DORIS VAHTRIK

Leg muscle function in relation to
gait and standing balance following
total knee arthroplasty in women

DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS

38

DORIS VAHTRIK

Leg muscle function in relation to
gait and standing balance following
total knee arthroplasty in women

Institute of Exercise Biology and Physiotherapy, University of Tartu, Tartu, Estonia

European Union
European Social Fund

Investing in your future

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original papers, which will be referred to in the text by Roman numerals (I–III):

I. **Vahtrik D., Gapeyeva H., Aibast H., Ereline J., Kums T., Haviko T., Märtson A., Schneider G., Pääsuke M.** Quadriceps femoris muscle function prior and after total knee arthroplasty in women with knee osteoarthritis. *Knee Surgery, Sports Traumatology, Arthroscopy,* 2012, 20 (10):2017–2025.

II. **Vahtrik D., Gapeyeva H., Ereline J., Pääsuke M.** Relationship between leg extensor muscle strength and knee joint loading during gait before and after total knee arthroplasty. *The Knee*, 2014, 21 (1):216–220.

III. **Vahtrik D., Gapeyeva H., Ereline J., Pääsuke M.** Postural stability in relation to anthropometric and functional characteristics in women with knee osteoarthritis following total knee arthroplasty. *Archives of Orthopaedic and Trauma Surgery*, 2014, 134 (5): 685–692.

The contribution of the dissertant to the completing the doctoral thesis:

Paper I–III. The dissertant had primary responsibility for protocol development, subject screening, performing measurements, preliminary and final data analysis, and writing of the manuscripts.

ABBREVIATIONS

AROM	−	active range of motion
BM	−	body mass
BMI	−	body mass index
COP	−	centre of pressure
GRF	−	ground reaction forces
HRT	−	half-relaxation time
KOOS	−	Knee injury and Osteoarthritis Outcome Score
LATc	−	latency of contraction
MRI	−	magnetic resonance imaging
MVC	−	maximal voluntary contraction
OA	−	osteoarthritis
QF	−	quadriceps femoris
ROM	−	range of motion
RFD	−	rate of isometric force development
TKA	−	total knee arthroplasty
VA	−	voluntary activation
VAS	−	visual analog scale
WOMAC	−	Western Ontario and McMaster Universities osteoarthritis index

1. INTRODUCTION

Osteoarthritis (OA) is a degenerative joint disease that progressively causes loss of joint function with the decline of physical activity and quality of life (Krasnokutsky et al., 2008). Despite that most currently recognized risk factors for prevalent knee joint OA are obesity, knee injury and selected physical activities (Cooper et al., 2000), the major risk factor in both males and females is aging (Buchanan and Kean, 2002).

Although several treatment options are available, total knee arthroplasty (TKA) is the end-stage treatment of knee joint arthritis (Berth et al., 2007). Approximately a half-million Americans (Krasnokutsky et al., 2008), 39 000 Australians (March and Bagga, 2004) and approximately 3000 Estonians (Estonian Health Insurance Fund, 2012) undergo total joint replacement surgery every year- corresponding characteristics are expected to rise with the continued expanding and aging population. Therefore the primary and secondary prevention strategies- to reduce obesity, prevent injuries and to improve rehabilitation and physical activity, are important to reduce the levels of functional disability and demand for total joint replacement surgery (March and Bagga, 2004).

In patients with knee joint OA, orthopedic assessment of the knee pain, knee range of motion, muscle strength and endurance testing, postural balance, proprioception and gait function evaluation are important. The outcome after TKA can be assessed by visual analog scale (VAS), Knee Society Scoring system (KSS), Western Ontario and McMasters Universities Osteoarthritis Index (WOMAC) (Bullens et al., 2001) or KOOS score (Knee injury and Osteo-arthritis Outcome Score) (Roos, Toksvig-Larsen, 2003). Due to limitations of physical activity, the knee joint OA is strongly associated with weakness of quadriceps femoris (QF) muscle (Hurley, 2003; Mizner et al., 2005a). Despite positive outcomes associated with TKA, which reduce knee pain and improve the functional properties, full recovery of the muscle strength and physical function to a normal level is rare (Valtonen et al., 2009; Maffiuletti et al., 2010). Many studies have confirmed that weakness of the QF muscle persists even years after surgery (Mizner et al., 2005b; Rossi et al., 2007; Valtonen et al., 2009; Zeni and Snyder-Mackler 2010). There exists an opinion that the lack of clinical benefit is due to the low exercise intensity tolerated at the postoperative period (Lin et al., 2009). Therefore the understanding of muscle dysfunction in OA knees still remains speculative (Dixon and Howe, 2005), and it is also unclear how extensive is the lack of central drive to the muscle during contraction.

OA of the knee joint affects also the major biomechanical factors ensuring the optimal load to the joint during walking (Hunt et al., 2010a). Biomechanical factors may play a part in the modulation of knee joint pathogenesis (Amin et al., 2004), in which large knee adduction moment and higher joint dynamic load during gait are mostly related to the severity of tibiofemoral OA (Winby et al., 2009; Alnahdi et al., 2011). Despite that several studies refer improvements in

gait's temporospatial parameters' following TKA (Huang et al., 2007; Yoshida et al., 2008; Milner, 2009), inter-limb differences in knee kinematics and moments persist if compared to healthy controls. Because only few studies have provided data on the relative force demands on lower limb muscles and joints during gait (Reguião et al., 2005), therefore, it is informative to investigate the relationship between the entire leg muscles' strength and knee joint loading during gait in patients with knee joint OA without and with knee prosthesis.

There are controversial data about postural stability and its impact on anthropometric and functional characteristics in patients with knee joint OA. Poor postural stability is the result of proprioceptive deficit, muscle weakness and knee pain (Hassan et al., 2001), which in turn leads to a greater body sway during standing in knee joint OA patients (Hinman et al., 2002). However, there is study reporting, that the subjects with knee joint OA doesn't not have any standing balance deficit (Lyytinen et al., 2010).

The first part of the present study was designed to assess isometric maximal and explosive strength, voluntary activation, and the capacity of rapid voluntary contraction and relaxation of the QF muscle prior, 3 and 6 months following TKA. The second part of the study measured isometric strength of the leg extensor muscles, knee joint loading during mid stance of gait and their possible relationship prior and after TKA. In the third part of the study the standing balance in relation to anthropometric and functional characteristics were investigated in patients with knee joint OA before and three and six months after TKA.

2. REVIEW OF LITERATURE

2.1. Definition, epidemiological and etiological aspects of osteoarthritis of the knee joint

OA is the most common form of arthritis (Kean et al., 2004). There is no agreed definition of OA, and also no agreement on the term to designate the disease. Many researchers prefer to determine the OA with degenerative joint disease. The term "osteoarthrosis" has been replaced by "osteoarthritis", because different histological, biochemical and radionuclude studies have shown the evidence of synovial inflammation (Buchanan and Kean, 2002).

OA of the knee joint is a degenerative and chronic disease characterized by a loss of joint cartilage tissue, subchondral cysts, meniscal tears, edema, degenerative changes of the capsular ligamentous supporting structures, and osteophyte formation (Buchanan and Kean, 2002). The clinical symptoms of OA of the knee include knee joint stiffness, pain, dysfunction (Kean et al., 2004) and joint crepitus (Altman, 1987).

OA is known as one of the oldest diseases in planet, which has been affecting already prehistoric animals, it has been found in Egyptian mummies and in all races, regardless of the geographical area (Buchanan and Kean, 2002). The prevalence of OA increases with age, where symptomatic OA is uncommon in people under age of 40 (5%). The prevalence of the disease increase to 10% of men and 20% of women in age 45–65 and more than 50% of women aged 85 years and over (March and Bagga, 2004).

OA of the knee joint is one of the major causes of pain and physical disability among older adults (Cooper, 1998). A World Health Organization report on the global burden of disease indicates that OA of the knee joint is likely to become the fourth most important cause of disability after cardio-vascular, respiratory diseases and cancers in women, and the eighth most important cause in men. OA of the knee joint include the female preponderance with the effects of obesity and age (Hart et al., 1999). It is recognized that OA of the knee joint is associated with an increase of body weight in women ($P = 0.0014$), but not in men (Slemenda et al., 1998). The primary prevention of OA of the knee joint should become a major aim of health care, which strategies requires a clear understanding of the risk factors for the disorder (Murray and Lopez, 1997).

The etiology of OA is multifactorial- the most important risk factors for prevalent of OA of the knee joint are obesity, selected physical activities, the presence of hand OA (Heberden's nodes) and a family history of the disease (Cooper et al., 2000). Female sex, lower educational level, joint malalignment and poor muscular strength have been shown to be risk factors for developing knee joint OA symptoms and disability as well (Felson and Zhang, 1998). Traumatic sports injuries to the knee joint may be significant precursor events to early onset of posttraumatic OA (Quatman et al., 2011).

OA is classified as idiopatic or primary, when the origin of the disease is unknown and secondary, if the disease is related to a known medical condition or event (Altman, 1987). Some causes of secondary OA are congenital dislocation of the hips, trauma involving the joint or nearby bone causing malalignment, rheumatoid arthritis, septic arthritis, avascular necrosis, Charcot's arhropathy, Paget's disease (Buchanan and Kean, 2002).

Diagnosis of OA has been based most often on radiographic appearance-joint space narrowing, tissue reaction about the joint, synovial effusions, bone changes at the joint margin; alterations of subchondral bone refer to OA. Computed tomography (CT) identifies also aseptic necrosis of the bone, magnetic resonance imaging (MRI) allows non-radiographic imaging of articular cartilage (Altman, 1987). Despite the fact that different scoring systems have been published, the Kellgren-Lawrence (KL) scale is the most commonly used radiographic grading scale assessing morphological change of hip and knee (Günther and Sun, 1999). Kellgren and Lawrence (1957) divided OA into 4 grades: the formation of osteophytes on the joint margins (grade 1); periarticular ossicles (grade 2); narrowing of joint cartilage associated with sclerosis of subchondral bone (grade 3); small pseudocystic areas with sclerotic walls situated in the subchondral bone (grade 4).

It has been identified, that previously named risk factors influence the incidence of OA of the knee joint more than radiographic progression (Cooper et al., 2000). Therefore, not all radiological OA is associated with clinical symptoms, and not all symptomatic OA is associated with disability (March and Bagga, 2004). 50% of patients with radiographic knee joint OA do not have pain and 50% of patients (older than 55 years) complaining the knee pain, have no definite radiographic evidence of OA (McAlindon et al., 1992). The radiographic changes can be classified according to disease severity and to their location within the joint- the two tibiofemoral joint compartments, the patello-femoral joint (Peat et al., 2001).

The cause of the knee pain in patients with knee joint OA is unknown (Felson et al., 2001). Although there are no pain receptors in the cartilage, the origin of the pain is thought to be due to stimulation of the A delta mechano-receptors and the C polymodal nerve endings in the synovium and surrounding tissues (Kean et al., 2004). Knee pain can cause bone marrow lesions and pain fibers in the bone. Bone marrow lesions were found in 77.5% persons with painful knees compared with 30% persons with no knee pain. Bone marrow lesions on MRI are strongly associated with the presence of pain in OA of the knee joint (Felson et al., 2001). However, some of the knee pain experienced in and around the joints is referred pain or sympathetic efferent pain (Kean et al., 2004).

Knowledge's of knee joint neurophysiology, joint anatomy, pathogenesis of OA, clinical signs and symptoms, imaging techniques and response to therapeutic agents are necessary tools to the understanding of the diagnosis and safe management of knee joint OA (Buchanan and Kean, 2002).

2.2. Treatment of osteoarthritis of the knee joint

2.2.1. Conservative treatment

The aim of the knee joint OA treatment is to reduce joint pain and stiffness, maintain or improve joint mobility, reduce physical disability or handicap, improve health-related quality of life, limit the progression of joint damage and educate patients about the nature of the disorder and its management (Zhang et al., 2008).

The treatment of symptomatic OA is a global problem, causing challenges to clinical skills and judgements for health professionals around the world (Zhang et al., 2007). There is no single treatment modality relieving joint pain. In addition to pharmacological treatment options, the nonpharmacologic interventions improve the quality of life as well. OA Research Society International (OARSI) has been published an update recommendations for the treatment of the knee and hip joint OA. Appropriate treatment modalities for all individuals with knee joint OA contain biomechanical interventions, intra-articular corticosteroids, exercise (land-based and water-based), self-management and education, strength training, and weight management (McAlindon et al., 2014). Nonpharmacologic measures such as weight loss, muscle strengthening exercises, and joint protection techniques have no inherent risk and minimal costs, and are therefore advised for all patients (Fraenkel et al., 2004). In addition to the above mentioned treatments, core recommendations for non-pharmacological treatment include also patients contact by telephone and provision of walking aids (Zhang et al., 2007). However, it has been found that regular telephone contact alone through psychosocial effect did not reduce knee pain (Thomas et al., 2002). Appropriate treatments for specific clinical subphenotypes include acetaminophen (paracetamol), balneotherapy, capsaicin, duloxetine, oral non-steroidal anti-inflammatory drugs (NSAIDs) (COX-2 selective and non-selective) and topical NSAIDs (McAlindon et al., 2014). Despite that paracetamol is an effective and safe agent for mild to moderate pain relief due to OA; it is less effective than NSAIDs, which are recommended to use at the lowest effective dose (Zhang et al., 2008).

There are several treatment modalities which effect is uncertain, like- acupuncture, avocado, soybean, rosehip, chondroitin, diacerein, glucosamine, intra-articular hyaluronic acid, opioids (oral and transdermal), crutches, transcutaneous electrical nerve stimulation and ultrasound. Not appropriate therapy in knee joint OA treatment is neuromuscular electrical stimulation (McAlindon et al., 2014).

Based on the fact that each of the therapy has only limited efficacy, effective management relies on the appropriate use of a number of available therapies (Zhang et al., 2007). In many cases, knee joint OA is relatively mild, and patients often stabilize with respect to pain and disability, adapting to the condition without needing large health care resources (Cooper et al., 2000). There exists an opinion that the combination of manual physical therapy and

supervised exercise yields functional benefits for patients with knee joint OA, which may delay or prevent the need for surgical intervention (Deyle et al., 2000). Whereas muscles are physiologically elastic tissues, which can be exercised to improve strength and endurance even in very elderly people, rehabilitation regimens addressed muscle dysfunction, might prevent or alleviate some of the problems associated with OA (Hurley, 2003). Exercise participation prior TKA dramatically reduces the odds of inpatient rehabilitation (Rooks et al., 2006).

2.2.2. Operative treatment

Surgical therapies are available for patients who fail to respond to more conservative therapy (Walker-Bone et al., 2000). The most common surgical methods in OA treatment are knee aspiration, joint lavage, osteotomy, knee fusion and total joint replacements (Zhang et al., 2007).

Arthroscopy is a diagnostic procedure, which enables the evaluation of the exact stage of OA (Hoffmann et al., 2010). During arthroscopy the joint lavage allows to remove joint debris, reduce the concentration of inflammatory substances in the knee, smooth cartilage lesions, release the ligaments, and perform meniscectomy or synovectomy (Spahn et al., 2013). In patients, the joint arthroscopy is a potential and sufficient treatment for middle stage of the knee joint OA, which results are an excellent or good in approximately 60% of patients in approximately 5 years (Spahn et al., 2013). According to KL scale, the good results were found in 85% of patients with KL grade II, 53% of patients with KL grade III and only 35% of patients with KL grade IV (Aaron et al., 2006). There has been found the correlation between the patient's age and outcome of arthroscopy- patients more than 60 years old have significantly worse postoperative results (Steadman et al. 2007). In contrast, it has been suggested that joint arthroscopy has a very short-term effect on pain relief or improvement of function (Reichenbach et al., 2010). It has been proposed that arthroscopic joint debridement can be combined with other types of treatment, such as osteotomies or cartilage- restoring techniques (drilling, abrasion, microfracturing, autologous chondrocyte implementation) (Spahn et al., 2013). Whereas there are no interventions proven to reduce cartilage or reduce the disease processes (Krasnokutsky et al., 2008), the patients must be informed that arthroscopy is not a definitive treatment as the progression of OA continues after arthroscopy (Spahn et al., 2013).

However, a proportion of patients progress to severe joint damage, pain, and disability, requiring joint replacement (Cooper et al., 2000). TKA is the end-stage treatment of knee arthritis (Berth et al., 2007). Despite the fact that term TKA indicates that knee is totally replaced, only joint is resurfaced- the cartilage surfaces are removed and replaced with metal and plastic components, the overall shape and structure of bones are maintained (Brugioni and Falkel, 2004).

During TKA surgery, the femoral condyles are replaced with metal, tibial plateau with the combination of plastic and metal components, and kneecap is

resurfaced with a round plastic "button". Knee surrounding tendons, ligaments and muscles are all preserved during the procedure. The choice of prosthesis type is based on surgeon preference and experience. The most common types of prostheses used for primary TKA are an unconstrained artificial joint, mobile bearing knee arthroplasty and posterior stabilized total knee arthroplasty. Fixation of the prosthetic components to the bone is done either with or without cement according to patient' s bone quality, age, and demands of the patient (Brugioni and Falkel, 2004).

In conclusion, despite positive outcomes associated with TKA, which reduce pain and improve the functional properties, full recovery of the muscle strength and physical function to a normal level is rare (Valtonen et al., 2009; Maffiuletti et al., 2010).

2.2.3. Postoperative rehabilitation

In patients with knee joint OA, postoperative rehabilitation starts as soon as possible after surgery. In recovery room it is possible that continuous passive movement (CPM) machine provides the movement of the new TKA. Usually during the first day after surgery a physical therapists supervises patient's knee range of motion (ROM), straight-leg raise, breathing exercises, transferring in the bed and out of the bed and walking with assistive device. The information about ice and leg elevation to control the swelling and pain in the knee and scar management principles are very important (Brugioni and Falkel, 2004). The average period of hospital stay is approximately 5 days.

Postoperative rehabilitation continues in the local rehabilitation hospital, in outpatient department or in patient's home. The adequate rehabilitation of patients with knee joint OA has to include a variety of ROM exercises, strengthening and stretching exercises (Deyle et al., 2005) movement control, balance and coordination exercises (Hurley, 2003), exercises to address motor (Roddy et al., 2005) and sensory deficits (Lin et al., 2007). Exercises should improve muscle strength and endurance, the control of movement, balance and coordination. It is also important that exercises could be converted into functional performance by practicing common activities of daily living (ADL) (Hurley, 2003). Group exercises and home exercises are equally effective and considered important by patient preference (Roddy et al., 2005). However, there is a study confirming no benefit in anterior cruciate injuries rehabilitation programme supervised by a physiotherapist compared to an unsupervised cohort (Hohmann et al., 2011). A simple home based exercise programme can reduce knee pain remarkably (Thomas et al., 2002). To improve the overall muscular and cardiovascular endurance cycling, walking, skiing or swimming are recommended (Brugioni and Falkel, 2004).

Despite that one year after TKA vast majority of patients can do almost anything they want, potential complications of TKA are exist: medical complications such heart, kidney, lung diseases and diabetes mellitus; surgical complications such as infection, joint stiffness, problems with wound healing, thromboembolism, neurovascular complications and revision of the TKA

(Brugioni and Falkel, 2004). TKA complications after post-traumatic arthrosis has been occurred in 57% of cases, including aseptic failure (26%), septic failure (10%), patellar tendon rupture (3%), patellar subluxation (6%), thromboembolism (6%), and wound breakdown requiring debridement and muscle flap coverage (6%) (Lonner et al., 1999).

