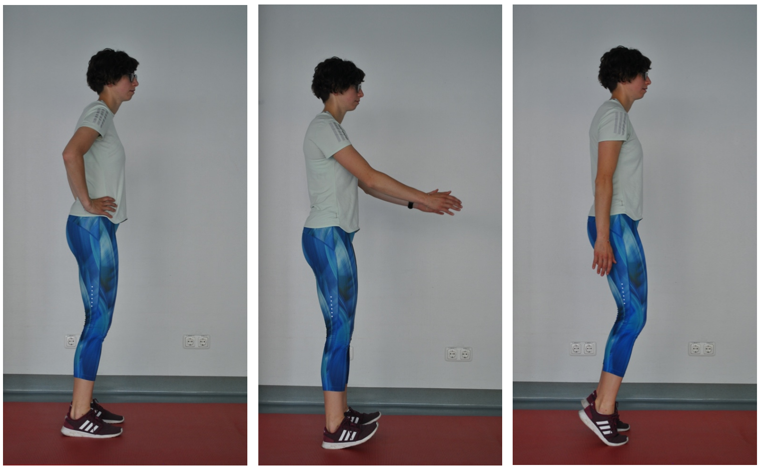
Ziel
10 Wdh pro Richtung

3. Fußwippen

Ausgangsposition
Beidbeiniger Stand

Ausführung
Bewegen Sie ihr Körpergewicht von der Ferse auf die Ballen und wieder zurück.

Ziel
20 Wdh



Training und Bewegungsanalyse bei Patienten mit Knieendoprothese

4. Uhr

Ausgangsposition
Beidbeiniger Stand,
Hände Richtung Decke

Ausführung
Oberkörper locker zur Seite schwingen und über die Mitte zurück in die Ausgangsposition führen.

Ziel
10 Wdh pro Richtung

5. Bogen seitlich

Ausgangsstellung
Beidbeiniger Stand, das vordere Bein überkreuzt das Standbein

Ausführung
Die Arme werden in Richtung des vorderen Beines bewegt.

Ziel
30 sek halten pro Seite

Training und Bewegungsanalyse bei Patienten mit Knieendoprothese

6. Katzenbuckel

Ausgangsstellung
Vierfüßlerstand mit geradem Rücken, Ellbogen leicht gebeugt

Ausführung
Der Rücken wird rund gemacht und dann langsam in die Gegenrichtung bewegt (Hohlkreuz mit leichter Bauchspannung).

Ziel
20 Wdh

Kräftigung

Die folgenden Kräftigungsübungen haben das Ziel die motorischen Kraftfähigkeiten zu verbessern. Dabei wurden Übungen gewählt ,die vor allem zur Verbesserung des Kraftniveaus der Beine und des Rumpfes führen. Alle Übungen werden fast ausschließlich mit dem eigenen Körpergewicht absolviert. Ab Woche 4 kommen vermehrt Übungen mit geringen Zusatzlasten hinzu.

1. Ausfallschritt

Ausgangsstellung:

Ausfallschritt mit geradem Rücken, Gegenstand vor dem Körper.

Ausführung:

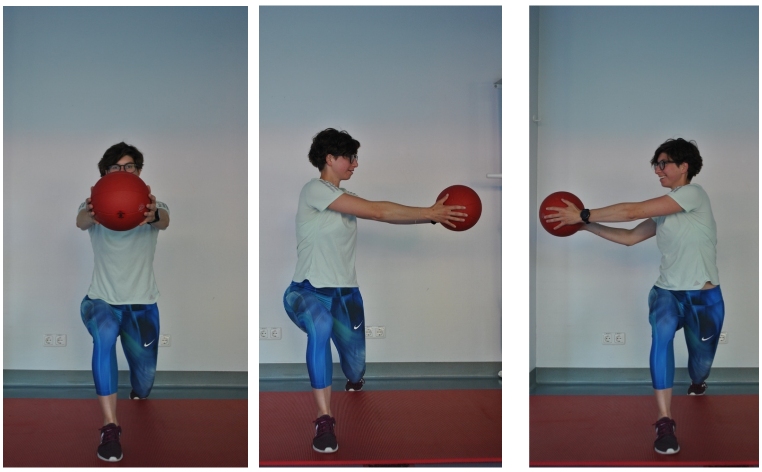
Hinteres Knie absenken bis kurz über dem Boden. Oberkörper in beide Richtungen rotieren.

Ziel:

3 Sätze

10 Wdh pro Bein

30 sek Pause zw. Sätzen



Knie sollte stabil nach vorne gerichtet sein, nicht nach innen/außen rotieren.

2. Muschel

<u>Ausgangsstellung:</u>

Seitlage, beide Beine sind im Hüft- und Kniegelenk leicht angebeugt, Theraband um den unteren Oberschenkel

<u>Ausführung:</u>

Das obere Knie wird in Richtung Decke geführt.

<u>Ziel:</u>

3 Sätze

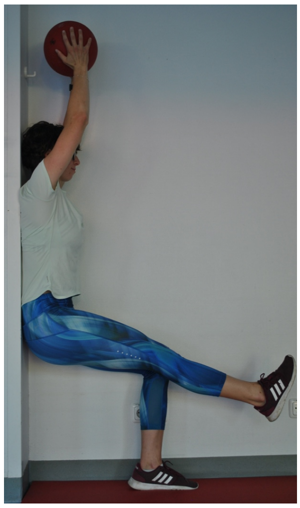
20 Wdh pro Bein

30 sek Pause zw. Sätzen

> Becken bleibt stabil und rotiert nicht nach vorne oder hinten. Beide Fersen halten Kontakt.

!

3. Wand sitzen



<u>Ausgangsposition:</u>

Sitzposition an einer Wand einnehmen. Der Kniewinkel sollte etwas mehr als 90 Grad betragen. Gegenstand über dem Kopf halten.

<u>Ausführung:</u>

Ein Bein anheben und Position halten.

<u>Ziel:</u>

3 Sätze

60 sek halten

30 sek Pause zw. Sätzen

> Gesamter Rücken hält Kontakt zur Wand. Fußsohle des Standbeins komplett am Boden.

!

4. Brücke

Ausgangsstellung:

Rückenlage, beide Beine hüftbreit angestellt, Theraband um den unteren Oberschenkel

Ausführung:

Becken heben, sodass Oberschenkel und Oberkörper eine Linie bilden, dann wieder senken.

Ziel:

3 Sätze

20 Wdh

30 sek Pause zw. Sätzen

Becken sollte stets in einer aufgerichtete Position sein, damit kein Hohlkreuz entsteht.

!

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5. Vierfüßlerstand

Ausgangsstellung

Kniestand mit geradem Rücken, Theraband um den unteren Oberschenkel

Ausführung:

Beide Knie werden ca 5cm über dem Boden angehoben. Oberschenkel gegen die Spannung des Therabandes halten.

Ziel:

3 Sätze

20 Wdh

30 sek Pause zw. Sätzen

Bauchspannung durchgehend halten. Hüfte stabil halten.

!

6. Maikäfer

Ausgangsstellung:

Rückenlage, Beine 90Grad in der Luft gebeugt, Arme halten Theraband gespannt

Ausführung:

Oberkörper abheben. Abwechselnd rechtes und linktes Bein strecken.

Ziel:

3 Sätze

20 Wdh

30 sek Pause zw. Sätzen

Nacken locker lassen. Anheben aus den Bauchmuskeln.

!

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7. Bogen Bauchlage

Ausgangsstellung:

Bauchlage, Arme und Beine gestreckt, Theraband über dem Kopf.

Ausführung:

Kontrolliertes Abheben und Senken von Armen und Beinen. Gleichzeitig ziehen Arme das Theraband auseinander.

Ziel:

3 Sätze

20 Wdh

30 sek Pause zw. Sätzen

Das Schambein wird Richtung Unterlage gedrückt, damit kein Hohlkreuz entsteht

!

Balance

Die letzten zwei Übungen sollen die koordinativen Fähigkeiten schulen. Dabei wird vor allem durch Gleichgewichtsübungen die Tiefenmuskulatur und vielfältige Bereiche des Gehirns stimuliert. Es wird die Fähigkeit den Körper im Gleichgewicht zu halten, oder während Bewungen wieder ins Gleichgewicht zu bringen, trainiert. Somit kann durch ein Balance Training das Sturzrisiko gesenkt werden.