2.3. Quadriceps femoris muscle function in patients with osteoarthritis of the knee joint

The function of QF muscles after TKA is a complex multifactorial issue (Greene and Schurman, 2008). The assessment of voluntary force production and relaxation capacity of QF muscle is an important outcome in the measurement of musculoskeletal disorders (Knight and Kamen, 2001; Todd et al., 2004; Mizner et al., 2005a; Maffiuletti et al., 2010). Despite the fact that there are many studies about the strength of QF muscle (O'Reilly et al., 1998; Andersen and Aagaard, 2006; Berth et al., 2007; Maffiuletti et al., 2010), the understanding of muscle dysfunction in OA knees still remains speculative (Dixon and Howe, 2005). Changes in periarticular muscles and the nerves controlling the QF muscle have received less attention (Hurley, 2003). Many studies have confirmed that weakness of the QF muscle persists even years after surgery (Mizner et al., 2005b; Rossi et al., 2007; Valtonen et al., 2009; Zeni and Snyder-Mackler, 2010), but it is still unclear why muscle strength does not recover after TKA and how extensive is the lack of central drive to the muscle during contraction.

Muscle contraction requires both central and peripheral activation process. The failure of central activation may reduce the force output of a muscle or not recruit all motor units during maximal voluntary contraction (MVC) (Stackhouse et al., 2000; Morton et al., 2005). Neuromuscular dysfunction may have serious consequences on the articular function (Hurley, 2003). The extent of central activation is rarely taken into consideration when assessing maximal muscle force. Changes occurring in periarticular muscles and the nerves controlling them have also received less attention (Hurley, 2003). It is difficult to ascertain whether post-exercise reduction in force represents structural damage to the muscle or is simply a reduction in voluntary drive (Morton et al., 2005). Insufficient attention has been paid to investigate the capacity of the relaxation of the QF muscle in patients with OA of the knee joint, which is also an important indicator of neuromuscular performance and movement control.

In order to function normally, a muscle needs to be strong, nonfatigued, under accurate motor control and have a good sensory mechanism (Hurley, 2003). After voluntary activation (VA) improvement, physical therapy should target the augmentation of QF muscle strength (Berth et al., 2002). Restoring lower limb functions to the levels of healthy adults, patients with OA of the knee joint rehabilitation must be more intensive than in standardized rehabilitation (Bade et al., 2010).

2.4. Leg extensor muscle strength and knee joint loading during gait in patients with osteoarthritis of the knee joint

OA of the knee affects the major biomechanical factors ensuring the optimal load to the joint during walking (Hunt et al., 2010a). Biomechanical factors may play a part in the modulation of knee joint pathogenesis (Amin et al., 2004), in which large knee adduction moment and higher joint dynamic load during gait is mostly related to the severity of tibiofemoral OA (Winby et al., 2009; Alnahdi et al., 2011). Muscles have important effect on movement; they ensure stability, protect against abnormal movement and dissipate harmful forces generated during gait (Hurley, 2003). Besides, muscle weakness causes modifications in the timing of muscle action (Erler et al., 2000), which help to avoid threatening postures and induce protective alignment during stance. Despite the fact that several studies refer improvements in gait's temporospatial parameters' following TKA (Huang et al., 2007; Yoshida et al., 2008; Milner, 2009), inter-limb differences in knee kinematics and moments persists if compared to healthy controls. It has been found that QF muscle weakness has a substantial impact on the movement patterns (Mizner and Snyder-Mackler, 2005), but no significant relationship between the overall magnitude of QF muscle strength and the rate of loading during heel strike transient has been suggested (Hunt et al., 2010a).

Since the maintenance of stance limb stability requires a good interplay of lower limb muscle activations (Jonkers et al., 2003), the methods estimating knee joint contact loads should also evaluate the surrounding muscles and soft tissues of the knee (Lloyd and Buchanan, 2001). In spite of difficulties to measure knee joint contact loads and muscle forces *in vivo* (Erdemir et al., 2007), 3D analysis allows the evaluation the dynamic behavior of a subject during walking. Because only few studies have provided data on the relative force demands on lower limb muscles and joints during gait (Reguião et al., 2005), therefore, it is informative to investigate the relationship between the entire leg muscles' strength and knee joint loading during gait in OA patients without and with knee prosthesis. As the leg muscles are working during leg straightening in the concentric regimen, then it is important to find the relationship between muscles' strength and knee joint loading during mid stance phase of gait. For clinicians and knee OA patients, it is important to know whether the knee mechanics in the operated leg are normal after TKA, to reduce the risk of further damage and deterioration of lower extremity joints, also in the non-operated knee (Milner, 2009).

2.5. Standing balance in relation to anthropometric and functional characteristics in patients with osteoarthritis of the knee joint

Postural stability is a complex of sensimotor function that includes movement detection and generation, and the control of coordinated voluntary and reflective motor responses (Fransson et al., 2000).

The most common assessment tools used to determine postural stability are the force platform and the center of pressure (COP) measures- single point location of the ground reaction force (GRF) vector (Doyle et al., 2007).

In postural stability assessment, it is important to normalize standing stability parameters with subject's height and foot length (Cimolin et al., 2001). Base of support, calculated from the foot length, is the relevant biomechanical variable in standing balance analysis (Chiari et al., 2002).

Due to the controversial information about standing balance in patients with lower limb joints OA, the main questions are raised: how serious is the disturbance of the standing balance and which factors having an impact to standing balance before and after (TKA).

Poor standing stability is the result of proprioceptive deficit, muscle weakness and knee pain (Hassan et al., 2001), which in turn leads to a greater body sway during standing in patients with knee joint OA (Hinman et al., 2002). Impairments in standing balance in patients with OA of the knee joint have been mentioned by multiple authors (Hurley et al., 1997; Hassan et al., 2001; Masui et al., 2006). It has been claimed, that improvements in static standing balance characteristics did not reach the level of statistical significance level during one year (Schwartz et al., 2012). However, there are studies which state that the subjects with knee joint OA did not have any standing balance deficit (Lyytinen et al., 2010), and that TKA does not lead to a negative effect on balance from elective joint replacement (Swanik et al., 2004). Additionally, it has been stated that the hip joint OA had no effect on static standing balance in men (Arokoski et al., 2006).

It is known that the purpose of TKA is to reduce knee pain, restore knee function and improve stability (Swanik et al., 2004), but the effect of TKA in patients with OA of the knee joint needs to emerge in all cases (Cho and Hwang, 2013). Due to maintenance of capsuloligamentous structures, reduced knee pain and inflammation, TKA results in mild improvements in proprioception, kinesthesia and balance (Swanik et al., 2004). Researchers have tried to find relationships between stabilometric parameters and selected anthropometric or functional factors. Different relationships between patients with OA of the knee joint standing balance and health-related quality of life (Schwartz et al., 2012), knee pain, lower extremity alignment (Hunt et al., 2010b), knee proprioception and MVC of the QF muscle (Hassan et al., 2001) have been established. It has been confirmed that the parameters quantifying the amount of oscillation (e.g. range of COP displacement) are highly dependent on body height and body mass (BM) (Chiari et al., 2002). Knee pain is considered a

significant predictor of standing stability (Hassan et al., 2001) and radiographic OA is a significant factor for increasing postural sway (Masui et al., 2006).

Biomechanical factors refer to anthropometric characteristics, foot placement during standing, joints and muscle functions (Chiari et al., 2002). A recent study has reported that none of the existing stabilometric parameters incorporates anthropometric characteristics (Argatov, 2013).

Based on the above, it is necessary to establish which standing balance characteristics are disturbed in knee joint OA patients and which anthropometric and functional factors affect knee joint OA patient's standing balance before and after TKA. Because individual evidence based therapeutic approach is an essential achieving goal, the relevant knowledge can be used in rehabilitation planning.

2.6. Clinical assessment

Clinical assessment of the patients with OA of the knee joint includes different functional tests. There are also specific questionnaires available (Roos, Toksvig-Larsen, 2003). Due to strong association with knee joint OA, pain related questions are very common. Several factors are associated with severe acute pain after knee surgery, including psychological factors and severe pre-operative pain (McCartney and Nelligan, 2014). Pain in patients with OA of the knee joint might be associated with central nervous sensitization rather than peripheral inflammation and injury (Imamura et al., 2008). It has been found that premorbid limited cognitive flexibility and memory capacities may be linked to the mechanisms of pain chronicity and probably also to its neuropathic quality (Attal et al., 2014). Traditionally, the pain can be evaluated using subjective VAS method in points ranging from 0 (no pain) to 10 (unbearable pain). It is also possible to evaluate superficial and deep hyperalgesia with pressure pain threshold measurements using a pressure algometer at subcutaneous, myotomal and sclerotomal structures (Imamura et al., 2008). Due to frequent low back pain complained by patients with OA of the knee joint, the author of the current study considers that respective clinical assessment must also include the peripheral nervous system testing.

The achievement of a satisfactory knee ROM is essential for functional restoration in patients after TKA (Kim et al., 2009). Respective measurements have prognostic significance preoperatively and are used to delineate postoperative rehabilitation (Lavernia et al., 2008). Traditional knee active range of motion (AROM) evaluation method is goniometry, were the patient is in supine position. During the measurement, lateral femoral condyle is used as the landmark to center the goniometer with the proximal limb directed toward the greater trochanter and the distal limb toward the lateral malleolus (Kim et al., 2009). The measured leg is flexed from the knee, the heel approximating the buttock until to maximum of 135° (Clarkson, 2005). Due to new multiple high-flexion knee prosthesis allowing flexing the knee joint past 140˚, accurate assessment of ROM will be very important to monitor the performance of

named devices (Lavernia et al., 2008). ROM affects patient's ability to perform independently ADL. Most severe functional disabilities after TKA includes difficulties in kneeling, squatting, sitting with legs crossed, walking, climbing stairs, working, recreational activities and using a bathtub (Kim et al., 2010).

Most studies have assessed the outcome after TKA using different objective criteria. To assess satisfaction after TKA, the KSS, WOMAC, Knee Society Clinical Rating System (KSCRS) and other questionnaires have been used (Bullens et al., 2001). Despite that KOOS questionnaire illustrate the validity and reliability in measuring the clinical condition of patients after treatment of focal cartilage lesions (Bekkers et al., 2009), this measure has the potential to use as the function component in an OA severity scoring system as well (Perruccio et al., 2008). KOOS is a self-administered self-explanatory question-naire covering five patient-relevant dimensions: Pain, Other Disease-Specific Symptoms, Activities of Daily Living, Sport and Recreation Function, and Knee-related Quality of Life (Roos et al., 1998). The improvement in 3 of 5 subscales during 1 month after TKA and the improvement in all KOOS sub-scales during 3 and 6 months after TKA have been found (Stevens-Lapsely et al., 2011). The KOOS questionnaire has been adapted for the use in Estonia (Tamm, 2000).

Based on the review of literature, the following hypotheses can be formulated: deficits with neuromuscular coordination disorders occur in the QF muscle function characteristics described in patients with OA of the knee joint, before the operation and 6 months following TKA (Paper I). Deficit in leg extensor muscle strength described in patients with OA of the knee joint, is related with the deficit in knee joint loading during gait before and half a year after TKA (Paper II). Postural stability in patients with OA of the knee joint is disturbed and related to several anthropometric and functional characteristics before and half-a-year after TKA (Paper III).

3. OBJECTIVES OF THE STUDY

The general objective of the present study was to evaluate leg muscle function in relation to gait and standing balance in women with osteoarthritis of the knee joint before and after total knee arthroplasty.

More specifically, the present study had the following aims:

(1) to assess maximal isometric strength, capacity of rapid voluntary contraction and relaxation, and voluntary activation of the QF muscle in women with osteoarthritis of the knee joint (Paper I);

(2) to assess isometric strength of the leg extensor muscles in relation to knee joint loading during mid stance of gait in women with and without osteoarthritis of the knee joint (Paper II);

(3) to assess static balance in relation to anthropometric and functional characteristics in women with and without osteoarthritis of the knee joint (Paper III);

(4) to assess knee pain, knee AROM and KOOS score in women with osteoarthritis of the knee joint (Paper I and III).

4. MATERIALS AND METHODS

4.1. Subjects

In total, eighteen women with degenerative OA of the knee in grade III or IV according to the KL scale, selected from the list of patients to undergo TKA surgery, participated in this study. Reasons, why not all eighteen patients did not participate in every study, were different infections occurring pre- or postoperatively. The anthropometric characteristics of the patients with OA of the knee joint and control subjects in the different studies are presented in Table 1. Six subjects also had a diagnosis of OA of the knee joint in the contralateral leg, but the disease was in the first grade according to the KL scale. The inclusion criteria of the study were the diagnosis of primary knee joint OA, the first TKA, and the ability to walk without aid. The exclusion criteria were significant cardiovascular or pulmonal disease, neuromuscular disease, and any other joint replacement of lower limb. The average period of OA of the knee joint symptoms before operation was 6 years.

Table 1. Age and anthropometric characteristics of the subject groups (mean ± SE).

Papers	n	Age (yr)	Height (cm)	Body mass (kg)	BMI (kg·m^{-2})
(Paper I)					
Patients with knee OA	12	60.2±2.0	159.9±1.5	86.9±2.9	34.1±1.2
(Paper II)					
Patients with knee OA	13	59.7±2.1	160.3±1.5	86.1±3.1	33.5±1.2**
Healthy controls	10	59.5±2.1	158.8±1.5	79.9±1.8	26.7±1.6
(Paper III)					
Patients with knee OA	14	60.2±2.1	160.2±1.2	88.6±3.6	34.7±1.3**
Healthy controls	10	59.5±2.1	158.8±1.5	79.9±1.8	26.7±1.6

OA = osteoarthritis; BMI = body mass index, **$p < 0.01$ compared to healthy controls.

In current study the assumed causes of patients OA of the knee joint were heavy physical work (7) and prior trauma (7). The data of patients were compared to ten healthy women (controls) (in Paper II and III). Individuals were excluded from the control group if they had had joint replacement of any joint of lower limbs, painful joints, or any other criteria listed for the patients' group.

Before participation in the study, all the patients and control group subjects gave a written informed consent. The study received the approval of the Ethics Committee of the University of Tartu.

4.1.1. Treatment

Knee surgery
Patients undergoing TKA were recruited from 2 orthopaedic surgeons at the University of Tartu Hospital in Traumatology and Orthopaedics clinic from September 2010 to June 2011. TKA is the end-stage treatment for knee arthritis. In surgery, an anterior linear incision for deeper tissues with the detachment of the musculus vastus medialis from the patella was performed. The patella was displaced aside of the joint, which disclosed the distal end of femur and the proximal end of tibia. Inflamed and damaged joint tissues were removed. In all cases, the condylar endoprosthesis GEMINI (W. Link Gmbh and Co., Germany) with rotating plateau was used because of moderate knee varus deformity (up to 10º) and stable knee ligaments. In all cases endoprosthesis components were fixed onto the bone with cementation. Using GEMINI prosthesis, the posterior cruciate ligament was preserved. During the operation any knee deformities were corrected and the ligaments were balanced.

Postoperative rehabilitation
The average period of hospital stay was approximately 5 days. Postoperative rehabilitation began on the first day after surgery with specific prevention activities against thromboembolism, knee mobilization and isometric exercises for strengthening thigh muscles. In addition to supervised physiotherapy, all patients trained the operated leg's mobility with CPM device. The physiotherapist of orthopaedics department instructed the patients how to transfer themselves into and out of bed, how to walk with crutches on level ground and stairs, and how to allow the weight bearing to the operated leg. Each subject received in a last stay of hospital a detailed supporting handout containing instructions and photographs of the exercises to be performed at home. The handout included ROM exercises, strengthening and stretching exercises (Deyle et al., 2005), movement control, balance and coordination exercises (Hurley, 2003). In addition, walking, cycling and swimming were recommended. All subjects filled in a training diary with the number of exercises from the handout, the number of repetitions and series, and comments in free form (e.g., cycling for 25 min). The study's author made phone calls to the patients monthly to check on the subjects' recovery and to make sure they performed the exercises. Additionally, during the 3 and 6 month examination, the subjects received counselling and encouragement to continue with specific exercises and physical activity. Walking without crutches and with full weight bearing was allowed about one and a half-month after TKA or when walking was secure and painless.

4.2. Study design

In all Papers the women with OA of the knee joint were examined 1 day before, 3 and 6 months after TKA in Tartu University Laboratory of Kinesiology and Biomechanics. In Paper I, the subjects were asked about their knee pain severity with VAS, the KOOS questionnaire was fulfilled, and the assessment of the QF muscle function was performed. Before muscle testing, the subjects performed a warm-up with exercise bike for 5 minutes. At first the MVC force of the QF was determined, followed by a signal lamp test, which allowed calculating the capacity for rapid voluntary contraction and relaxation. After five-minute rest period, voluntary activation (VA) of the QF muscle was recorded. In all trials, 3 attempts were performed with two-minute recovery time.

In Paper II, gait analysis was performed at first. Before the leg extensor muscle strength testing (Paper II, III), the subjects performed a warm-up with exercise bike for five minutes. To determine MVC force of the leg extensor muscles, three attempts were performed with two-minute recovery time.

In Paper III, the anthropometric measurements like BM, body height and foot length were performed first. After those, functional measurements- knee pain, knee AROM and the assessment of static standing balance – were conducted. Finally, the leg extensor muscle strength testing was performed. In patients, the non-operated leg was tested initially, thereafter the operated leg (Paper I-III). Control group subjects were participated in the study once. Their study protocol was structured on the same principles as in patients group, except they did not fulfil the VAS and KOOS questionnaires.

4.3. Methods

4.3.1. Measurements of quadriceps femoris muscle function

Voluntary isometric force generation and relaxation characteristics
In Paper I, during the isometric QF muscle test, subjects sat in a custom-made dynamometric chair equipped with a chair-fixed standard calibrated strain-gauge transducer DST 1778 (Russia) connected with the plate by a rigid bar (knees and hips at 90 and 110º, respectively) (Pääsuke et al., 1999; Gapeyeva et al., 2007) (Figure 1). Velcro belts placed over the shoulders and pelvis secured the subject's body position. The strain-gauge transducer pad was placed approximately 3 cm above the apex of the lateral malleolus on the anterior aspect of the leg. Signals from the strain-gauge transducer were linear from 0 to 2,500 N. The force signals were sampled at the frequency of 1 kHz and stored on computer hard disk, using WsportLab software (Urania, Estonia). During the testing of QF muscle isometric MVC force, the subjects were asked to produce maximal force (approx. 3 s) with exertion of knee extension against the cuff of the strain-gauge system (Gapeyeva et al., 2007). From three maximum attempts, the highest force value was taken for further calculation. The strong verbal encouragement was used to motivate the participants.
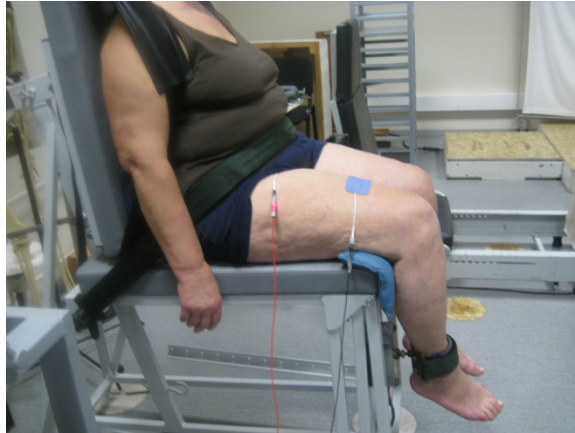
Figure 1. The experimental setup for the measurement of isometric maximal voluntary contraction force of the quadriceps femoris muscle with the location of the electrical stimulation electrodes.

To determine the capacity for rapid voluntary isometric contraction and relaxation of the QF muscle, the subjects were instructed to react to the signal lamp quickly and forcefully by extending the leg against a cuff fixed to a strain-gauge system. The maximal effort was maintained as long as the signal lamp was on (approx. 2 s) and the muscles were relaxed quickly after the signal lamp was turned off. The following characteristics were calculated: latency of contraction (LATc) – the time delay between the visual signal and the onset of force production, rate of isometric force development (RFD_{50}) – the first derivate of force development (dF/dt) at the level of 50% of MVC, and half-relaxation time (HRT) – the time of half of the decline in force during relaxation (Zeni and Snyder-Mackler, 2010).