1. Bergab

Ausgangsstellung

Aufrechter Einbeinstand auf einer Erhöhung (Stufe), Theraband unter Standbein fixieren.

Ausführung

Kontrolliertes Absenken und wieder Strecken des Standbeins von der Erhöhung. Arme ziehen gleichzeitigTheraband Richtung Schultern.

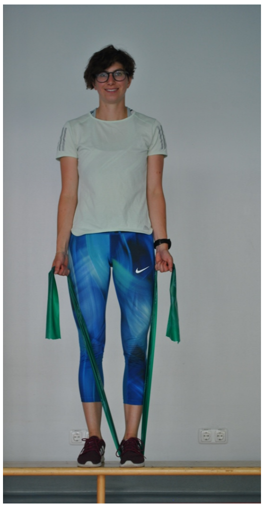
Ziel

3 Sätze

10 Wdh pro Bein

30 sek Pause zw. Sätzen

Knie nicht nach innen/außen rotieren. !



2. Wadenheber

Ausgangsposition

Einbeinstand auf unebenen Untergrund (zB Handtuch).

Ausführung

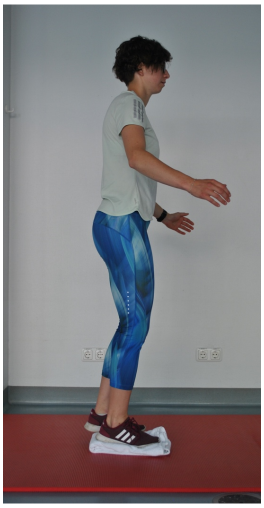
Standbein heben und senken. Gleichgewicht halten.

Ziel

3 Sätze

30 sek pro Bein

30 sek Pause zw. Sätzen



The Oxford Happiness Questionnaire (German Version)

Oxford Happiness Questionnaire

Nachstehend finden Sie eine Reihe von Aussagen über das Lebensglück. Bitte geben Sie an, inwieweit Sie zustimmen oder nicht zustimmen, jeweils durch die Eingabe einer Zahl in das leere Feld nach jeder Aussage in der folgenden Auflistung.

1. = stimmt absolut nicht
2. = stimmt häufig nicht
3. = stimmt teilweise nicht
4. = stimmt ein wenig
5. = stimmt häufig
6. = stimmt absolut

Wenn Ihnen die genaue Beantwortung einer Frage schwerfällt, geben Sie bitte jene Antwort, die für Sie im Allgemeinen oder die meiste Zeit wahr ist.

Bitte lesen Sie sich die Aussagen genau durch, weil einige positiv und andere negativ formuliert sind. Denken Sie dabei nicht zu lange über Ihre Antworten nach, es gibt keine "richtigen" oder "falschen" Antworten (und auch keine Fangfragen). Die erste Antwort, die Ihnen einfällt, ist wahrscheinlich die richtige für Sie.

	1	2	3	4	5	6
Ich fühle mich nicht besonders wohl mit der Art, wie ich bin. (R)						
Ich bin intensiv an anderen Menschen interessiert.						
Ich fühle, dass das Leben sehr lohnend ist.						
Ich habe sehr positive Gefühle für fast jeden						
Ich wache selten ausgeruht auf. (R)						
Ich bin wenig optimistisch, was die Zukunft angeht. (R)						
Ich finde die meisten Dinge amüsant.						
Ich bin immer wieder engagiert und involviert.						
Das Leben ist gut.						
Ich glaube nicht, dass die Welt ein guter Ort ist. (R)						
Ich lache viel.						
Ich bin über alles in meinem Leben zufrieden.						
Ich glaube nicht, dass ich attraktiv bin. (R)						