The reproducibility of the torque measurements was assessed with repeated static load on the strain-gauge transducer. The relative error between trials and the relative difference was less than 0.5%. The high reliability of maximal isometric strength measurements using the chair-fixed dynamometer and test-retest correlations with a 5-day interval between measurements ($r = 0.92$) has been demonstrated in an earlier study (Raudsepp and Pääsuke, 1995).

Voluntary activation
Electrical stimulation allows assessing the activation process of peripheral part of the neuromuscular system. During the testing of VA of the QF muscle, the transcutaneous electrical stimulation with supramaximal square wave pulses (100% MVC) of 1 ms duration was applied using an isolated voltage stimulator (Medicor MG-440, Hungary) and two self-adhesive surface electrodes (5x10 cm, Medicompex SA, Switzerland) placed on the groin (anode) and proximal (cathode) third of the thigh. Electrical stimulation was applied through femoral nerve. Twitch-interpolated technique was used to estimate VA of the QF muscle

(Knight and Kamen, 2001; Gapeyeva et al., 2007). The subjects were asked to reach their maximal force level during 3 s (the total duration of contraction was approximately 5 s) and to maintain it after the supramaximal stimulus was delivered and until they were asked to relax. Visual feedback was provided by the display of strain-gauge amplifier. When the subject's QF muscle was completely activated, additional force was generated by superimposed twitches. Additional force produces extra activity for incompletely activated motor units during the stimulus. Figure 2 provides an example of the typical VA force determination diagram. The intensity of stimulus was assessed first to avoid the effect of twitch potentiation caused by prior contractions (Gapeyeva et al., 2007). The subjects performed three trials with the interval of 2 min and the trial with the greatest prestimulus voluntary force was taken for further analysis. The highest mean prestimulus force (MVC force) (F_V) and maximal poststimulus force (F_{ES}) were used to calculate voluntary activation of the QF muscle by the formula: $VA = (F_V : F_{ES}) \cdot 100(\%)$. The $VA \geq 95\%$ was used as the definition of full activation of the QF muscle (Machner et al., 2002; Deyle et al., 2005).
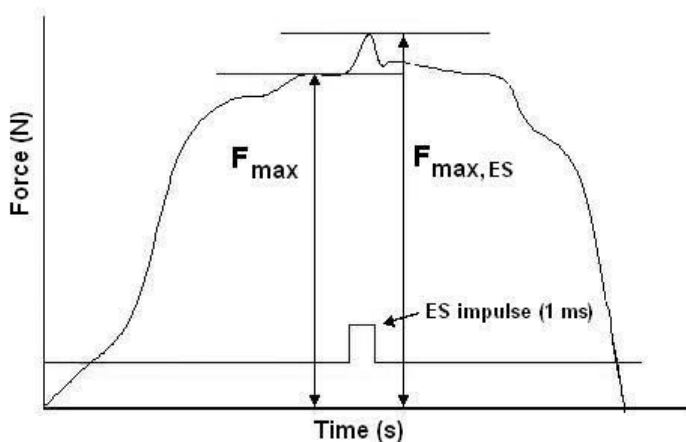
Figure 2. A typical force-time curve obtained during assessment of voluntary activation of the quadriceps femoris muscle. Fmax – isometric force before electrical stimulation-Fmax,ES – force developed during electrical stimulation.

4.3.2. Measurements of leg extensor muscle strength

During the measurement of isometric MVC force of the leg extensor muscles the subjects were seated on a custom-made dynamometric chair in a horizontal frame with knee and hip angles equal to 110º and 120º, respectively (Figure 3) (Paper II and III). The tested foot was placed on a footplate mounted on a steel bar held in ball bearings on the frame.

The subjects were instructed to push the footplate as forcefully as possible for two-three seconds in two cases: unilateral contraction of the operated leg and unilateral contraction of the non-operated leg. Three trials were performed for each case and the greatest value was taken as the MVC force (Müürsepp et al., 2011). Strong verbal encouragement was used to motivate the participants. A rest period of two minutes was allowed between the trials. In Paper III, the MVC force is relative to the body mass. It has been demonstrated that using this dynamometer a significant test-retest correlation in the measurement of isometric MVC force of the leg extensor muscles was suggested ($r = 0.91$- 0.81) Raudsepp, Pääsuke, 1995).
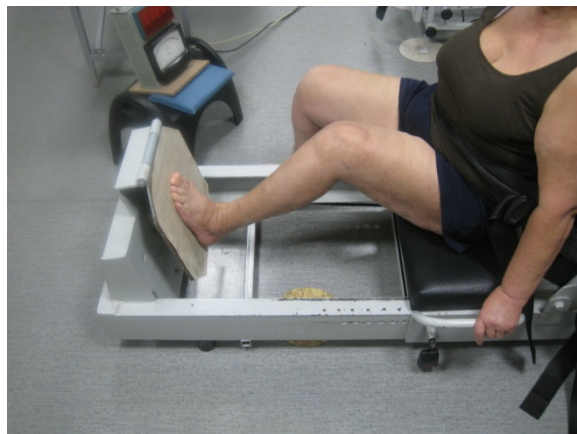
Figure 3. The experimental setup for the measurement of the isometric maximal voluntary contraction force of the leg extensor muscles.

4.3.3. Gait analysis

In Paper II, three-dimensional gait analysis was performed using optic-electronic movement analysis system Elite (BTS, Italy). Reflective marker trajectories were recorded with six cameras at a frequency of 100 Hz, and the GRF were measured simultaneously with two Kistler force platforms (Kistler 9286A, Sweden) embedded in a 5,8 m walkway. Reflective markers were placed to the subjects' skin bilaterally over the following anatomical landmarks regarding to the Davis protocol: acromion, processus spinosus C_7 and L_4, anterior and posterior superior iliac spines, lateral femoral trochanter, lateral aspect of thigh, lateral femoral epicondyle, lateral tibial epicondyle, lateral aspect of the shank, lateral malleolus, calcaneus, and the top of the foot at the base of the second metatarsal (Davis et al., 1991). Temporospatial data and GRF were computed by Elite Clinic (BTS S.p.A., Italy) software. Rates of knee

joint loading were calculated from the vertical component of the GRF using a computer-driven algorithm with all values normalized to BM. Values of stance time (ms), cadence (step/min), and knee joint flexion moment as KM2 (the first maximal knee extension moment in early stance) and knee joint power as KP2 (maximal power generation in stance corresponding to concentric knee extensor activity) during mid stance were used for future analysis. Step length data was normalized with subject's height. The trial was selected as successful when each foot contacted one platform, and the gait cycle was time-normalized to 100%. Three successful gait cycles were averaged to obtain a mean for each patient and control subject. All subjects were instructed to walk at their self-selected normal speed on barefoot. Figure 4 provides an example of the typical knee extension/flexion moment curve obtained during one gait cycle. The approach used to collect temporospatial data of gait is identical to that described in previous investigations (Mündermann et al., 2005; Hunt et al., 2010a).
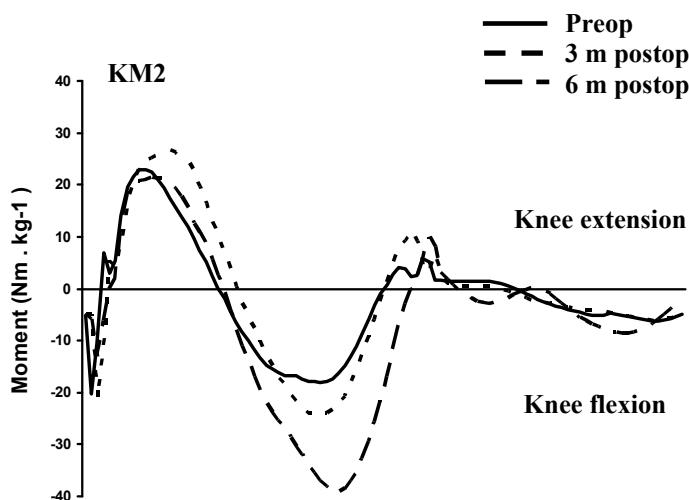
Figure 4. A typical curve of knee extension/flexion moment for one gait cycle preoperatively, three and six months after unilateral total knee arthroplasty. KM2 – knee joint flexion moment during mid stance.

4.3.4. Measurement of standing balance

In Paper III, balance during quiet bilateral standing was assessed using two stable dynamographic force plates Kistler 9286A (Switzerland). The movement of the COP was analysed by force transducers mounted symmetrically on a platform, which allows to record positions and displacements of COP at 20 Hz. The COP is a single point location of GRF vector (Doyle et al., 2005). The subjects were asked to stand during 30 seconds with the right and left leg on different platforms (distance between feet being 20 cm), eyes open (Figure 5).

28

During testing the subjects were asked to remain as stable as possible, with arms at the sides, to breathe normally and to look straight ahead at a black dot located at the eye level two meters away. To protect against falling, the lead author of the study stood within the touching distance of the subject.

Figure 5. Experimental setup for the measurement of balance during quiet bilateral standing.

Stabilometric measures incorporating both position and velocity of COP are more useful in characterizing balance control than displacement measures alone (Argatov, 2013). It has been found that during a 60-s trial length the acceptable level of reliability (G $\geq$ 0.07) of COP measures of anteroposterior (AP) and mediolateral (ML) standard deviation, average velocity and 95% confidence ellipse area (Doyle et al., 2005). In the current study the following body sway characteristics were recorded by movement analysis system Elite Clinic and SWAY® software (BTS S.P.A.): (COP) sway displacement in AP and ML (mm) direction; trace speed (mm/s) and COP equivalent area (mm^2).The trace speed as COP velocity was obtained by dividing the trace length by the test period time, showing high to very high reliability with intraclass correlation coefficient with the range of 0.74–0.91 (Salavati et al., 2009). Equivalent area – also described as ellipse area (Doyle et al., 2005) or elliptical area (Lyytinen et al., 2010) – indicates the area related with COP trajectory. In the current study, all analysed standing balance parameters were normalized to the subject's body height (m) and foot length (mm) to avoid the potential misinterpretation of data in between-group comparisons (Chiari et al., 2002; Menegoni et al., 2009).

4.3.5. Clinical assessment

In paper I, each patient was interviewed pre and postoperatively for the severity of knee pain and KOOS was calculated. Knee pain was assessed by VAS in points ranging from 0 (no pain) to 10 (unbearable pain). KOOS is a 42-item self-administered self-explanatory questionnaire covering five patient-relevant dimensions: Pain, Other Disease-Specific Symptoms, ADL Function, Sport and Recreation Function, and knee-related Quality of Life (Roos and Toksvig-Larsen, 2003). The five patient-relevant dimensions of KOOS were scored by a specific formula separately. The scores were transformed to a 0–100 scale, zero representing extreme knee problems and 100 representing no knee problems.

In Paper III, knee AROM was assessed by Baseline extendable goniometer. With patient in prone position, the centre of goniometer was placed to the middle of lateral epicondyle of the femur; stationary arm parallel to femur, movable arm to fibula (Clarkson, 2005). Before assessment, the leg was in the anatomical position with the knee in extension (0°). The measured leg was flexed from knee, the heel approximating the buttock. During the assessment it was ensured that there was no tilting of the pelvis. Normal AROM in knee flexion is 0–135°.

To determine the impact of anthropometric and functional characteristics on postural stability (Paper III), the following anthropometric characteristics were used for analysis: BM, BMI, body height and foot length. Body height was measured by a fixed wall height measure to the nearest 0.1 cm. Body mass was measured to the nearest 0.05 kg, using a medical electronic scale with the subject in light clothing, wearing no shoes. Foot length was measured from the most protruding posterior point of the heel to the tip of the hallux, or when the second toe was longer than hallux, then to tip of second toe, using the extendable anthropometer (Lafayette, USA). According to the factors influencing rehabilitation process mostly, in current study functional characteristics include knee pain, knee AROM, isometric MVC force of leg extensor muscles and stabilometric parameters.

4.4. Statistical evaluation of the data

The collected data was analyzed using Statistica 10 software (Paper I-III). All data are presented as means and standard error of mean (±SE) with probability values of < 0.05 to indicate statistical significance. One-way analysis of variance (ANOVA) followed by Bonferroni post hoc comparisons was used to evaluate differences between the operated and non-operated leg. A paired t-test was used to evaluate differences between pre and postoperative characteristics (Paper I-III).

Relationship between the lower leg extensor muscle strength and knee joint loading during mid stance (Paper II) and relationship between standing balance and anthropometric and functional characteristics (Paper III) was examined using a Spearman's correlation coefficients.

5. RESULTS

5.1. Quadriceps femoris muscle function characteristics in women with osteoarthritis of the knee joint

5.1.1. Isometric maximal voluntary contraction force and relaxation characteristics

Isometric MVC force of the operated leg was significantly lower before, 3 and 6 months after TKA when compared with the non-operated leg (Fig. 6a) (Paper I). Three months after TKA, MVC force decreased significantly in the operated leg. Six months after TKA, there was a significant increase of MVC force when compared to the same parameters 3 months after TKA. However, compared to the preoperative level, half a year after TKA, the MVC force in the operated leg was significantly lower. MVC force in the non-operated leg was equal in strength before, 3 and 6 months after TKA.

RFD$_{50}$ of the QF muscle in the operated leg was significantly lower 3 months after TKA, the significant difference persisted between the operated and non-operated leg 3 and 6 months after TKA (Fig. 6b).

LATc of the QF muscle did not differ significantly between the operated and non-operated leg before, 3 and 6 months after TKA (Fig. 7a). A significant shortening in LATc was suggested in the non-operated leg 3 months after TKA. No significant differences in HRT between the operated and non-operated leg was established neither before nor 3 and 6 months after TKA (Fig. 7b).
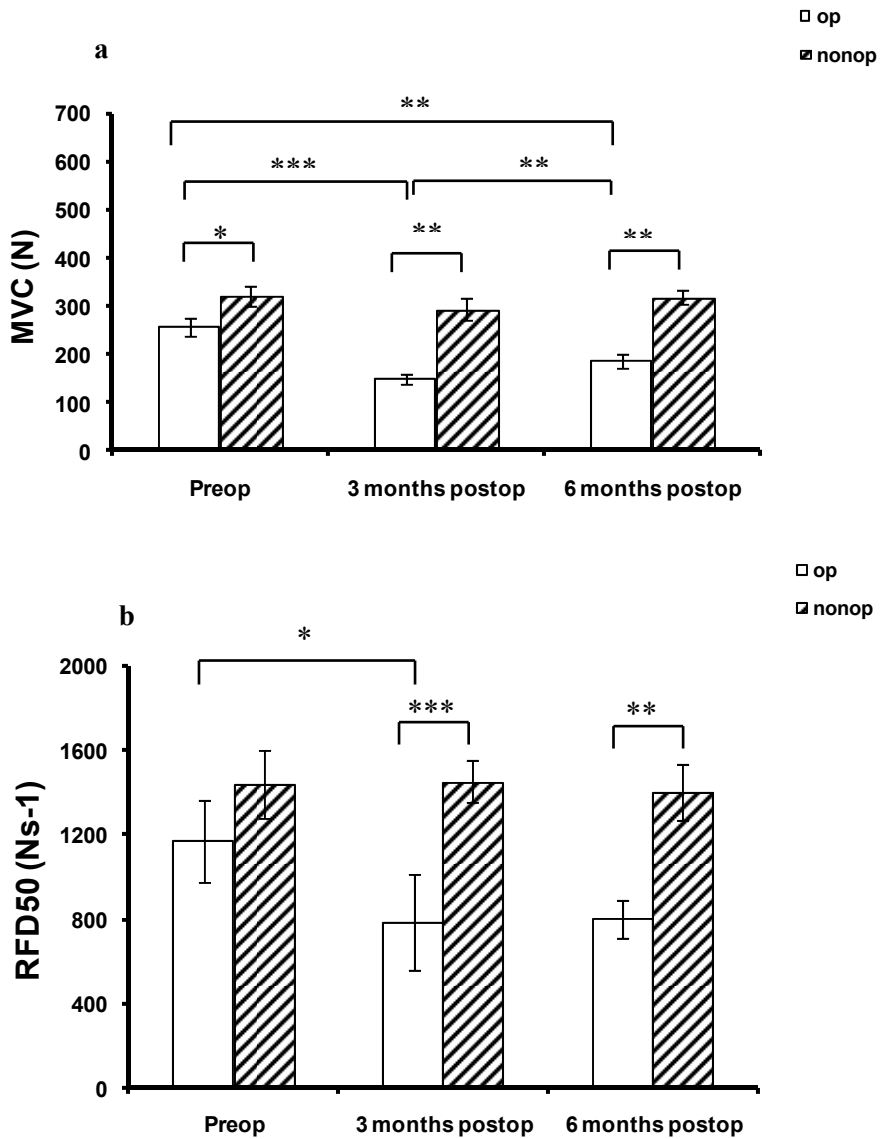
Figure 6. Isometric maximal voluntary contraction (MVC) force (a) and rate of isometric force development at level of 50% of MVC (RFD_{50}) (b) of the quadriceps femoris muscle in women with osteoarthritis of the knee before, 3 and 6 months after unilateral total knee arthroplasty (mean ±SE). $*p < 0.05$; $**p < 0.01$; $***p < 0.001$.
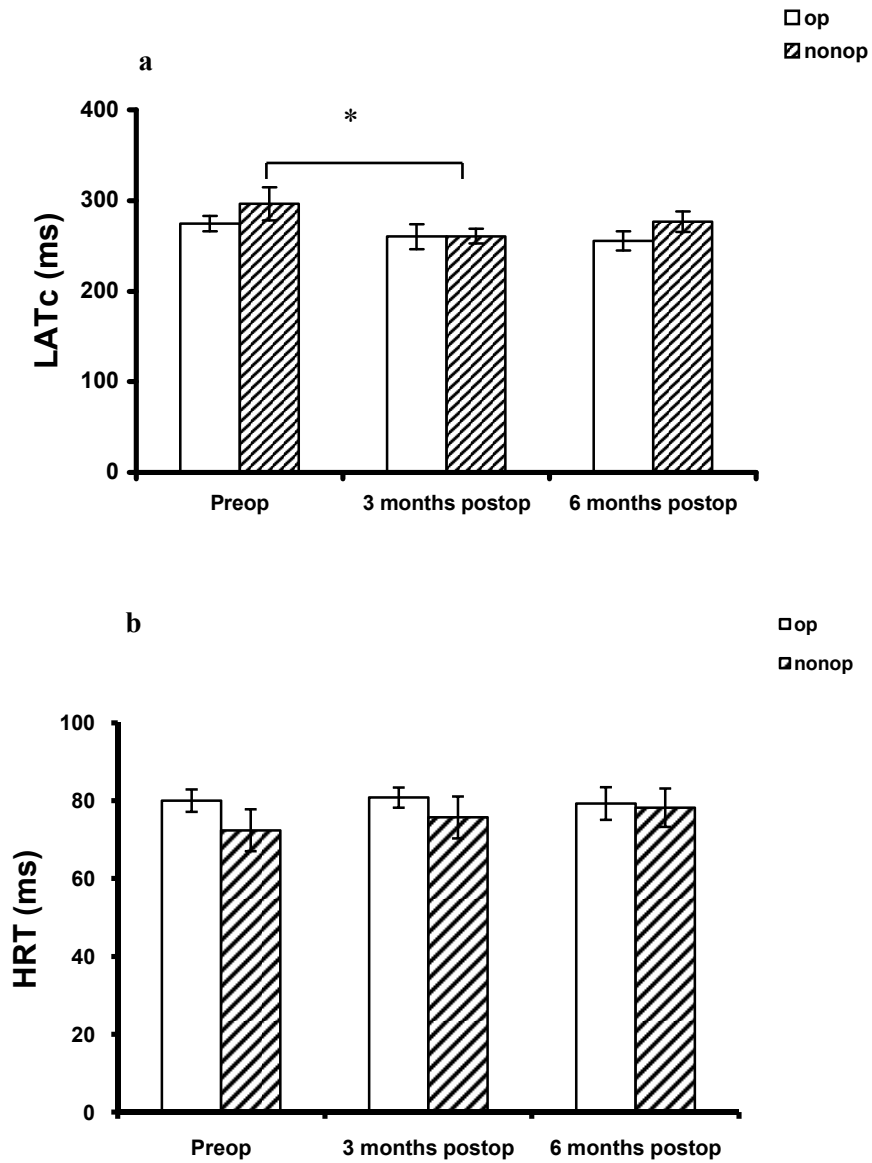
Figure 7. Latency of contraction (LATc) (a) and the half-relaxation time (HRT) (b) of the quadriceps femoris muscle in women with osteoarthritis of the knee before, 3 and 6 months after unilateral total knee arthroplasty (mean ±SE). *$p < 0.05$.