Es besteht eine Kluft zwischen, was ich tun möchte und dem, was ich getan habe. (R)						
Ich bin sehr glücklich.						
Ich finde Schönheit in einigen Dingen.						
Ich habe immer eine fröhliche Wirkung auf andere.						
Ich finde Zeit für alles, was ich will.						
Ich fühle, dass ich nicht besonders viel Kontrolle über mein Leben habe. (R)						
Ich fühle mich in der Lage, egal was es ist, anzugehen.						
Ich fühle mich geistig rege und wach.						
Ich erlebe oft Freude und Hochgefühle.						
Ich finde es nicht leicht, Entscheidungen zu treffen. (R)						
Ich habe keinen Sinn und Zweck in meinem Leben. (R)						
Ich habe das Gefühl, sehr viel Energie zu haben.						
Ich habe einen guten Einfluss auf das Geschehen.						
Ich habe keinen Spaß mit anderen Menschen. (R)						
Ich fühle mich nicht besonders gesund. (R)						
Ich habe keine sehr glücklichen Erinnerungen. (R)						

German Version of the Oxford Knee Score and Visual Analogue Scale adapted by Endogap Clinic Garmisch-Partenkirchen

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Akademisches Lehrkrankenhaus der Ludwig-Maximilians-Universität München endogap Klinik für Gelenkersatz

Chefarzt Dr. med. Christian Fulghum
Leitender Arzt Dr. med. Rolf Schipp
Leitender Arzt Dr. med. Florian Wolpert
Leitender Arzt Wolfgang Reng

PROMS
Patientenfragebogen - Knie

______________________ ______________________
Name des Patienten Datum

______________ ________ ________
Geburtsdatum Größe Gewicht

Die Fragen beziehen sich auf Ihren aktuellen Gesundheitszustand nur auf das aktuell betroffene Gelenk.
Bitte wählen Sie das Feld, welches Ihre Situation derzeit am besten beschreibt und markieren Sie bitte bei jeder Frage genau eine Antwortmöglichkeit.

Schmerz

1. Haben Sie Schmerzen

1 Keine Schmerzen

2 Geringe Schmerzen ohne Beeinträchtigung im Alltag oder selten nächtlicher Schmerz oder nur nach langem Sitzen

3 mittlere Schmerzen, gelegentlich Medikamente nötig oder unregelmäßig nächtlicher Schmerz oder Schmerzen nach dem Sitzen

4 Schmerzen mit Beeinträchtigung im Alltag, regelmäßig Medikamente nötig oder meist Nachtschmerz, starke Schmerzen nach dem Sitzen

5 starke Schmerzen mit wesentlicher Einschränkung, immer Nachtschmerz oder stärkste Schmerzen nach dem Sitzen

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Aktivität des täglichen Lebens

2. Können Sie schuhe oder Socken an- / ausziehen?

- 1 ohne Schwierigkeiten
- 2 mit geringen Schwierigkeiten
- 3 mit mittleren Schwierigkeiten
- 4 sehr beschwerlich
- 5 nicht möglich

3. Können Sie ihre Körperpflege und Toilettengang selbst verrichten?

- 1 ohne Schwierigkeiten, keine Hilfe nötig
- 2 mit geringen Schwierigkeiten
- 3 mit mittleren Schwierigkeiten, geringe Hilfe nötig
- 4 Große Schwierigkeiten
- 5 Unselbstständig, immer Hilfe benötigt

4. Wie lange können Sie sitzen, können Sie vom Stuhl aufstehen?

- 1 Unbegrenzt sitzen, ohne Schwierigkeiten aufstehen,…
- 2 Kann lange sitzen, geringe Beschwerden beim Aufstehen
- 3 Kann länger sitzen, Aufstehen mit Hilfe
- 4 Kann kurze Zeit sitzen, Aufstehen mit Hilfe
- 5 Kann kaum sitzen, Aufstehen unselbstständig

5. Sehen Sie sich derzeit in der Lage in ein KFZ ein- bzw. auszusteigen oder öffentliche Verkehrsmittel zu benutzen?

- 1 Ja, uneingeschränkt
- 2 Wenige Probleme
- 3 Mäßige Probleme
- 4 Starke Probleme
- 5 Nein, nicht möglich

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Mobilität

6. Benötigen Sie Gehhilfen?

- 1 Nein
- 2 Unterarmgehstützen
- 3 Rollator / Gehbock
- 4 Rollstuhl
- 5 bettlägrig