5.1.2. Voluntary activation

VA of the QF muscle did not differ significantly in the operated and non-operated leg either before or 3 and 6 months after TKA (Fig. 8).
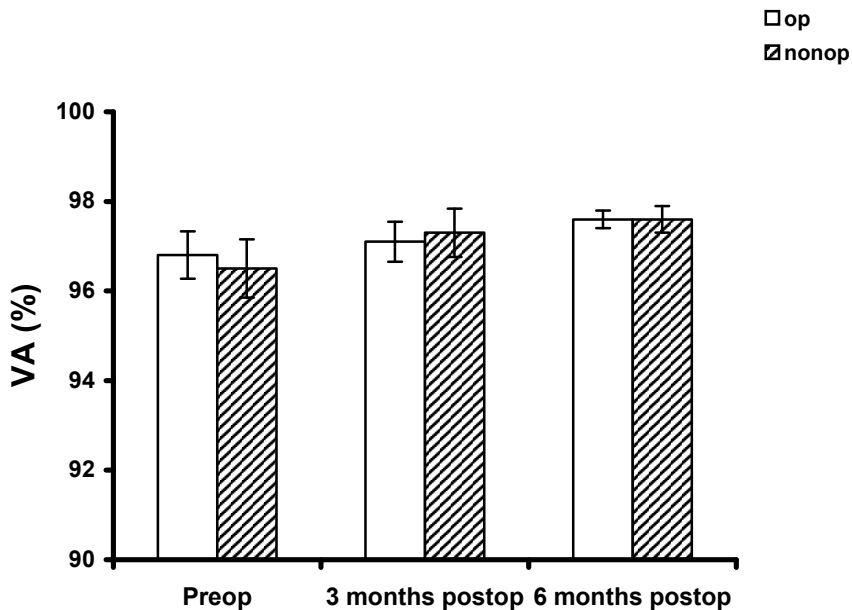
Figure 8. Voluntary activation (VA) of the quadriceps femoris muscle in women with osteoarthritis of the knee before, 3 and 6 months after unilateral total knee arthroplasty (mean ±SE).

5.2. Isometric maximal voluntary contraction force of the leg extensor muscles

Isometric MVC force of the leg extensor muscles for the operated leg did not differ significantly before TKA when compared to the non-operated leg (Fig.9) (Paper II, III). The isometric MVC force for the operated leg did not differ significantly before and six months after TKA. However, compared to the non-operated leg, MVC force for the operated leg was significantly lower three and six months after TKA. Compared to healthy controls, MVC force for the operated leg was significantly lower before, three and six months after TKA.
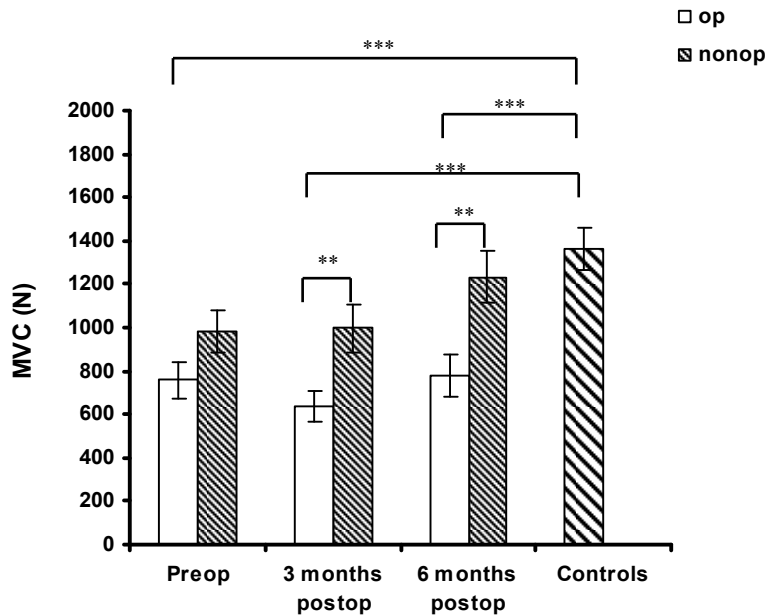
Figure 9. Isometric maximal voluntary contraction (MVC) force of the leg extensor muscles in women with osteoarthritis of the knee before, three and six months after unilateral total knee arthroplasty and controls (mean ±SE). **$p < 0.01$; ***$p < 0.001$.

5.3. Temporaspatial data and ground reaction forces during gait

Step length during gait for the operated leg was significantly longer six months after TKA when compared with the same parameter before and three months after TKA (Fig.10a) (Paper II). Compared with the controls, step length for the operated leg was significantly shorter before and three months after TKA, whereas six months after TKA it did not differ significantly compared with controls.

Gait velocity for the operated and non-operated leg increased significantly six months after TKA when compared with the same characteristic before and three months after TKA (Fig.10b). When compared to healthy controls, gait velocity in patients was significantly lower both before, three and six months after TKA.
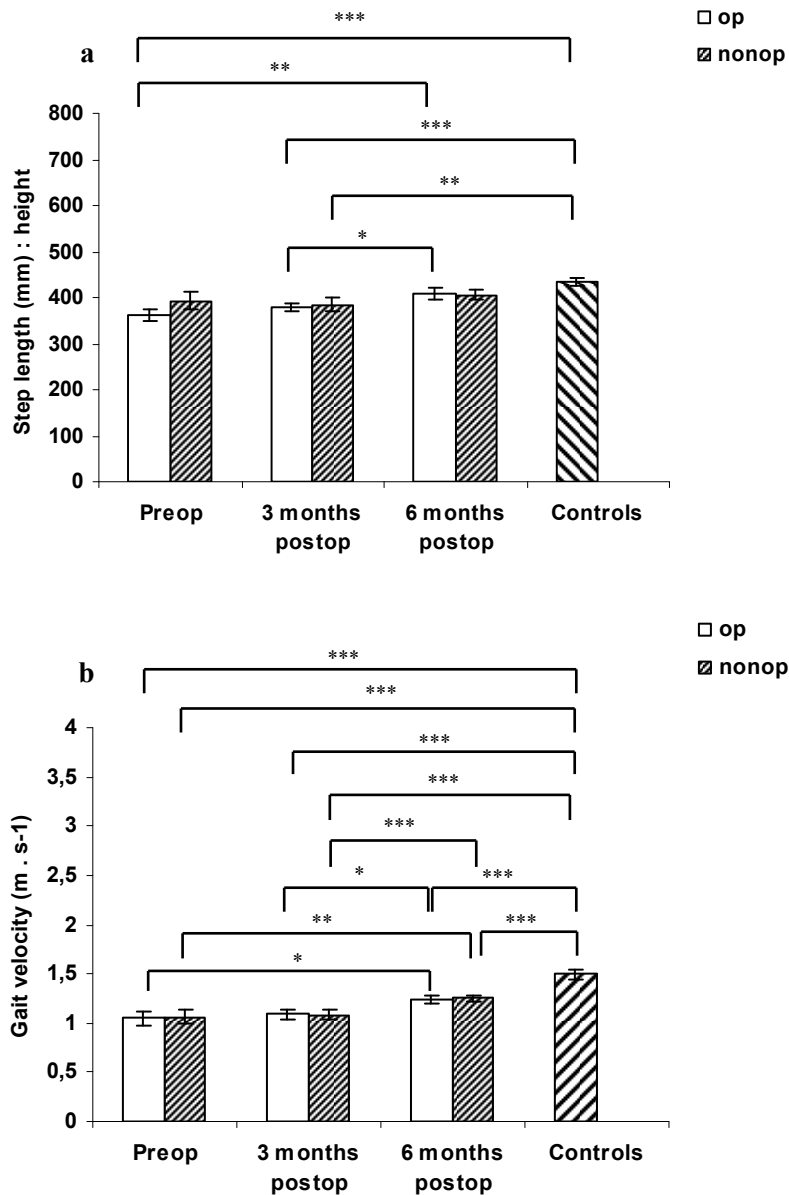
Figure 10. Step length in relation to subject's height (a) and gait velocity (b) in women with osteoarthritis of the knee before, three and six months after unilateral total knee arthroplasty and controls (mean ±SE). *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

In patients, KM for the operated leg during mid stance did not differ significantly six months after TKA, compared to the preoperative level (Fig.11a) (Paper II). Compared to healthy controls, the KM for the operated leg was significantly lower before, three and six months after TKA.

Patients produced significantly less KP for the operated leg during mid stance three months after TKA than pre-TKA (Fig.11b). Six months after TKA, KP in patients for the operated leg was significantly lower than for the non-operated leg and in healthy controls.

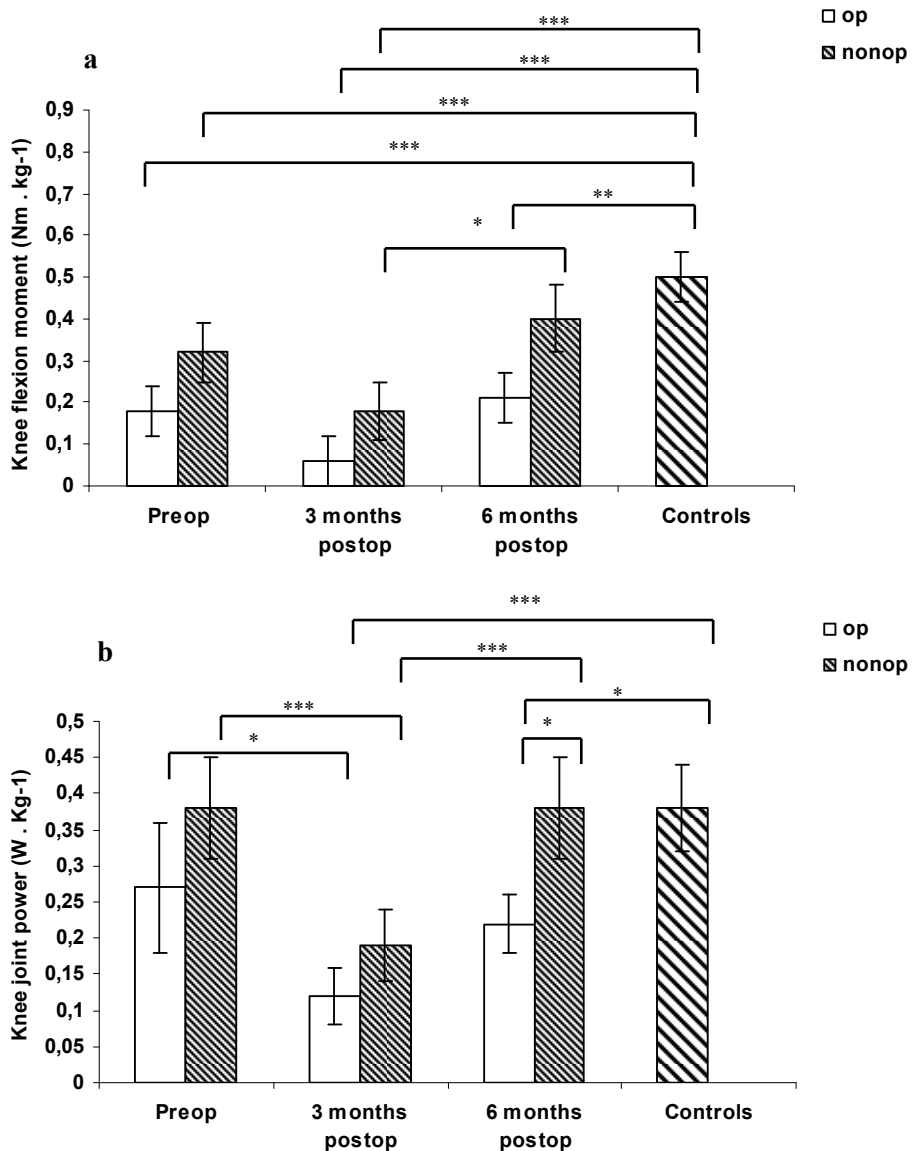**Figure 11.** Knee flexion moment (a) and knee joint power (b) during mid stance following gait in women with osteoarthritis of the knee before, three and six months after unilateral total knee arthroplasty and controls (mean ±SE). $*p < 0.05$; $**p < 0.01$; $***p < 0.001$.

5.3.1. Correlations between the isometric maximal voluntary contraction force of the leg extensor muscles and gait temporospatial parameters

No significant correlation between the isometric MVC force of the leg extensor muscles and KP for operated leg was found preoperatively and six months after TKA (Table 2) (Paper II). Three months after TKA, a moderate negative correlation ($r=-0.55$; $p<0.01$) between the isometric MVC force of the leg extensor muscles and KP for the operated leg emerged. In healthy controls, a moderate positive correlation between leg extensor muscle strength and knee joint loading was noted (KM2 $r=0.59$; $p<0.01$; KP2 $r=0.63$; $p<0.01$).

Table 2. Correlations between leg extensor muscle strength and gait temporospatial parameters in patients with OA of the knee and controls.

	Preoperatively		3 months postop		6 months postop		Controls	
	MVC op	MVC non	MVC op	MVC non	MVC op	MVC non		MVC dom leg
MVC non	0,55*		0,44		0,83*			
St l op	0,21	0,48	–0,02	0,43	0,51*	0,63 *	St l dom	0,63*
St l non	0,57*	0,33	0,37	0,50*	0,53*	0,37		
Vel op	0,61*	0,56*	0,24	0,24	–0,55*	–0,52*	Vel dom	0,40
Vel non	0,70*	0,65*	0,23	0,27	–0,17	0,07		
KM2 op	–0,08	0,20	0,27	0,30	–0,10	–0,05	KM2 dom	0,59*
KM2 non	–0,20	–0,03	–0,27	0,20	0,56*	0,19		
KP2 op	–0,30	–0,08	–0,55*	0,10	–0,28	–0,29	KP2 dom	0,63*
KP2 non	–0,20	0,20	–0,01	0,02	–0,19	0,01		

MVC = maximal voluntary contraction; op = operated leg; non = non-operated leg; st = step; l = length; vel = velocity; KM2 = knee flexion moment in mid stance; KP2 = knee joint power in mid stance; dom = dominant leg. *$p < 0.05$.

5.4. Standing balance characteristics

COP sway displacement in AP and ML direction for the operated leg did not differ significantly before, 3 and 6 months after TKA (Table 3) (Paper III). In addition, there was no statistical difference in these characteristics between the operated and non-operated leg. Compared to the controls' dominant leg, the COP in AP direction for the operated leg was significantly higher before, 3 and 6 months after TKA. COP sway displacement in ML direction did not differ significantly from the control group during the study period.

Despite the fact that three months after TKA the trace speed for the operated leg increased, the shift was not statistically significant. Six months after TKA, the characteristic of trace speed was equal to the preoperative level. Between the operated and non-operated leg, statistical difference in trace speed was noted only before TKA. Compared to healthy controls' dominant leg, trace speed for the operated leg was statistically even lower before and 6 months after TKA.

Table 3. Standing balance characteristics normalized with the subject's body height and foot length in women with osteoarthritis of the knee before, 3 and 6 months after unilateral total knee arthroplasty and controls (mean ±SE).

Parameters	OA patients			Controls	p value					
	Before TKA	3 mo after TKA	6 mo after TKA							
	I	II	III	IV	I-II	I-III	I-IV	II-III	II-IV	III-IV
COP in AP (m^{-1}) op	0.07±0.01	0.06±0.01	0.06±0.01	0.04±0.01	0.29	0.43	< 0.05	0.29	< 0.05	< 0.05
COP in AP (m^{-1}) non-op	0.06±0.01	0.07±0.01	0.07±0.01	0.05±0.01	0.23	0.21	0.24	0.86	0.06	< 0.05
COP in ML (m^{-1}) op	0.02±0.01	0.01±0.01	0.01±0.01	0.01±0.01	0.74	0.08	0.36	0.39	0.91	0.611
COP in ML (m^{-1}) nonop	0.01±0.01	0.01±0.01	0.02±0.01	0.01±0.01	0.22	0.09	0.81	0.31	0.86	0.434
Trace speed ($s \cdot m^{-1}$) op	0.53±0.03	0.57±0.06	0.48±0.04	0.71±0.04	0.31	0.15	< 0.01	< 0.05	0.08	< 0.001
Trace speed ($s \cdot m^{-1}$) nonop	0.44±0.03	0.48±0.03	0.53±0.04	0.70±0.06	0.32	< 0.05	< 0.001	0.07	< 0.01	< 0.05
Eqv area ($mm \cdot m^{-1}$)op	33.6±6.69	25.5±2.50	25.1±2.86	22.2±3.16	0.41	0.22	0.18	0.89	0.41	0.517
Eqv area ($mm \cdot m^{-1}$)op	24.5±5.25	26.4±4.30	31.8±4.82	22.7±3.03	0.32	0.13	0.78	< 0.05	0.52	0.162

OA = osteoarthritis; TKA = total knee arthroplasty; mo = months; COP = centre of pressure; AP = sway displacement in anterio-posterior direction; ML = sway displacement in mediolateral direction; eqv area = equivalent area; op leg = operated leg; non op leg = non-operated leg, in controls respectively dominant leg and non-dominant leg.

The equivalent area of COP for the operated leg did not differ significantly before, 3 and 6 months after TKA and compared to the non-operated leg and controls' dominant leg.

5.4.1. Correlations between standing balance, anthropometric and functional characteristics

Correlation analysis indicated that the COP sway displacement characteristic in AP direction was statistically associated with an increased equivalent area, and the BMI was negatively correlated with trace speed and knee AROM (Paper III) (Table 4).

Table 4. Correlations between standing balance, anthropometric and functional characteristics in the operated leg in women with osteoarthritis of the knee (n=14) before unilateral total knee arthroplasty (TKA)

	AP	ML	Trace speed	Eqv area	AROM	MVC: BM	BMI	Body height	Weight
AP									
ML	0.72*								
Trace speed	-0.15	-0.31							
Eqv area	0.63*	0.32	0.61*						
AROM	0.01	0.12	0.41	0.31					
MVC:BM	-0.44	-0.19	0.02	-0.30	0.53*				
BMI	-0.08	-0.15	-0.55*	-0.40	-0.69*	-0.29			
Body height	0.13	0.13	-0.29	-0.11	-0.12	0.13	-0.18		
Weight	-0.02	-0.12	-0.67*	-0.46	-0.72*	-0.21	0.89*	0.29	
Foot length	-0.07	0.03	-0.35	-0.24	-0.28	-0.12	0.22	0.72*	0.53*
VAS	-0.04	-0.06	-0.02	0.08	-0.24	0.17	0.09	0.37	0.24

AP = COP sway displacement in anterioposterior direction; ML = COP sway displacement in mediolateral direction; eqv area = equivalent area; AROM = knee active range of motion; MVC:BM = isometric maximal voluntary contraction force of the leg extensor muscles normalized to body mass; BMI = body mass index; VAS = visual analogue scale. *$p < 0.05$

5.5. Knee pain, knee active range of motion and KOOS score

Preoperatively, knee pain (Paper I, III) in the operated leg evaluated by VAS was significantly higher (5 points) than in non-operated leg (1 point). Postoperatively, patients reported significant decrease in knee pain.