7. Müssen Sie wegen des betroffenen Knies hinken?

- 1 Kein Hinken
- 2 Manchmal, geringes Hinken nur für wenige Schritte
- 3 Oft und dann länger oder mittleres Hinken
- 4 Meistens oder starkes Hinken
- 5 Immer oder starkes Hinken

8. Können Sie Treppen über eine Etage auf- und abwärts steigen?

- 1 Ja, keine Probleme
- 2 Wenig Probleme
- 3 Mäßig Probleme, Geländer nötig
- 4 Starke Probleme
- 5 Unmöglich

9. Wie lange oder wie weit können Sie ohne Beschwerden gehen? (mit oder ohne Gehhilfen?

- 1 unbegrenzt
- 2 Gehen am Stück bis 2km bzw. 15-30 Minuten möglich
- 3 Gehen am Stück bis 500m bzw. 5-15 Minuten möglich
- 4 Im Zimmer mobil
- 5 Gehen nicht möglich

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10. Sehen Sie sich in der Lage, sich hinzuknien und wieder aufzustehen?

- 1 problemlos
- 2 Wenig Probleme
- 3 Mäßige Probleme
- 4 Starke Probleme
- 5 unmöglich

11. Fühlen Sie sich durch ihre Kniebeschwerden ihr Alltagsbeschäftigungen, wie Hausarbeit, Einkauf oder in Ihrer Berufsausübung eingeschränkt?

- 1 Gar nicht
- 2 wenig
- 3 mäßig
- 4 stark
- 5 extrem

12. Werden Sie durch Ihre Knieschmerzen in der Nachtruhe gestört?

- 1 Nie
- 2 Selten
- 3 Gelegentlich
- 4 Meistens
- 5 Immer

13. Können Sie schwere Tätigkeiten ausüben oder länger als eine Stunde stehen?

- 1 Ja, keine Probleme
- 2 Wenige Probleme
- 3 Mäßige Probleme
- 4 Starke Probleme
- 5 Nicht möglich

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14. Sehen Sie sich in der Lage zu Laufen oder zu Joggen?

- 1 Problemlos, auch auf unebenen Grund
- 2 keine Probleme auf ebenen Grund, mittlere Probleme auf unebenem Grund
- 3 Mittlere Probleme
- 4 Starke Probleme
- 5 Kann nicht laufen bzw. joggen

15. Sehen Sie sich in der Lage schnelle Wendungen während des Laufens zu machen oder zu springen?

- 1 Ja, keine Probleme
- 2 Wenig Probleme
- 3 Mäßige Probleme
- 4 Starke Probleme
- 5 nein

Allgemeinzustand

16. Fühlen Sie sich ängstlich oder deprimiert?

- 1 Nein
- 2 Wenig
- 3 Mäßig
- 4 Stark
- 5 Extrem

17. Geben Sie ihren heutigen Gesundheitszustand auf einer Skala von 0-100 an Der beste denkbare Gesundheitszustand ist mit 100 zu bewerten, der schlechteste mit 0.