Three months after TKA, patients demonstrated a significant reduction in knee AROM (Paper III) for the operated leg, whereas 6 months after TKA, it did not differ significantly compared to the preoperative characteristic and non-operated leg (Table 5).

Table 5. Knee pain (points from visual analogue scale) and knee active knee range of motion in women with osteoarthritis of the knee before, 3 and 6 months after unilateral total knee arthroplasty and controls.

Para-meters	OA patients			Controls	p value					
	Before TKA	3 mo after TKA	6 mo after TKA							
	I	II	III	IV	I-II	I-III	I-IV	II-III	II-IV	III-IV
VAS (points)	5.1±0.4	3.1±0.6	1.5±0.4	0	< 0.01	< 0.001	-	0.02	-	-
AROM op (°)	107.1±3.3	94.4±3.3	104.1±2.5	126.1±1	< 0.05	0.53	< 0.001	< 0.01	< 0.001	< 0.001
AROM non-op (°)	117.1±3.2	120.1±2.1	111.1±8.2	122.1±2	0.39	0.42	0.21	0.24	0.41	0.23

TKA = total knee arthroplasty; mo = months; VAS = visual analogue scale; AROM = active range of motion; op leg – operated leg; non-op leg – non-operated leg; in controls respectively dominant leg and non-dominant leg.

KOOS score (Paper I) indicated that three patient-relevant dimensions such as Pain, ADL Function, and knee-related Quality of Life were improved significantly 3 and 6 months after TKA (Fig. 12). Sport and Recreation Function scores were also higher than prior TKA, but the changes were not significant. Only other Disease-Specific Symptom scores were lower than before TKA, showing a tendency for improvement 6 months postoperatively.
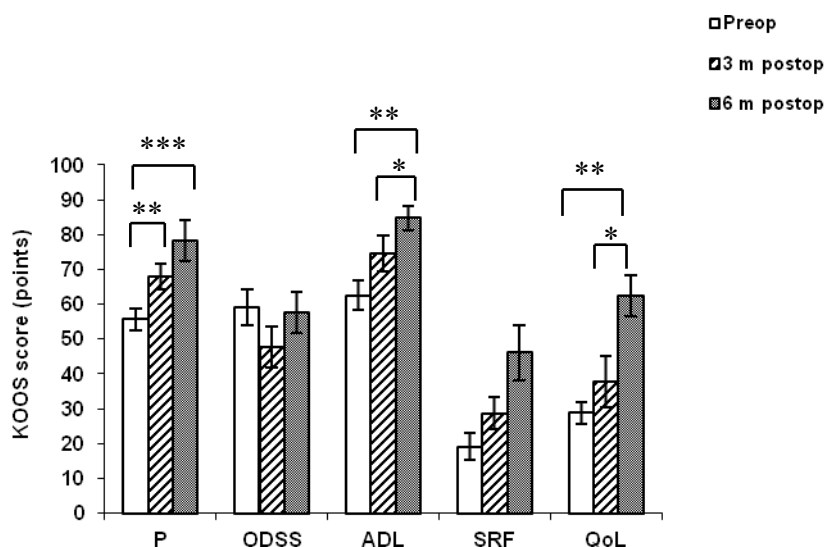

Figure 12. KOOS score in women with osteoarthritis of the knee before, 3 and 6 months after unilateral total knee arthroplasty (mean±SE).
P = pain; ODSS = other disease-specific symptoms, ADL = activities of daily living, SRF = sport and recreation function, QoL = knee-related quality of life. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

6. DISCUSSION

6.1. Isometric maximal voluntary contraction force and voluntary activation of the quadriceps femoris muscle

The most important finding of the Paper I was that patients with OA of the knee joint have reduced maximal and explosive strength of the QF muscle with no changes in VA and capacity for rapid contraction and relaxation both before and after TKA.

Patients with OA of the knee joint showed remarkable weakness of the QF muscle in the operated leg before, 3 and 6 months after unilateral TKA (Figure 6a). MVC of the QF muscle in the operated leg compared to non-operated leg was 18% lower before TKA, and significantly lower 3 and 6 months after TKA (47 and 39%, respectively). Comparing the same characteristics with the previous study (Gapeyeva et al., 2007), there was isometric MVC force deficit in the operated leg before and 6 months after TKA being 31 and 32%, respectively, and compared to controls being 48 and 44%. Twenty-six days after TKA the decrease in QF muscle strength even 60% was established (Stevens et al., 2003).

There are several explanations about QF muscle weakness in patients with OA of the knee joint. As known, QF muscle strength is strongly associated with knee pain and disability in the community (O'Reilly et al., 1988). One cause of QF muscle weakness is the impairment in central nervous system activation (Stackhouse et al., 2000). Increased severity of joint damage may cause an increase in alteration of afferent inputs and subsequently a decrease in QF muscle strength and VA (Pap et al., 2004). Muscular coordination disorders are present already before surgery and are also caused by the implantation of a TKA (Erler et al., 2000). Based on the results of the current study, where knee pain was reduced during half a year after TKA to a minimum (Table 5) and central nervous system activation was not impaired (Figure 8), may presume that the weakness of the QF muscle in patients with OA of the knee joint may be caused by muscular coordination or muscle power transfer error through ligaments attached to the bone. Postoperatively the power transfer is disturbed even more because of the prosthesis, the affected ligaments (including patellar ligament) and scar tissue does not allow a proper power transfer from muscle to ligament. It has been argued that coordination disorders can be improved by rehabilitation (Erler et al., 2000), but there is also evidence confirming that the full recovery of the muscle strength and physical function to a normal level is rare (Valtonen et al., 2009; Maffiuletti et al., 2010). Because OA of the knee joint has been ongoing for years and patients with rehabilitation specialists typically focus on muscle strength usually after surgery, it is common that patients achieve a strength level that is essential for everyday living and make no attempt to restore muscle strength to the opposite leg's level.

Explosive muscle strength characterized by RFD is a term to describe the ability to rapidly develop muscular force during isometric conditions (Andersen

and Aagaard, 2006). It has been found that voluntary RFD is dependent on MVC (Andersen and Aagaard, 2006) and there exists an opinion that RDF shows larger side-to-side difference compared with MVC strength (Maffiuletti et al., 2010). In the current study, isometric RFD_{50} of the QF muscle for involved leg was 17.5% lower as compared to uninvolved leg before TKA. This difference between the legs increased 3 and 6 months after TKA, being 48 and 42%, respectively (Figure 6b). It is known that the RFD is influenced by both central and peripheral components. The force generation results of the current study suggest that in patients with OA of the knee joint rapid neural activation of muscles, that is, recruitment of motor units does not differ during isometric MVC force or during rapid voluntary force production. The patients with OA of the knee joint have a remarkable weakness of the QF muscle, so they are also unable to perform quicker moves in walking, ascending, or descending from a chair or stairs, etc. In the current study emerged a tendency for MVC and explosive force production improvement half a year after TKA. Postoperative QF muscle strength is a critical part of the success of TKA and is affected by the patient's preoperative comorbidities, surgical technique, and postoperative rehabilitation (Greene and Shurman, 2008).

The reaction time to visual stimuli or LATc or rapid voluntary contraction assesses the preparation of isometric knee extension movement. There is contradictory information in literature about the movement preparation of the QF muscle. Whereas one study confirms that the ability of the QF muscle to generate force rapidly and efficiently is diminished in persons with OA of the knee joint (Marks et al., 1995), the other declares that in patients with OA of the knee joint, compromised temporal parameters and magnitude of force generation during patellar tendon reflex reactions do not appear (Dixon and Howe, 2005). Understandably there were different methods used, allowing the authors to make appropriate conclusions, but the question remains – does an impairment of neuromuscular function in patients with OA of the knee joint exist? Data of the current study indicated no significant differences in the LATc during unilateral MVC of the QF muscle in the operated leg either before or 3 and 6 months after TKA. Only the non-operated leg contracted significantly slower during MVC 3 months after TKA as compared to the same characteristic before TKA (Figure 7a). Despite the subjects having knee pain and QF muscle weakness, the rapid voluntary contraction was not prolonged and the movement preparation was not affected.

Despite that there is abundant information about MVC and VA of the QF muscle, one relevant article can be found about relaxation characteristics, which data coincide with the findings of current research (Gapeyeva et al. 2007). In the current study, no significant prolongation of HRT of the QF muscle was observed either between operated and non-operated leg or before, 3 and 6 months after TKA (Figure 7b). Voluntary muscle relaxation occurs as a consequence of excitation of corticospinal projection neurons or intracortical inhibitory interneurons (Toma et al., 1999). Both the presupplementary motor area and supplementary motor area proper play an important role in motor inhibition.

44

On this basis, it can be considered that the patients with OA of the knee joint have control over QF muscle contraction and relaxation. On the other hand, it is known that fatigue occurs as a result of repeated activation of skeletal muscle (Toma et al., 1999). The subjects of the current study performed nine individual efforts to measure QF muscle strength and its contractile properties. It is possible that such a short effort does not cause an excitation of corticospinal neurons, or individual muscle contraction did not cause the fatigue.

In Paper I, the twitch interpolation technique was used to measure the level of VA or excitations of motoneurons of QF muscle. The method is called twitch interpolation because the stimulus consists of one single pulse (Herbert and Gandevia, 1999). To ensure that all motor units are activated during muscle contraction, several studies (Stackhouse et al., 2000; Machner et al., 2002; Berth et al., 2007) have used double or multiple stimuli in an effort. However, there is a study (Behm et al., 1996), which confirms that single stimuli are equally effective in producing full activation as compared to stimuli applied as paired or in trains. During the last decade, several articles have been published, confirming that the failure of voluntary muscle activation, resulting from an inability to recruit all of the muscle's motor units, causes significant bilateral VA deficit in patients with OA of the knee joint (Berth et al., 2002; Mizner et al., 2003; Mizner et al., 2005b). There are also studies (Stevens et al., 2003; Berth et al., 2007; Gapeyeva et al., 2007) where VA of QF muscle did not differ between the involved and uninvolved leg. The current study demonstrated that patients with OA of the knee joint could nearly completely (VA > 95%) activate the QF muscle during isometric MVC both before and after TKA (Figure 8). The same results with the same method were also yielded in TKA patients by Gapeyeva with colleagues (2007). When comparing young and elderly subjects, it was found that despite reduced maximal force, there were no differences in the ability of young (mean age 26 years) and elderly (mean age 80 years) subjects to voluntarily activate their muscles (Roddy et al., 2005). It has also been found (Knight and Kamen, 2001) that despite considerable less muscular strength in the older group, muscular activation was greater than 95% of maximum, being equal in both young and older individuals.

Individual physical therapy did not influence the results of VA, LATc, and HRT of the QF muscle; however, in patients, the knee pain was decreased, the quality of life improved significantly, and there was a tendency for MVC and explosive force production improvement half a year after TKA. All subjects of the current study received postoperative inpatient rehabilitation and exercise instructions for home. According to the training diaries, the average number of training days per week was four, with the duration of 25 min. The subjects performed during each workout 1–3 exercises from each group of exercises (strengthening, range of motion, balance and coordination, stretching). Three months after TKA, the loading of exercises was more specified. For example, 5 months after TKA, the knee extension with adjustable ankle weights (2 kg) was performed with 2 sets and 20 repetitions per set. General physical activity and operated leg's functionality were improved also by walking (9 patients), cycling

(5 patients), swimming (4 patients), gardening (5 patients), and farm working (2 patients). Postoperative counselling and recommendations for performing exercises at home helped the patients to participate in self-management of their condition and be responsible for their health.

Due to the contradictory results, the question remains about the sensitivity of the interpolated technique. Interpolated twitch technique is valid and reliable for analyzing high-intensity contractions (Behm et al., 1996). It has been found (Stackhouse et al., 2000) that there were no significant differences in the central activation ratio across train types during maximal efforts (75 and 100% of MVC; 100Hz 120 ms train), but submaximal effort (25 and 50% of MVC; 100 Hz 250 ms; 50Hz 500-ms) produced significantly lower central activation ratio. Therefore, it is important to determine the relationship between the central activation ratio and the level of muscle contraction.

Since the level of VA quantifies as an interpolated twitch ratio or central activation ratio (Morton et al., 2005), the results of Paper I may suggest that despite reduced maximal force, the patients with OA of the knee have good central activation for muscle contraction. Future studies should focus on power transfer from muscle to ligament, possibly yielding better answers for the question, which structures disturb the full recovery of muscle after joint disease, trauma, or knee operation. The clinical importance of the study was the knowledge that patients with OA of the knee can rapidly contract and relax their QF muscles and consequently that muscle strength exercises could be performed more intensively than it is recommended in standardized rehabilitation protocol (Bade et al., 2010).

6.2. Relationship between leg extensor muscle strength and knee joint loading during gait

The important finding of the Paper II was that in patients with OA of the knee joint, the increase of leg extensor isometric strength, step length, gait velocity and the knee joint loading during gait for the operated leg, was noted six months after TKA. The second finding of the study was that due to weak leg extensor muscles, on the third postoperative month, patients applied an excessive load to knee joint during mid stance of gait. In healthy subjects the stronger knee surrounding muscles provide stronger knee joint loading during gait.

Based on the knowledge that knee mobility and stability are the major factors in the normal pattern of walking, the purpose of the Paper II was to assess the isometric strength of knee surrounding muscles, and the economy and the rate of force development in knee joint during gait. For clinicians, it is important to reduce the difference between leg extensor muscle strength and knee joint loading for the operated and non-operated leg during gait, to avoid potential bilateral knee arthroplasty (Huang et al., 2007).

In current study, leg extensor muscle strength recovers to the preoperative level (difference being only 3%) half a year after TKA to the preoperative level,

but remains still significantly weaker than the non-operated leg (38%) and the dominant leg of controls (44%) (Figure 9). Since there is a strong association between the closed-chain assessment of the strength and physical function of leg extensor muscles according to WOMAC (Rossi et al., 2007), the activation of all the leg muscles in everyday activities may be one of the reasons for better recovery of the entire leg muscles' strength after TKA.

It has been found that unilateral TKA produces asymmetrical gait in bilateral severe OA of the knee joint patients (Mündermann et al., 2005; Huang et al., 2007). In current study, the step length and gait velocity in patients with OA of the knee joint increased significantly (12% and 19%, respectively) half a year after TKA (Figure 10 a,b). Step length did not differ significantly six months after TKA (650 mm) from healthy controls (690 mm) but gait velocity was significantly prolonged (1.24 m·s^{-1}) as compared to control subjects (1.5 m·s^{-1}). In comparison, one year after TKA was patients' length of step 630 mm and walking speed 1.12 m·s^{-1} (Börjesson et al., 2005). In summary, no significant differences between the operated and non-operated leg emerged in the temporospatial data of gait. One major contributor to good functional results may be the postsurgical rehabilitation during which patients perform for several months after TKA home-based exercises (Hurley, 2003; Deyle et al., 2005). Therapeutic exercises, including land-based aerobic and strengthening exercises or physical activity are very important for patients with OA of the knee joint (Valderrabano, Steiger, 2001; Rooks et al., 2006; Brown et al., 2010).

Unilateral TKA affects not only knee kinetics and kinematics of the operated leg but also the motion of the non-operated knee (Huang et al., 2007; Alnahdi et al., 2011). The understanding of the reaction of forces impacting the lower limb joints permits to prevent or to limit the overload. In Paper II, both factors indicating knee joint loading- the KM and the KP for the operated leg during mid stance, did not improve significantly half a year after TKA. Compared to the healthy controls, named characteristics were significantly lower before, three and six months after TKA (Figure 11 a,b). This result is consistent with the findings of previous studies, confirming that the maximum external knee flexion moment during weight acceptance is lower in arthroplasty groups compared to controls (Smith et al., 2004; Milner, 2009). Despite the fact that preoperatively and three months post-operatively the knee joint loading for the non-operated leg was significantly weaker, it did not differ significantly from controls same parameters six months after TKA. It has been found that the knee adduction moment can be reduced by supervised exercise in middle-aged patients presenting early signs of knee joint OA (Thorstensson et al., 2007). A recent study found that 12 months after TKA the inter-limb differences in peak knee flexion angle and ROM persist (Yoshida et al., 2008), but 28 months following recovery from unilateral TKA, peak vertical GRF and joint loading rates are similar in the involved and uninvolved limbs (Milner, 2008). There-fore, it is essential to teach patients to shift the body weight to the operated leg (total body weight is allowed one and a half month after surgery) together with appropriate exercises, in order to reduce the differences in leg extensor muscles

strength, gait temporospatial and knee joint loading parameters between the operated and non-operated leg.

Preoperatively and six months after TKA, no correlation between the isometric MVC force of the leg extensor muscles and knee joint loading for the operated leg was found. Three months after TKA a moderate negative correlation between these characteristics was noted. Although three months after TKA, both MVC force of leg extensor muscles and KP for the operated leg were decreased, according to the correlation analysis may confirm, that due to weak leg extensor muscles, an excessive load is applied to knee joint. In healthy controls, a moderate positive correlation between leg extensor muscle strength and knee joint loading was found (Table 2). Despite the fact that there is an opinion, that the relationship between QF muscle strength and joint impact loading is non-significant (Hunt et al., 2010a), there is a study reporting positive relationship between muscle strength and gait performance (Nadeau et al., 1996). Because individuals with motor disabilities use an intra-limb and between-limbs compensations to maintain gait speed (Reguião et al., 2005), it is essential to avoid potential bilateral arthroplasty or other secondary musculoskeletal disorders. Therefore, it is very important that patients with OA of the knee joint get individual rehabilitation both pre- and postoperatively.

In conclusion, Paper II confirmed – the more weak are the leg muscles, the more excessive load is applied to knee joint, and stronger knee surrounding muscles provide stronger knee joint loading during gait. This knowledge can be emphasized to patients to train the knee surrounding muscles, achieving a stable knee joint for everyday activities or postpone potential TKA surgery.

6.3. Standing balance in relation to anthropometric and functional characteristics

The important finding of Paper III was that in patients' with OA of the knee joint, standing balance characteristics did not differ significantly before and after TKA. Compared to healthy controls, the COP of sway displacement in AP direction is mostly disturbed before and after TKA. The second finding of the study was that increased standing stability is associated with an increased equivalent area of COP and higher BMI ensures reduced trace speed and lower knee ROM in the operated and non-operated leg.

Postural control requires the complex interaction of musculoskeletal and neural systems including joint range of motion, spinal flexibility, muscle properties, integration of visual, vestibular and somatosensory systems and processes ensuring adaptive aspects of postural control. The purpose of Paper III was to assess the impact of anthropometric and functional characteristics on standing balance in women with OA of the knee prior to and after TKA. Poor postural stability is the result of proprioceptive deficit, muscle weakness and knee pain (Hassan et al., 2001), which in turn leads to a greater body sway during standing in patients with OA of the knee joint (Hinman et al., 2002).

Despite the fact that movement control, balance and coordination exercises are recommended for patients with OA of the knee joint (Hurley, 2003), it is informative to know how much balance is disturbed in patients with OA of the knee joint and which factors affect standing balance most.

It has been found that TKA results in mild improvements in proprioception, kinesthesia, and balance due to reduced pain and inflammation (Swanik et al., 2004). However, it has also been found that three months is not sufficient to improve static balance (Hue et al., 2004) and respective improvements did not reach statistical significance within one year after TKA (Schwartz et al., 2012). This study confirmed that despite knee surgery or postoperative rehabilitation, the characteristics of standing balance did not differ significantly pre- and post-operatively. In current study, COP sway displacement in AP and ML direction and the equivalent area of COP for the operated leg did not differ before and 3 and 6 months after TKA and compared to the non-operated leg. Trace speed was also equal to preoperative level six month after TKA (Table 3). This result is consistent with the findings of previous study (Lyytinen et al., 2010) confirming that knee replacement does not lead to a negative effect on balance.

As described above, human postural control is complex phenomenon, which improves gradually after TKA, due to intrasensory proprioceptive compensation either at knee, or at other lower limb joint levels (Gauchard et al., 2010). To ensure stability, the nervous system generates force to control motion of the COP and the central nervous system tightly controls both the relative position between COP and base of support as well as the relative velocity to maintain stability (Salavati et al., 2009). The knee joint also recovers its corrective compensatory role in postural regulation through neuroplasticity and the preventive sensimotor strategies are performed through muscular activation (Gauchard et al., 2010). However, the possible mechanisms accounting for the impaired standing stability are not fully understood (Lyytinen et al., 2010). Despite the fact, that patients of current study have OA of the knee joint diagnosis and accompanying knee pain, reduced knee ROM and muscle strength, the characteristics of standing stability did differ neither before nor after TKA. Results of the current study allow concluding that nervous system generates adequately force to control motion of the COP in patients with OA of the knee joint. Due to reacquisition of the compensatory role of the knee in balance control and the possibility of developing an appropriate muscular activation sequence, the standing stability is mainly regulated by anticipatory neuro-sensory strategies (Gauchard et al., 2010). To obtain more fundamental answers about the factors affecting standing stability, future studies should focus more on the link between the somatosensory or nervous system and standing stability.

However, when comparing patients with OA of the knee joint with age- and sex-matched controls, subjects with symptomatic OA of the knee joint have partially disturbed standing balance (Hassan et al., 2001; Hinman et al., 2002; Masui et al., 2006). The same tendencies were also revealed in current study but only in characteristics of COP sway displacement in AP direction and trace speed (Table 2). Compared to healthy controls' dominant leg, the trace speed

for the operated leg was statistically lower before and 6 months after TKA. Correlation analysis demonstrated that trace speed is associated with a higher BMI, which was higher in the patients' group (Table 4). It is known that factors associated with OA of the knee joint include the female preponderance with the effects of obesity (Hart et al., 1999). Severe obesity has been negatively influenced in addition to other functional characteristics also postoperative WOMAC scores (Núňez et al., 2007). It is also determined that center of the total BM is an important factor controlled by postural control system and higher BM requires more effort in maintaining standing stability (Greve et al., 2007). Ideal alignment in standing allows the body to maintain standing stability using a little internal energy as possible (Horak, 2006). Whereas in overweight patients the center of total BM doesn't locate above the base of support, then greater COP sway displacement in AP direction is understandable. In current study, higher BMI was related to lower knee ROM (Table 4), which may be explained by structurally heterogeneous muscles including fat tissue with disrupted blood supply and therefore the recovery of the elasticity of knee surrounding soft tissue structures (knee joint capsule, ligaments, tendons) is slower.

Based on results of the current study it can be concluded that in reducing knee pain, improving knee ROM or muscle strength, therapeutic exercises are important. Postural stability exercises in patients with OA of the knee joint require a specific purpose. This may be fall prevention or performing motor tasks requiring postural adjustment (Hue et al., 2004). In current study, static standing balance of patients with OA of the knee joint was not disturbed. Because the standing stability was related to higher BM, then the counseling addressed to nutrition and healthy lifestyle in patients with OA of the knee joint is very important.

Although all standing balance parameters analyzed in the current study were normalized to the subject's body height (m) and foot length (mm) (Chiari et al., 2002; Menegoni et al., 2009), a paired t-test evaluating differences between pre- and postoperative characteristics indicated the same differences as non-normalized characteristics.

In conclusion, OA of the knee joint cause disturbances in standing balance only in AP direction and contrary to our expectation, much fewer anthropometric and functional characteristics had an influence on standing balance.

6.4. Knee pain, knee active range of motion and KOOS score

Pain is common in patients suffering from OA of the knee joint similarly before and during the first postoperative week after TKA. Pain management includes both pharmacological treatment and physical therapy (Moffet et al., 2004; Hay et al., 2006). Pain relief, measured by VAS score is probably the most important goal in joint arthroplasty correlates highly with quality of life and satisfaction

with knee operation (Britton et al., 1997). It is well known that TKA reliably reduces knee pain and improves knee functions (O'Reilly et al., 1998). As expected, the participants of the present study showed remarkable reduction in knee pain and improvement in knee AROM for the operated leg after unilateral TKA (Paper I and III) (Table 5). Based on earlier research which indicates that pain and muscle strength may particularly influence standing stability (Hassan et al., 2001), the correlation analysis with specific characteristics was done. The correlation analysis of Paper III indicated that knee pain and muscle strength have no impact on static standing balance. Also it was found that knee pain does not have impact on knee ROM and leg extensor muscle strength (Table 4).

Three months after TKA, patients with OA of the knee joint demonstrated a significant reduction in knee AROM for the operated leg, whereas 6 months after TKA, it did not differ significantly compared to the preoperative characteristic and non-operated leg. Compared to controls, knee AROM for the operated leg was significantly lower before, 3 and 6 months after TKA. Although knee active flexion decreased after surgery, half a year after TKA it was (104°±2.5) as extensive as before TKA (107°±3.3), which is sufficient for descending stairs and rising up from chair. More than twelve months after the operation, knee flexion has been measured to be 105° (Cho and Hwang, 2013).

KOOS score indicated that three patient-relevant dimensions such as Pain, ADL Function, and knee-related Quality of Life improved significantly 3 and 6 months after TKA. Sport and Recreation Function scores were also higher than prior TKA, but the changes were not significant. Only other Disease-Specific Symptom scores were lower than before TKA, showing a tendency for improvement 6 months postoperatively (Figure 12). Also longer follow-up study confirmed that thirty-six months after TKA in patients with severe OA of the knee joint, the health related quality of life was improved significantly, especially in the pain dimension (Núňez et al., 2007).

Based on the results of the current study we may confirm that TKA and postoperative recovery were effective in reducing knee pain and increasing quality of life in subjects with knee prosthesis. Individual physical therapy did not influence the results of VA, LATc, and HRT of the QF muscle (Paper I) and standing balance (Paper III) characteristics. However, there was a tendency for MVC and explosive force production improvement in QF and leg extensor muscles half a year after TKA. The improvement of muscle strength can be associated with the improvement of knee joint loading during gait. Despite that current study demonstrated, that higher BMI ensures reduced trace speed during postural stability test, obesity is the factor requiring attention in prevention new potential joint damages. Patient's knowledge's about OA of the knee joint disease, respective rehabilitation and healthy lifestyle are very important in reducing patient's disability and the cost of treatment.

In conclusion, the author of the current study shares the opinion that functional limitations 6 months after TKA requires more intensive therapeutic approaches than in standardized rehabilitation, to restore muscle functions to the levels of healthy adults (Bade et al., 2010).

CONCLUSIONS

1. In women with OA of the knee joint, isometric voluntary maximal and explosive muscle strength of the QF muscle for the operated leg is remarkably reduced before and after TKA, whereas electrically evoked twitch characteristics are not disturbed either before or after TKA.

2. In women with OA of the knee joint, leg extensor muscle isometric strength for the operated leg recovers half a year after TKA to the preoperative level, remaining still significantly decreased compared with the non-operated leg and the respective characteristics of controls.

3. In women with OA of the knee joint, temporospatial parameters of gait do not differ significantly in the operated and non-operated leg, whereas the knee joint loading during mid stance and gait velocity for the operated leg are six months after TKA significantly lower compared to healthy controls. Due to weakened leg extensor muscles, on a third postoperative month, patients with OA of the knee joint apply an excessive load to knee joint during mid stance of gait.

4. Static balance during quiet bilateral standing does not differ significantly before and after TKA in women with OA of the knee joint. Compared with healthy controls, only the COP of sway displacement in AP direction is disturbed both before and after TKA. Increased standing stability is associated with an increased equivalent area of COP and higher BMI ensure reduced trace speed and lower knee ROM in the operated and non-operated leg.

5. In women with OA of the knee joint, half a year after TKA knee pain in the operated leg is minimal, KOOS score is higher and knee joint AROM is comparable to preoperative level.

REFERENCES

1. **Aaron** RK, Skolnick AH, Reinert SE, Ciombor DM. (2006) Arthroscopic debridement for osteoarthritis of the knee. J Bone Joint Surg Am 88:936–943.
2. **Alnahdi** AH, Zeni JA, Snyder-Mackler L. (2011) Gait after unilateral knee arthroplasty: frontal plane analysis. J Orthop Res 29:647–625.
3. **Altman** RD. (1987) Criteria for the classification of osteoarthritis of the knee and hip. Scand J Rheumatol Suppl. 65:31–39.
4. **Andersen** LL, Aagaard P. (2006) Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. Eur J Appl Physiol 96:46–52.
5. **Amin** S, Luepongsak N, McGibbon CA, LaValley MP, Krebs DE, Felson DT. (2004) Knee adduction moment and development of chronic knee pain in elders. Arthrit Care Res 51:371–376.
6. **Argatov** I. (2013) A subject-specific postural instability parameter. Gait Posture 37:141–143.
7. **Arokoski** JPA, Leinonen V, Arokoski MH, Aalto H, Valtonen H. (2006) Postural control in male patients with hip osteoarthritis. Gait Posture 23:45–50.
8. **Attal** N, Masselin-Dubois A, Martinez V, Jayr C, Albi A, Fermanian J, Bouhassira D, Baudic S. (2014) Does cognitive functioning predict chronic pain? Results from a prospective surgical cohort. Brain 17 (in press).
9. **Bade** MJ, Kohrt WM, Stevens-Lapsley JE. (2010) Outcomes before and after total knee arthroplasty compared o healthy adults. J Orthop Sports Phys Ther 40: 559–567.
10. **Behm** DG, St-Pierre DMM, Perez D. (1996) Muscle inactivation: assessment of interpolated twitch technique. J Appl Physiol 81:2267–2273.
11. **Berth** A, Urbach D, Awiszus F. (2002) Improvement of voluntary quadriceps muscle activation after total knee arthroplasty. Arch Phys Med Rehabil 83:1432–1436.
12. **Berth** A, Urbach D, Neumann W, Awiszus F. (2007) Strength and voluntary activation of quadriceps femoris muscle in total knee arthroplasty with midvastus and subvastus approaches. J Arthroplast 22:83–88.
13. **Britton** AR, Murray DW, Bulstrode CJ, McPherson K, Denham RA. (1997) Pain levels after total hip replacement. J Bone Joint Surg 79-B:93–8.
14. **Brown** K, Swank AM, Quesada PM, Nyland J, Malkani A, Topp R. (2010) Prehabilitation versus usual care before total knee arthroplasty: A case report comparing outcomes within the same individual. Physiother Theor and Pract 26:399–407.
15. **Brugioni** DJ, Falkel J. (2004) Total knee replacement & rehabilitation. The knee owner's manual. 1st ed. Hunter House, pp. 26–29.
16. **Buchanan** WW, Kean WF. (2002) Osteoarthritis I: Epidemiological risk factors and historical considerations. Inflammopharmacology 10:5–21.
17. **Bullens** PHJ, van Loon CJM, de Waal Malefijt MC, Laan RFJM, Veth RPH. (2001) Patient satisfaction after total knee arthroplasty. Acomparison between subjective and objective outcome assessments. J Arthroplasty 16:740–747.
18. **Börjesson** M, Weidenhielm L, Mattsson E, Olsson E. (2005) Gait and clinical measurements in patients with knee osteoarthritis after surgery: a prospective 5-year follow-up study. The Knee 12:121–127.

19. **Chiari** L, Rocchi L, Cappello A. (2002) Stabilometric parameters are affected by anthropometry and foot placement. Clin Biomech 17:666–677.
20. **Cho** SD, Hwang CH. (2013) Improved single-limb balance after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 21: 2744–2750.
21. **Cimolin** V. Galli M. Grugni G. Vismara L. Precilios H. Albertini G. Rigoldi C. Capodaglio P. (2011) Postural strategies in Prader-Willi and Down syndrome patients. Res Dev Disabil 32:669–673.
22. **Clarkson** HM. (2005) Joint Motion and Function Assessment. Lippincott Williams & Wilkins.
23. **Cooper** C. (1998) Epidemiology of osteoarthritis. In. Klippel JH, Dieppe PA, editors. Rheumatology 2nd ed. London: Mosby 1–20.
24. **Cooper** C, Snow S, McAlindon TE, Kellingrey S, Stuart B, Coggon D, Dieppe PA. (2000) Risk factors for the incidence and progression of radiographic knee osteoarthritis. Arthritis Rheum 43:995–1000.
25. **Davis** RB, Õunpuu S, Tyburski D, Gage JR. (1991) A gait analysis data collection and reduction technique. Hum Movement Sci 10:575–87.
26. **Deyle** GD, Allison SC, Matekel RL, Ryder MG, Stang JM, Gohdes DD, Hutton JP, Henderson NE, Garber MB. (2005) Physical therapy treatment effectiveness for osteoarthritis of the knee: a randomized comparison of supervised clinical exercise and manual therapy procedures versus a home exercise program. Phys Ther 85: 1301–1317.
27. **Deyle** GD, Henderson NE, Matekel RL, Ryder MG, Garber MB, Allison SC. (2000) Effectiveness of manual physical therapy and exercise in osteoarthritis of the knee. Ann Inter Med 132: 173–181.
28. **Dixon** J, Howe TE. (2005) Quadriceps force generation in patients with osteo-arthritis of the knee and asymptomatic participants during patellar tendon reflex reactions: an exploratory cross-sectional study. BMC Musculoskelet Disord 6:46–53.
29. **Doyle** RJ, Hsiao-Wecksler, Ragan BG, Rosengren KS. (2007) Generalizability of center of pressure measures of quiet standing. Gait Posture 25:166–171.
30. **Doyle** TL, Newton RU, Burnett AF. (2005) Reliability of traditional and fractal dimension measures of quiet stance centre of pressure in young, healthy people. Arch Phys Med Rehabil 86:2034–2040.
31. **Erdemir** A, McLean S, Herzog W, van de Bogert AJ. (2007) Model-based estimation of muscle forces exerted during movements. Clin Biomech 22:131–154.
32. **Erler** K, Neumann U, Brückner, J. Venbrocks R, Anders C, Scholle HC. (2000) EMG mapping-applications and results in assessment of muscle coordination disorders in patients with a knee endoprosthesis (knee TEP). Z Orthop Ihre Grenzgeb 138:197–203.
33. **Felson** DT, Zhang Y. (1998) An update on the epidemiology of knee and hip osteoarthritis with a view to prevention. Arthritis Rheum 41:1343–1355.
34. **Felson** DT, Chaisson CE, Hill CL, Totterman SMS, Gale ME, Skinner KM, Kazis L, Gale DR. (2001) The association of bone marrow lesions with pain in knee osteoarthritis. Ann Intern Med 134:541–549.
35. **Fraenkel** L, Bogardus ST, Concato J, Wittink DR. (2004) Treatment options in knee osteoarthritis the patients perspectives. Arch Intern Med 164: 1299–1304.
36. **Fransson** PA, Johansson R, Hafström A, Magnusson M. (2000) Methods for evaluation of postural control adaptation. Gait Posture 12:14–24.
37. **Gapeyeva** H, Buht N, Peterson K, Ereline J, Haviko T, Pääsuke M. (2007) Quadriceps femoris muscle voluntary isometric force production and relaxation

characteristics before and 6 months after unilateral total knee arthroplasty in women. Knee Surg Sports Traumatol Arthrosc 15:202–211.

38. **Gauchard** GC, Vancon G, Meyer P, Mainard, D, Perrin, PP. (2010) On the role of knee joint in balance control and postural strategies: Effect of total knee replacement in elderly subjects with knee osteoarthritis. Gait Posture 32:155–160.

39. **Greene** KA, Schurman II JR. (2008) Quadriceps muscle function in primary total knee arthroplasty. J Arthroplast 23:15–19.

40. **Greve** J, Alonso A, Bordini ACPG, Camanho GL. (2007) Correlation between body mass index and postural balance. Clin Sci 6:717–720.

41. **Günther** KP, Sun Y. (1999) Reliability of radiographic assessment in hip and knee osteoarthritis. Osteoarthr Cartil 7:239–246.

42. **Hart** DJ, Doyle DV, Spector TD. (1999) Incidence and risk factors for radiographic knee osteoarthritis in middle-aged women. Arthritis Rheum 14:17–24.

43. **Hassan** BS, Mockett S, Doherty M. (2001) Static postural sway, proprioception, and maximal voluntary quadriceps contraction in patients with knee osteoarthritis and normal control subjects. Ann Rheum Dis 60:612–618.

44. **Hay** EM, Foster NE, Thomas, E, Peat G, Phelan M, Yates HE, Blenkinsopp A, Sim J. (2006) Effectiveness of community and enhanced pharmacy review for knee pain in people aged over 55 presenting to primary care: pragmatic randomised trial. BMJ 333:995–998.

45. **Herbert** RD, Gandevia SC. (1999) Twitch interpolation in human: mechanisms and implications for measurement of voluntary activation. J Neurophysiol 82: 2271–2283.

46. **Hinman** RS, Bennell KL, Metcalf BR, Crossley KM. (2002) Balance impairments in individuals with symptomatic knee osteoarthritis: a comparison with matched controls using clinical tests. Rheumatol 41:1388–1394.

47. **Hoffmann** GO, Marticke J, Grossstuck R, Hoffmann M, Lange M, Plettenberg HK, Braunschweig R, Schilling O, Kaden I, Spahn G. (2010) Detection and evaluation of initial cartilage pathology in man: a comparison between MRT, arthroscopy and near-infrared spectroscopy (NIR) in their relation to initial knee pain. Pathophysiology 17:1–8.

48. **Hohmann** E, Tetsworth K, Bryant A. (2011) Physiotherapy-guided versus home-based, unsupervised rehabilitation in isolated anterior cruciate injuries following surgical reconstruction. Knee Surg Sports Traumatol Arthrosc 19:1158–1167.

49. **Horak** FB. (2006) Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? Age Ageing 35-S2: ii7-ii11.

50. **Huang** HT, Chen CH, Chang JJ, Guo LY, Lin HT, Wu WL. (2007) Quantitative gait anlysis after unilateral knee arthroplasty for patients with bilateral knee osteoarthritis. J Med Biol Eng 28:11–16.

51. **Hunt** MA, Hinman RS, Metcalf BR, Lim B-W, Wrigley TV, Bowles KA et al. (2010a) Quadriceps strength is not related to gait impact loading in knee osteoarthritis. The Knee 17:296–302.

52. **Hunt** MA, McManus FJ, Hinman RS, Bennell KL. (2010b) Predictors of single-leg standing in individuals with medial knee osteoarthritis. Arthritis Care Res 62:496–500.

53. **Hue** OA, Seynnes O, Ledrole D, Colson SS, Bernard P-L. (2004) Effects of a physical activity program on postural stability in older people. Aging Clin Exp Res 16:1–7.

54. **Hurley** MV. (2003) Muscle dysfunction and effective rehabilitation of knee osteoarthritis: what we know and what we need to find out. Arthr Care Res 49: 444–452.

55. **Hurley** MV, Scott DV, Rees J, Newham DL. (1997) Sensimotor changes and functional performance in patients with knee osteoarthritis. Ann Rheum Dis 56;641–648.

56. **Imamura** M, Imamura ST, Kaziyama HHS, Targino RA, Hsing WT, Marques de Souza LP, Cutait MM, Fregini F, Camanho GL. (2008) Impact of nervous system hyperalgesia on pain, disability, and quality of life in patients with knee osteo-arthritis: a controlled analysis. Arthritis Rheum 59; 1424–1431.

57. **Jonkers** I, Stewart C, Spaepen A. (2003) The complementary role of the plantarflexors, hamstrings and gluteus maximus in the control of stance limb stability during gait. Gait Posture 17:264–272.