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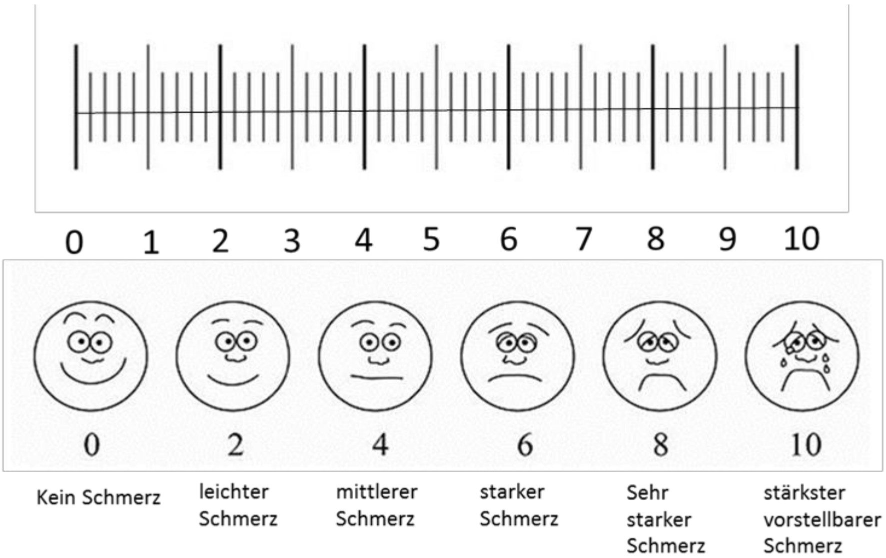
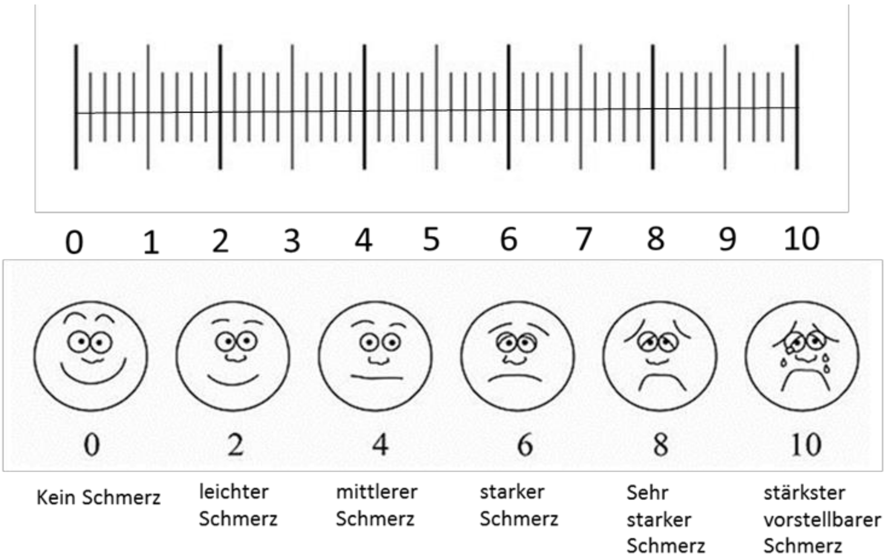
18. Geben Sie Ihren aktuellen Schmerz in Ruhe an



19. Geben Sie Ihren aktuellen Schmerz in Belastung / Bewegung an



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WHO-BREF26 Questionnaire (German Version)

WHO Lebensqualität Pat ID_________ Datum_______

Bitte lesen Sie jede Frage, überlegen Sie, wie Sie sich in den vergangenen zwei Wochen gefühlt haben, und kreuzen Sie das Kästchen auf der Skala an, das für Sie am ehestens zutrifft. Wenn Sie sich bei der Beantwortung einer Frage nicht sicher sind, wählen Sie bitte die Antwortkategorie, die Ihrer Meinung nach am ehesten zutrifft. Oft ist dies die Kategorie, die Ihnen als erstes in den Sinn kommt.

		sehr schlecht	schlecht	mittel-mäßig	gut	sehr gut
1	Wie würden Sie Ihre Lebensqualität beurteilen?	☐	☐	☐	☐	☐
		sehr un-zufrieden	un-zufrieden	weder zufrieden noch un-zufrieden	zufrieden	sehr zufrieden
2	Wie zufrieden sind Sie mit Ihrer Gesundheit?	☐	☐	☐	☐	☐

In den folgenden Fragen geht es darum, wie stark Sie während der vergangenen zwei Wochen bestimmte Dinge erlebt haben.

		überhaupt nicht	ein wenig	mittel-mäßig	ziemlich	äußerst
3	Wie stark werden Sie durch Schmerzen daran gehindert, notwendige Dinge zu tun?	☐	☐	☐	☐	☐
4	Wie sehr sind Sie auf medizinische Behandlung angewiesen, um das tägliche Leben zu meistern?	☐	☐	☐	☐	☐
5	Wie gut können Sie Ihr Leben genießen?	☐	☐	☐	☐	☐
6	Betrachten Sie Ihr Leben als sinnvoll?	☐	☐	☐	☐	☐
7	Wie gut können Sie sich konzentrieren?	☐	☐	☐	☐	☐
8	Wie sicher fühlen Sie sich in Ihrem täglichen Leben?	☐	☐	☐	☐	☐
9	Wie gesund sind die Umweltbedingungen in Ihrem Wohngebiet?	☐	☐	☐	☐	☐

In den folgenden Fragen geht es darum, in welchem Umfang Sie während der vergangenen zwei Wochen bestimmte Dinge erlebt haben oder in der Lage waren, bestimmte Dinge zu tun.