58. **Kean** WF, Kean R, Buchanan WW. (2004) Osteoarthritis: symptoms, signs and source of pain. Inflammopharmacology 12:3–31.

59. **Kellgren** JH, Lawrence JS. (1957) Radiological assessment of osteo-arthrosis. Ann Rheum Dis 16:494–501.

60. **Kim** TK, Kwon SK, Kang YG, Chang CB, Seong SC. (2010) Functional disabilities and satisfaction after total knee arthroplasty in female asian patients. J Arthorplasty 25:458–464.

61. **Kim** TK, Park KK, Yoon SW, Kim SJ. Chang CB, Seong SC. (2009) Clinical value of regular passive ROM exercise by a physical therapist after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 17:1152–1158.

62. **Knight** CA, Kamen G. (2001) Adaptations in muscular activation of the knee extensor muscles with strength training in young and older adults. J Electromyogr and Kinesiol 11:405–412.

63. **Krasnokutsky** S, Attur M, Palmer G, Samuels J, Abramson SB. (2008) Current concepts in the pathogenesis of osteoarthritis. Osteoarthr Cartil 16:S1-S3.

64. **Lavernia** C, Apuzzo MD, Rossi MD, Lee D. (2008) Accuracy of knee range of motion assessment after total knee arthroplasty. J Arthrpolasty 23: 85–91.

65. **Lin** DH, Lin YF, Chai HM, Han YC, Jan MH. (2007) Comparison of proprio-ceptive functions between computerized proprioception facilitation exercise and closed kinetic chain exercise in patients with knee osteoarthritis. Clin Rheumatol 26:520–528.

66. **Lin** C-WC, March L, Crosbie J, Crawford R, Graves S, Naylor J, Harmer A et al. (2009) Maximum recovery after knee replacement- the MARKER study rationale and protocol. BMC Musculoskelet Disord 10: 69- 78.

67. **Lloyd** DG, Buchanan TS. (2001) Strategies of muscular support of varus and valgus isometric loads at the human knee. J Biomech 34:1257–1267.

68. **Lonner** JH, Pedlow FX, Siliski JM. (1999) Total knee arthroplasty for post-traumatic arthrosis. J Arthroplasty 14: 969- 975.

69. **Lyytinen** T, Liivakaino T, Bragge T, Hakkarainen M, Jarjalainen PA, Arokoski JPA. (2010) Postural control and thigh muscle activity in men with knee osteo-arthritis. J Electromyogr Kines 20:1066–1074.

70. **Machner** A, Pap, G, Awiszus F. (2002) Evaluation of quadriceps strength and voluntary activation after unincompartmental arthroplasty for medial osteoarthritis of the knee. J Orthop Res 20:108–111.

71. **Maffiuletti** N, Bizzini M, Widler K, Munzinger U. (2010) Asymmetry in quadriceps rate of force development as a functional outcome measure in TKA. Clin Orthop Relat Res 468:191–198.

72. **March** LM, Bagga H. (2004) Epidemiology of osteoarthritis in Australia. MJA 180:S6-S10.

73. **Marks** R, Kumar S, Percy J, Semple J. (1995) Force-time measurement of the quadriceps femoris muscles of healthy women and women with osteoarthritis of the knee. Eur J Phys Med Rehabil 5:88–92.

74. **Masui** T, Hasegawa Y, Yamaguchi J, Kanoh T, Ishiguro N, Suzuki S. (2006) Increasing postural sway in rural-community-dwelling elderly persons with knee osteoarthritis. J Orthop Sci 11:353–358.

75. **McAlindon** TE, Snow S, Cooper C, Dieppe PA. (1992) Radiographic patterns of osteoarthritis of the knee joint in the community: the importance of the pattelofemoral joint. Ann Rheum Dis 51:844–849.

76. **McAlindon** TE, Bannuru RR, Sullivan MC, Arden NK, Berenbaum F, Bierma-Zeinstra SM, Hawker GA, Henrotin Y, et al. (2014) OARSI guidelines for the non-surgical management of knee osteoarthritis. Osteoarthr Cartil doi.org/10.1016/j.joca.2014.01.003 In Press.

77. **McCartney** CJ, Nelligan K. (2014) Postoperative pain management after total knee arthroplasty in elderly patients: treatment options. Drugs Aging DOI 10.1007/s40266–013–0148-y.

78. **Menegoni** F, Galli M, Tacchini E, Vismara L, Cavigioli M, Capodaglio P. (2009) Gender-specific effect of obesity on balance. Obesity 17:1951–1956.

79. **Milner** CE. (2008) Interlimb asymmetry during walking following unilateral total knee arthroplasty. Gait Posture 28:69–73.

80. **Milner** CE. (2009) Is gait normal after total knee arthroplasty? Systramatic review of the literature. J Orthop Sci 14:114–120.

81. **Mizner** RL, Petterson SC, Stevens JE, Vandenborne K, Snyder-Mackler L. (2005a) Early quadriceps strength loss after total knee arthroplasty. the contributions of muscle atrophy and failure of voluntary muscle activation. J Bone Joint Surg Am 87:1047–1053.

82. **Mizner** RL, Petterson SC, Stevens JE, Axe MJ, Snyder-Mackler L. (2005b) Pre-operative quadriceps strength predicts functional ability 1 year after total knee arthroplasty. J Rheumatol 32:1533–1539.

83. **Mizner** RL, Snyder-Mackler L. (2005) Altered loading during walking and sit-to-stand is affected by quadriceps weakness after total knee arthroplasty. J Orthop Res 23:1083–1090.

84. **Mizner** RL, Stevens JE, Snyder-Mackler L. (2003) Voluntary activation and decreased force production of the quadriceps femoris muscle after total knee arthroplasty. Phys Ther 83:359–365.

85. **Moffet** H, Collet JP, Shapiro SH, Paradis G, Marquis F, Roy L. (2004) Effectiveness of intensive rehabilitation on functional ability and quality of life after first total knee arthroplasty: a single- blind Randomized controlled trial. Arch Phys Med Rehabil 85:546–556.

86. **Morton** JP, Atkinson G, MacLaren DP, Cable NT, Gilbert G, Broome C, McArdle A, Drust B. (2005) Reliability of maximal muscle force and voluntary activation as markers of exercise-induced muscle damage. Eur J Appl Physiol 94:541–548.

87. **Murray** CJL, Lopez AD. (1997) The global burden of disease. Geneva: World Helath Organization.

88. **Mündermann** A, Dyrby CO, Andriacchi TP. (2005) Secondary gait changes in patients with medial compartment knee osteoarthritis. Arthritis Rheum 52:2835–2844.

89. **Müürsepp** I, Aibast H, Pääsuke M. (2011) Motor performance and haptic perception in preschool boys with specific imparment of expressive language. Acta Pædiatr 100:1038–1042.

90. **Nadeau** S, Gravel D, Arsenault AB, Bourbonnais D. (1996) A mechanical model to study the relationship between gait speed and muscular strength. IEEE Trans Rehabil Eng 4:386–394.

91. **Núñez** M, Núñez E, Luis del Val J, Ortega R, Segur JM, Victoria Hernandez M, Lozano L, Sastre S, Macule F. (2007) Health-related quality of life in patients with osteoarthritis after total knee replacement: Factors influencing outcomes at 36 months of follow-up. Osteoarthr Cartil 15:1001–1007.

92. **O'Reilly** SC, Jones A, Muir KR, Doherty M. (1998) Quadriceps weakness in knee osteoarthritis: the effect on pain and disability. Ann Rheum Dis 57:588–594.

93. **Pap**, G, Machner, A, Awiszus, F. (2004) Strength and voluntary activation of the quadriceps femoris muscle at different severities of osteoarthritic knee joint damage. J Orthop Res 22:96–103.

94. **Peat** G, McCarney R, Croft P. (2001) Knee pain and osteoarthritis in older adults: a review of community burden and current use of primary health care. Ann Rheum Dis 60:91–97.

95. **Perruccio** AV, Lohmander LS, Canizares M, Tennant A, Hawker GA, Conaghan PG, Roos EM, et al. (2008) The development of a short measure of physical function for knee OA KOOS-Physical Function Short form (KOOS-PS) – an OARSI/OMERACT initiative. Osteoarthr Cartil 16:542–550.

96. **Pääsuke** M, Ereline J, Gapeyeva H. (1999) Neuromuscular fatique during repeated exhaustive submaximal static contractions of knee extensor muscles in endurance-trained, power-trained and untrained men. Acta Physiol Scand 166:319–326.

97. **Quatman** CE, Hettrich CM, Schmitt LC, Spindler KP. (2011) The clinical utility and diagnostic performance of magnetic resonance imaging for identification of early and advanced knee osteoarthritis: A systematic review. Am J Sport Med 39:1557–1568.

98. **Raudsepp** L, Pääsuke M. (1995) Gender differences in fundamental movement patterns, motor performances, and strength measurements of prepubertal children. Pediatr Exerc Sci 7:294–304.

99. **Reguião** LF, Nadeau S, Milot MH, Gravel D, Bourbonnais D, Gagnon D. (2005) Quantification of level of effort at the plantarflexors and hip extensors and flexor muscles in healthy subjects walking at different cadences. J Electromyogr Kines 15:393–405.

100. **Reichenbach** S, Rutjes AWS, Nüesch E, Trelle S, Jüni P. (2010) Joint lavage for osteoarthritis of the knee. Cochrane Database Syst Rev, issue 5, art no. CD007320. doi:10.1002/14651858.CD007320.pub2.

101. **Roddy** E, Zhang W, Doherty M et al. (2005) Evidence-based recommendations for the role of exercise in the management of osteoarthritis of the hip or knee—the MOVE consensus. Rheumatology 44:67–73.

102. **Rooks** DS, Huang J, Bierbaum BE, Bolus SA, Rubano J, Connolly CE et al. (2006) Effect of preoperative exercise on measures of functional status in men and women undergoing total hip and knee arthroplasty. Arthritis Care Res 55:700–708.

103. **Roos** EM, Toksvig-Larsen, S. (2003) Knee injury and osteoarthritis outcome score (KOOS)- validation and comparison to the WOMAC in total knee replacement. Health Qual Life Out 1:17.

104. **Rossi** MD, Hasson S, Kohia M, Pineda E, Bryan W. (2007) Relationship of closed and open chain measures of strength with perceived physical function and mobility following unilateral total knee replacement. J Geriatr Phys Ther 30:23–27.

105. **Salavati** M, Hadian MR, Mazaheri M, Negahban H, Ebrahimi I, Talebian S, Jafari AH, Sanjari MA, Sohani SM, Parnianpour M. (2009) Test-retest reliability of center of pressure measures of postural stability during quiet standing in a group with musculoskeletal disorders consisting of low back pain, anterior cruciate ligament injury and functional ankle instability. Gait Posture 29:460–464.

106. **Schwartz** I, Kandel L, Sajina A, Litinezki D, Herman, Matta Y. (2012) Balance is an important factor for quality of life and function after primary total knee replacement. J Bone Joint Surg Br 94:782–786.

107. **Shumway-Cook** A, Woollacott MH. (2012) Motor control. Lippingott Williams& Wilkins.

108. **Smith** AJ, Lloyd DG, Wood DJ. (2004) Pre-surgery knee joint loading patterns during walking predict the presence and severity of anterior knee pain after total knee arthroplasty. J Orthop Res 22:260–266.

109. **Slemenda** C, Heilman DK, Brandt KD, Katz BP, Mazzuca SA, Braunstein EM, Byrd D. (1998) Reduced quadriceps strength relative to body weight: A risk factor for knee osteoarthritis in women? Arthritis Rheum 11:1951–1959.

110. **Spahn** G, Hohmann GO, Klinger HM. (2013) The effects of arthroscopic joint debridement in the knee osteoarthritis: results of a meta-analysis. Knee Surg Sports Traumatol Arthrosc 21:1553–1561.

111. **Stackhouse** SK, Dean JC, Lee SCK, Binder-MacLeod SA. (2000) Measurement of central activation failure of the quadriceps femoris in healthy adults. Muscle Nerve 23:1706–1712.

112. **Steadman** JR, Ramappa AJ, Maxwell RB, Briggs KK. (2007) An arthroscopic treatment regimen for osteoarthritis of the knee. Arthroscopy 23:948–955.

113. **Stevens** JE, Mizner RL, Snyder-Mackler L. (2003) Quadriceps strength and volitional activation before and after total knee arthroplasty for osteoarthritis. J Orthop Res 21:775–779.

114. **Stevens-Lapsely** JE, Schenkman, Dayton MR. (2011) Comparison of self-reported knee injury and osteoarthritis outcome score to performance measures in patients after total knee arthroplasty. Phys Med Rahabil 3:541–549.

115. **Swanik** CB, Lephart SM, Rubash HE. (2004) Proprioception, kinesthesia, and balance after total knee arthroplasty with cruciate-retaining and posterior stabilized prosthesis. J Bone Joint Surg 86-A:328–334.

116. **Tamm** A. (2000) Adaptation of the KOOS questionnaire for the use in Estonia. www.koos.nu.

117. **Tervishoiuteenused**.http://www.haigekassa.ee/haigekassa/statistika/tervishoiuteen used (23.01.2014).

118. **Thomas** KS, Muir KR, Doherty M, Jones AC, O'Reilly SC, Bassey EJ. (2002) Home based exercise programme for knee pain and knee osteoarthritis: randomised controlled trial. BMJ 325: 1–5.

119. **Thorstensson** CA, Hendriksson M, von Porat A, Sjödahl C, Roos EM. (2007) The effect of exercise on knee adduction moment in early knee osteoarthritis- a pilot study. Osteoarth Cartilage 15:1163–1170.

120. **Toma** K, Honda M, Hanakawa T, Okada T, Fukuyama H, Ikeda A, Nishizawa S, Konishi J, Shibasaki H. (1999) Activities of the primary and supplementary motor areas increase in preparation and execution of voluntary muscle relaxation: an event-related fMRI study. J Neurosci 19:3527–3534.

121. **Todd** G, Gorman RB, Gandevia SC. (2004) Measurement and reproducibility of strength and voluntary activation of lower-limb muscles. Muscle Nerve 29: 834–842.

122. **Valderrabano** V, Steiger C. (2011) Treatment and prevention of osteoarthritis through exercise and sports. J Ageing Res 10:1–6.

123. **Valtonen** A, Pöyhönen T, Heinonen A, Sipilä S. (2009) Muscle deficits persist after unilateral knee replacement and have implications for rehabilitation. Phys Ther 89:1072–1079.

124. **Walker-Bone** K, Javaid K, Arden N, Cooper C. (2000) Regular review: medical management of osteoarthritis. BMJ 321:936–940.

125. **Winby** CR, Loyd DG, Besier TF, Kirk TB. (2009) Muscle and external load contribution to knee joint contact loads during normal gait. J Biomech 42:2294–2300.

126. **Yoshida** Y, Mizner RL, Ramsey DK, Snyder-Macler L. (2008) Examining outcomes from total knee arthroplasty and the relationship between quadriceps strength and knee function over time. Clin Biomech 23:320–328.

127. **Zeni** JA, Snyder-Mackler L. (2010) Early postoperative measures predict 1-and 2-year outcomes after unilateral total knee arthroplasty: importance of contralateral limb strength. Phys Ther 90:43–54.

128. **Zhang** W, Moskowitz RW, Nuki G, Abramson S, Altman RD, Arden N, Bierma-Zeinstra S, et al. (2007) OARSI recommendations for the management of hip and knee osteoarthritis, Part I: Critical appraisal of existing treatment guidelines and systematic review of current research evidence. Osteoarthr Cartil 15:981–1000.

129. **Zhang** W, Moskowitz RW, Nuki G, Abramson S, Altman RD, Arden N, Bierma-Zeinstra S, et al. (2008) OARSI recommendations for the management of hip and knee osteoarthritis, Part II: OARSI evident- based, expert consensus guidelines. Osteoarthr Cartil 13:137–162.

SUMMARY IN ESTONIAN

Naispatsientide alajäseme lihaste funktsionaalse seisundi, kõnni ning seismistasakaalu seosed põlveliigese endoproteesimise järgselt

Sissejuhatus

Osteoartroos (OA) on degeneratiivne liigeshaigus, mis progresseeruvalt põhjustab liigese funktsioonilangust, koos kehalise aktiivsuse ja elukvaliteedi langusega (Krasnokutsky et al., 2008). OA risikifaktorid on vanus (Buchanan ja Kean, 2002), ülekaal, põlveliigese vigastus, suur kehaline aktiivsus (Cooper jt., 2000). Ka naissugu, madal haridustase, ebaõige liigesteljelisus ning nõrgad põlveliigest ümbritsevad lihased võivad olla OA sümptomite tekkepõhjuseks (Felson ja Zhang, 1998).

Põlveliigese endoproteesimine on operatiivse ravi meetod, mida rakendatakse OA-i lõpp-staadiumi ravis. Aastas teostatakse Ameerikas ligikaudu pool miljonit (Krasnokutsky jt., 2008), Austraalias 39 000 (March ja Bagga, 2004) ning Eestis 3000 (Eesti Haigekassa, 2012) põlve- ja puusaliigese endoproteesimist. Nimetatud operatsioonide arvud võivad suureneda lähtuvalt rahvastiku arvu ja vanuse kasvust veelgi. Tuginedes eelöeldule, on primaarsed ja sekundaarsed OA preventsiooni eesmärgid vähendada ülekaalulisust, ennetada tugiliikumisaparaadi vigastusi, innustada inimesi kehalisele aktiivsusele ning arendada rehabilitatsiooniteenust (March ja Bagga, 2004).

Põlveliigese OA-ga patsientide funktsionaalne hindamine sisaldab põlvevalu (VAS; ingl k *visual analogue scale*), põlveliigese liikuvuse, lihasjõu ja -astupidavuse, tasakaalu, proprioretseptsiooni ning kõnni hindamist. Eksisteerib mitmeid põlveliigese OA küsimustikke (põlveliigese osteoartriidi tulem-KOOS; ingl k *Knee injury and Osteoarthritis Outcome Score*), mis võimaldavad hinnata patsientide elukvaliteeti, funktsionaalsust, igapäevaeluga hakkamasaamist. Lähtuvalt kehalise aktiivsuse langusest, on põlveliigese OA tugevalt seotud reie nelipealihase nõrkusega (Hurley, 2003; Mizner jt., 2005a). Vaatamata sellele, et põlveliigese endoproteesimisel on valdavalt positiivsed tagajärjed põlvevalu vähenemise ning alajäseme funktsionaalsuse taastumise näol, taastub alajäsemete lihaste jõud ning kehaline aktiivsus harva haiguseelsele tasemele (Valtonen jt., 2009; Maffiuletti jt., 2010). Mitmed uuringud kinnitavad, et reie nelipealihase jõu langus eksisteerib aastaid pärast põlveliigese endoproteesimist (Mizner jt., 2005b; Rossi jt., 2007; Valtonen jt., 2009; Zeni ja Snyder-Mackler 2010). Siiani puudub täpsem teave põlveliigese OA patsientide lihaskontraktsiooni ja tsentraalse närvisüsteemi mehhanismide kohta.

Põlveliigese OA mõjutab liigese optimaalset koormamist kõnni ajal (Hunt jt., 2010a). Vaatamata sellele, et mitmed uuringud kinnitavad kõnni ajalis-ruumiliste karakteristikute paranemist pärast põlveliigese endoproteesimist (Huang jt., 2007; Yoshida jt., 2008; Milner, 2009), eksisteerib põlve kinemaatikas alajäsemete vaheline erinevus võrreldes tervete vaatluaasalustega.

Ka põlveliigese OA patsientide seismise tasakaal ja seda mõjutavate antropomeetriliste ning funktsionaalsete karakteristikute osas esineb eriarvamusi. Eksisteerib uuringuid, mis kinnitavad, et põlveliigese OA patsientide halb tasakaal on tingitud proprioretseptiivsest defitsiidist, lihasjõu langusest ja põlvevalust (Hassan jt., 2001). Samas on leitud, et põlveliigese OA patsientidel ei esine tasakaaluhäireid (Lyytinen jt., 2010).