		überhaupt nicht	ein wenig	mittel-mäßig	ziemlich	äußerst
10	Haben Sie genug Energie für das tägliche Leben?	☐	☐	☐	☐	☐
11	Können Sie Ihr Aussehen akzeptieren?	☐	☐	☐	☐	☐
12	Haben Sie genug Geld, um Ihre Bedürfnisse erfüllen zu können?	☐	☐	☐	☐	☐
13	Haben Sie Zugang zu den Informationen, die Sie für das tägliche Leben brauchen?	☐	☐	☐	☐	☐
14	Haben Sie ausreichend Möglichkeiten zu Freizeitaktivitäten?	☐	☐	☐	☐	☐
		sehr schlecht	schlecht	mittel-mäßig	gut	sehr gut
15	Wie gut können Sie sich fortbewegen?	☐	☐	☐	☐	☐

In den folgenden Fragen geht es darum, wie zufrieden, glücklich oder gut Sie sich während der vergangenen zwei Wochen hinsichtlich verschiedener Aspekte Ihres Lebens gefühlt haben.

		sehr un-zufrieden	un-zufrieden	weder zufrieden noch un-zufrieden	zufrieden	sehr zufrieden
16	Wie zufrieden sind Sie mit Ihrem Schlaf?	□	□	□	□	□
17	Wie zufrieden sind Sie mit Ihrer Fähigkeit, alltägliche Dinge erledigen zu können?	□	□	□	□	□
18	Wie zufrieden sind Sie mit Ihrer Arbeitsfähigkeit?	□	□	□	□	□
19	Wie zufrieden sind Sie mit sich selbst?	□	□	□	□	□
20	Wie zufrieden sind Sie mit Ihren persönlichen Beziehungen?	□	□	□	□	□
21	Wie zufrieden sind Sie mit Ihrem Sexualleben?	□	□	□	□	□
22	Wie zufrieden sind Sie mit der Unterstützung durch Ihre Freunde?	□	□	□	□	□
23	Wie zufrieden sind Sie mit Ihren Wohnbedingungen?	□	□	□	□	□
24	Wie zufrieden sind Sie mit Ihren Möglichkeiten, Gesundheitsdienste in Anspruch nehmen zu können?	□	□	□	□	□
25	Wie zufrieden sind Sie mit den Beförderungsmitteln, die Ihnen zur Verfügung stehen?	□	□	□	□	□

In der folgenden Frage geht es darum, wie oft sich während der vergangenen zwei Wochen bei Ihnen negative Gefühle eingestellt haben, wie zum Beispiel Angst oder Traurigkeit.

		niemals	nicht oft	zeitweilig	oftmals	immer
26	Wie häufig haben Sie negative Gefühle wie Traurigkeit, Verzweiflung, Angst oder Depression?	□	□	□	□	□

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Declaration on Honor

Hiermit versichere ich, dass ich die vorliegende Arbeit selbstständig verfasst und keine anderen Hilfsmittel als die angegebenen verwendet habe. Die Stellen, die anderen Werken (gilt ebenso für Werke aus elektronischen Datenbanken oder aus dem Internet) wörtlich oder sinngemäß entnommen sind, habe ich unter Angabe der Quelle und Einhaltung der Regeln wissenschaftlichen Zitierens kenntlich gemacht. Diese Versicherung umfasst auch in der Arbeit verwendete bildliche Darstellungen, Tabellen, Kartenskizzen und gelieferte Zeichnungen. Mir ist bewusst, dass Täuschungen nach der für mich gültigen Studien- und Prüfungsordnung geahndet werden. Die Arbeit wurde bisher weder im In- noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde vorgelegt

Ort, Datum

Unterschrift der Verfasserin