Käesoleva töö eesmärgiks oli välja selgitada alajäsemete lihaste funktsionaalse seisundi, kõnniparameetrite ning seismistasakaalu näitajate vahelised seosed põlveliigese OA-ga naispatsientidel enne ning pärast põlveliigese endoproteesimist.

Uurimistöö ülesanded

Põhieesmärgist lähtuvalt püstitati uurimistöös järgmised ülesanded:
1. Määrata reie nelipealihase tahtelise isomeetrilise maksimaaljõu, plahvatusliku jõu ning elektrostimulatsiooniga esile kutsutud üksikkontraktsiooni näitajad naispatsientidel enne ja pärast põlveliigese endoproteesimist.
2. Määrata alajäseme sirutajalihaste tahtelise isomeetrilise maksimaaljõu ja kõnni toeperioodi vertikaalmomendi faasis põlveliigesele mõjuva koormuse vaheline seos naispatsientidel ja kontrollgrupil.
3. Määrata keha staatilise tasakaalu, antropomeetriliste ja funktsionaalsete näitajate vaheline seos naispatsientidel ja kontrollgrupil.
4. Hinnata põlveliigese valu, määrata põlveliigese aktiivne liikuvus ning KOOS skoor naispatsientidel enne ja pärast põlveliigese endoproteesimist.

Uuritavad ja kasutatav metoodika

Uuringus osales neliteist degeneratiivse põlveliigese OA-ga naispatsienti, kelle liigeshaiguse areng oli vastavalt Kellgren-Lawrence Skaalale III või IV staadiumis. Vaatlusalused kaasati uuringusse ortopeedide poolt teostatava põlveliigese endoproteesilõikuse patsientide nimekirjast. Kuuel vaatlusalusel oli diagnoositud bilateraalne OA, kuid mitteopereeritava põlve haigus oli vastavalt Kellgren-Lawrence Skaalale esimeses staadiumis. Patsientide uuringusse kaasamise kriteeriumid olid põlveliigese OA diagnoos, esimene liigese endoproteeslõikus ning võime kõndida ilma käimisabivahendita. Uuringusse ei kaasatud patsiente, kellel oli kardiovaskulaarne, pulmonaalne, neuromuskulaarne haigus, või teostatud varasemalt endoproteeslõikusi. Keskmine põlveliigese OA sümptomite kestvus enne endoproteesimist oli 6 aastat. Eeldatavad põlveliigese OA põhjused olid raske füüsiline töö (7 patsienti) ning varasem põlveliigese trauma (7 patsienti).

Kõiki põlveliigese OA-ga naispatsiente uuriti 1 päev enne, 3 ja 6 kuud pärast põlveliigese endoproteesimist Tartu Ülikooli Kinesioloogia ja Biomehaanika laboris. II ja III uuringus võrreldi põlveliigese OA-ga naispatsientide funktsionaalseid näitajaid kontrollgrupi samaealiste, tervete naiste funktsionaalsete näitajatega. Kontrollgrupi uuritavatega teostati uuring ühekordselt.

Käesoleva töö esimeses osas hinnati naispatsientide põlvevalu VAS skaalal ning täideti KOOS küsimustik. Reie nelipealihase kontraktiilsete omaduste ning tahtelise isomeetrilise jõu määramiseks kasutati spetsiaalset elektromehaanilist dünamomeetrit. Määrati reie nelipealihase maksimaaljõud, plahvatuslik jõud, elektrostimulatsiooniga esile kutsutud üksikkontraktsiooni jõu ning lihase kontraktsiooni- ja lõõgastusparameetrid.

Uurimustöö teises osas teostati esmalt kõnnianalüüs, seejärel mõõdeti alajäseme sirutajalihaste isomeetriline maksimaaljõud. Uuritavate kõnni bio-mehaaniliseks analüüsiks kasutati optilis-elektroonilist aparatuurikompleksi Elite (BTS, Itaalia). Liigutustegevuse 3-D kinemaatiline analüüs 6 infrapuna-kaamera ja kahe dünamograafilise platvormi abil võimaldas hinnata järgmisi kõnni ajalisi ja ruumilisi parameetreid: sammu pikkus, kõnni kiirus ning kõnni toeperioodi vertikaalmomendi faasis põlveliigesele mõjuvad jõud nagu põlveliigese paintusmoment ja põlveliigese võimsus. Alajäseme sirutajalihaste maksimaalse kontraktsioonijõu määramiseks kasutati spetsiaalselt konstrueeri-ritud dünamograafilist seadet.

Uurimustöö kolmandas osas teostati uuritavate antropomeetrilised ja funktsionaalsed (põlvevalu, põlveliigese aktiivne liikuvus, alajäseme sirutaja-lihaste maksimaaljõud) mõõtmised ning hinnati keha staatilist tasakaalu seistes. Keha staatilise tasakaalu hindamiseks seistes kasutati dünamograafilist plat-vormi Kistler 9286A (Šveits), kus uuritav seisis 30 sekundit vastavalt parem ja vasak jalg kahel kõrvuti asetseval platvormil silmad avatud. Töös analüüsitud tasakaaluparameetrid olid: keha survetsentri kõikumise näitaja ette-taha ning külgsuunas, survetsentri liikumise kiirus ja kõikumise poolt moodustatud kujundi pindala.

Uuringus osalenud naispatsientidel hinnati kõikide mõõtmiste korral esmalt haige jalg, siis haigusest mittehaaratud jalg. Uuringus osalemiseks allkirjastasid kõik vaatlusalused uuringus osalemise nõusolekulehe. Käesolev uuring oli kooskõlastatud Tartu Ülikooli Inimuuringute Eetika Komiteega.

Kokkuvõte

Tuginedes käesoleva uurimistöö tulemustele võib väita, et põlveliigese endopro-teesimine ning sellele järgnenud taastumine leevendas oluliselt patsientide põlvevalu ning parandas elukvaliteeti. Individuaalne füsioteraapia ei mõjutanud reie nelipealihase tetaanilist üksikkontraktsiooni jõudu ning lihase kontrakt-siooni- ja lõõgastusparameetrid, samuti keha staatilist tasakaalu. Vaatamata eelöeldule, eksisteeris tendents reie nelipealihase ja alajäseme sirutajalihaste jõu kasvule pool aastat pärast põlveliigese endoproteesimist. Alajäseme sirutaja-lihaste jõu langus 3 kuud pärast põlveliigese operatsiooni põhjustas ülemäärase koormuse põlveliigesele kõnni toeperioodi vertikaalmomendi faasis. Vaatamata sellele, et patsientide suurem kehamassi indeks tagas väiksema keha surve-tsentri kõikumise kiiruse keha staatilise tasakaalu hindamisel seistes, on ülekaalulisus faktor, mis vajab tähelepanu uute võimalike liigeskahjustuste ennetamisel. Patsientide teadmised põlveliigese OA-st, selle taastusravist ning

tervislikest eluviisidest on väga olulised funktsionaalsete häirete ning ravi-teenuste vähendamisel.

Kokkuvõtteks võib tõdeda, et pool aastat pärast põlveliigese endoprotee-simist eksisteeriv opereeritud alajäseme lihaste oluliselt väiksem jõud võrreldes mitteopereeritud jalaga, nõuab traditsiooniliste rehabilitatsiooniprotokollide kohaselt veelgi intensiivsemat füsioterapeutilist sekkumist (Bade et al., 2010).

Järeldused

1. Enne ja pool aastat pärast põlveliigese endoproteesimist on põlveliigese osteoartroosiga naispatsientidel reie nelipealihase tahteline maksimaalne ja plahvatuslik jõud haigusest haaratud alajäsemel oluliselt vähenenud, see-juures elektrostimulatsiooniga esile kutsutud reie nelipealihase üksik-kontraktsiooni parameetrid ning lihase kontraktsiooni- ja lõõgastuspara-meetrid ei erine oluliselt pre- ega postoperatiivselt

2. Pool aastat pärast põlveliigese endoproteesimist on naispatsientidel ope-reeritud alajäseme sirutajalihaste isomeetriline maksimaaljõud samaväärne preoperatiivse tasemega, jäädes oluliselt väiksemaks mitte opereeritud alajäsemega võrreldes.

3. Naispatsientide opereeritud alajäseme ajalis-ruumilised parameetrid kõnnil ei erine mitte opereeritud alajäseme samadest näitajatest, kuid võrreldes kontrollgrupiga on opereeritud alajäseme põlveliigesele mõjuv koormus kõnni toeperioodi vertikaalmomendi faasis ning kõnnikiirus oluliselt väik-sem. Kolmandal postoperatiivsel kuul nähtub seos alajäseme sirutajalihase jõu languse ning kõnnil põlveliigesele avalduva suure koormuse vahel.

4. Põlveliigese osteoartoosiga naispatsientidel ilmneb suurem nihe bilateraalsel seismisel võrreldes tervete vaatlusalustega nii enne kui pärast põlveliigese endoproteesimist vaid ette-taha suunas. Naispatsientide keha staatiline tasakaal seismisel on seotud suurema keha survetsentri trajektoori alaga. Suurem kehamassi indeks on seotud väiksema keha survetsentri kõikumise kiiruse ning väiksema põlveliigese liikuvusega nii opereeritud kui mitte opereeritud jalal.

5. Pool aastat pärast põlveliigese endoproteesimist on naispatsientide valu opereeritud põlveliigeses minimaalne, KOOS skoor on suurem ning põlve-liigese aktiivne liikuvus on samaväärne preoperatiivse tasemega.

ACKNOWLEDGEMENTS

PUBLICATIONS

CURRICULUM VITAE

Name: Doris Vahtrik
Date of birth: 14.06.1972
Citizenship: Estonia
Address: Ravila 14a 50411, Tartu
Phone/fax: 737 5379
E-mail: Doris.Vahtrik@ut.ee

Education:
2006–2014   University of Tartu, Faculty of Exercise and Sport Sciences, Doctorate Study
2001–2003   University of Tartu, Faculty of Exercise and Sport Sciences, MSc
1996–1999   Oulu University of Applied Sciences (physiotherapy)
1991–1995   University of Tartu, Faculty of Exercise and Sport Sciences, BSc
1979–1990   Tartu Secondary School No 5

Professional Employment:
2013–   University of Tartu, Faculty of Exercise and Sport Sciences, Institute of Exercise Biology and Physiotherapy, lecturer
2000–2013   University of Tartu, Faculty of Exercise and Sport Sciences, Institute of Exercise Biology and Physiotherapy, assistant
1999–2000   University of Tartu, Faculty of Exercise and Sport Sciences, Institute of Exercise Biology, laboratory technician
1994–1999   Tartu University Hospital, department of rehabilitation, physiotherapists

Specialized courses:
2014   Mulligan Therapy. Manual mobilization. Vaidas Stalioraitis, Australian Mulligan concept therapy teacher; University of Tartu; Tartu
2013   Orthopedical manual therapy. Kathy Berglund, North American Institute of Orthopedical Manual Therapy; University of Tartu; Tartu
2012   Conference „Science, sport, medicine IX"; Tartu
2011   International Conference on Rheumatism. Estonian Sociaty of Rheumatology; Tallinn
2010   1st Baltic and North Sea Conference on Physical and Rehabilitation Medicine; Stockholm
2010   „Dialogue of best practices in formal and nonformal adult learning in rehabilitation education DIAFONARE"; Tartu
2009   „Postural stability and its assessment by digital biometric method"; Tartu

Membership in professional organizations:
Estonian Union of Physiotherapists- member of professional committee, superior of professional evaluation committee

Scientific activity:
Main research interest:
- Lower limb muscles functionality, postural stability and gait characteristics in patients with knee osteoarthritis prior and after knee replacement

Publications:
Articles in international refereed journals – 3
Other scientific articles – 6
Abstracts – 4

ELULOOKIRJELDUS

Nimi: Doris Vahtrik
Sünniaeg: 14.06.1972
Kodakondsus: Estonia
Aadress: Ravila 14a 50411, Tartu
Telefon/fax: 737 5379
E-post: Doris.Vahtrik@ut.ee

Haridus:
2006–2014 Tartu Ülikool kehakultuuriteaduskond, doktoriõpe (liikumis- ja spordiiteadused)
2001–2003 Tartu Ülikool kehakultuuriteaduskond, MSc (liikumis- ja spordi-teadused)
1996–1999 Oulu Tervishoiu Ametikõrgkool (füsioteraapia)
1991–1995 Tartu Ülikool kehakultuuriteaduskond, BSc (liikumis- ja spordi-teadused)
1979–1990 Tartu 5. Keskkool

Erialane teenistuskäik:
2013– Tartu Ülikool kehakultuuriteaduskond, Spordibioloogia ja füsioteraapia instituut, lektor
2000–2013 Tartu Ülikool kehakultuuriteaduskond, Spordibioloogia ja füsioteraapia instituut, assistent
1999–2000 Tartu Ülikool Kehakultuuriteaduskond, Spordibioloogia instituut, vanemlaborant
1994–1999 Tartu Ülikooli Kliinikum, taastusravi osakond, liikumisravi spetsialist, füsioterapeut

Erialane enesetäiendus:
2014 Mulligani teraapia-manuaalne mobilisatsioon. Vaidas Stalioraitis, Aust-raalia Mulligani teraapia õpetaja; Tartu Ülikool, Tartu
2013 Ortopeediline manuaalteraapia. Kathy Berglund, Põhja-Ameerika Orto-peedilise Manuaalteraapia Instituut, Tartu Ülikool; Tartu
2012 Konverents „Teadus, sport, meditsiin IX"; Tartu
2011 Ravusvaheline reumakonverents. Eesti Reumatoloogia Selts; Tallinn
2010 1st Baltic and North Sea Conference on Physical and Rehabilitation Medicine; Stockholm
2010 „Dialogue of best practices in formal and nonformal adult learning in rehabilitation education DIAFONARE"; Tartu
2009 „Keha tasakaal ja selle mõõtmine digitaliseeritud biomeetria meetodil"; Tartu

Erialaorganisatsioonid:
Eesti Füsioterapeutide Liit- kutsekomisjoni liige, hindamiskomisjoni esimees

Teadustegevus:

Peamised uurimisvaldkonnad:

- põlveliigese osteoartroosiga naispatsientide alajäseme lihaste funktsionaalne seisund, posturaalstabiilsus ja kõnniparameetrid enne ja pärast endoproteesimist

Publikatsioonid:

Teaduslikud artiklid rahusvahelise levikuga ajakirjades – 3
Muud teaduslikud artiklid – 6
Konverentside teesid – 4

DISSERTATIONES KINESIOLOGIAE
UNIVERSITATIS TARTUENSIS

1. **Lennart Raudsepp.** Physical activity, somatic characteristics, fitness and motor skill development in prepubertal children. Tartu, 1996, 138 p.
2. **Vello Hein.** Joint mobility in trunk forward flexion: methods and evaluation. Tartu, 1998, 107 p.
3. **Leila Oja.** Physical development and school readiness of children in transition from preschool to school. Tartu, 2002, 147 p.
4. **Helena Gapeyeva.** Knee extensor muscle function after arthroscopic partial meniscectomy. Tartu, 2002, 113 p.
5. **Roomet Viira.** Physical activity, ecological system model determinants and physical self-perception profile in early adolescence. Tartu, 2003, 167 p.
6. **Ando Pehme.** Effect of mechanical loading and ageing on myosin heavy chain turnover rate in fast-twitch skeletal muscle. Tartu, 2004, 121 p.
7. **Priit Kaasik.** Composition and turnover of myofibrillar proteins in volume – overtrained and glucocorticoid caused myopathic skeletal muscle. Tartu, 2004, 123 p.
8. **Jarek Mäestu.** The perceived recovery-stress state and selected hormonal markers of training stress in highly trained male rowers. Tartu, 2004, 109 p.
9. **Karin Alev.** Difference between myosin light and heavy chain isoforms patterns in fast- and slow-twitch skeletal muscle: effect of endurance training. Tartu, 2005, 117 p.
10. **Kristjan Kais.** Precompetitive state anxiety, self-confidence and ahtletic performance in volleyball and basketball players. Tartu, 2005, 99 p.
11. **Aire Leppik.** Changes in anthropometry, somatotype and body composition during puberty: a longitudinal study. Tartu, 2005, 161 p.
12. **Jaan Ereline.** Contractile properties of human skeletal muscles: Association with sports training, fatigue and posttetanic potentiation. Tartu, 2006, 133 p.
13. **Andre Koka.** The role of perceived teacher feedback and perceived learning environment on intrinsic motivation in physical education. Tartu, 2006, 137 p.
14. **Priit Purge.** Performance, mood state and selected hormonal parameters during the rowing season in elite male rowers. Tartu, 2006, 101 p.
15. **Saima Kuu.** Age-related contractile changes in plantarflexor muscles in women: associations with postactivation potentiation and recreational physical activity. Tartu, 2006, 101 p.
16. **Raivo Puhke.** Adaptive changes of myosin isoforms in response to long-term strength training in skeletal muscle of middle-aged persons. Tartu, 2006, 99 p.

17. **Eva-Maria Riso.** The effect of glucocorticoid myopathy, unloading and reloading on the skeletal muscle contractile apparatus and extracellular matrix. Tartu, 2007, 114 p.

18. **Terje Sööt.** Bone mineral values in young females with different physical activity patterns: association with body composition, leg strength and selected hormonal parameters. Tartu, 2007, 94 p.

19. **Karin Tammik.** Neuromuscular function in children with spastic diplegic cerebral palsy. Tartu, 2007, 102 p.

20. **Meeli Saar.** The relationships between anthropometry, physical activity and motor ability in 10–17-year-olds. Tartu, 2008, 96 p.

21. **Triin Pomerants.** Ghrelin concentration in boys at different pubertal stages: relationships with growth factors, bone mineral density and physical activity. Tartu, 2008, 80 p.

22. **Tatjana Kums.** Musculo-skeletal function in young gymnasts: association with training loads and low-back pain. Tartu, 2008, 128 p.

23. **Maret Pihu.** The components of social-cognitive models of motivation in predicting physical activity behaviour among school students. Tartu, 2009, 116 p.

24. **Peep Päll.** Physical activity and motor skill development in children. Tartu, 2009, 102 p.

25. **Milvi Visnapuu.** Relationships of anthropometrical characteristics with basic and specific motor abilities in young handball players. Tartu, 2009, 114 p.

26. **Rita Gruodytė.** Relationships between bone parameters, jumping height and hormonal indices in adolescent female athletes. Tartu, 2010, 82 p.

27. **Ragnar Viir.** The effect of different body positions and of water immersion on the mechanical characteristics of passive skeletal muscle. Tartu, 2010, 142 p.

28. **Iti Müürsepp.** Sensorimotor and social functioning in children with developmental speech and language disorders. Tartu, 2011, 90 p.

29. **Ege Johanson.** Back extensor muscle fatigability and postural control in people with low back pain. Tartu, 2011, 106 p.

30. **Evelin Lätt.** Selected anthropometrical, physiological and biomechanical parameters as predictors of swimming performance in young swimmers. Tartu, 2011, 90 p.

31. **Raul Rämson.** Adaptation of selected blood biochemical stress and energy turnover markers to different training regimens in highly trained male rowers. Tartu, 2011, 84 p.

32. **Helen Jõesaar.** The effects of perceived peer motivational climate, autonomy support from coach, basic need satisfaction, and intrinsic motivation on persistence in sport. Tartu, 2012, 108 p.

33. **Sille Vaiksaar.** Effect of menstrual cycle phase and oral contraceptive use on selected performance parameters in female rowers. Tartu, 2012, 86 p.

34. **Anna-Liisa Parm.** Bone mineralization in rhythmic gymnasts before puberty: associations with selected anthropometrical, body compositional and hormonal parameters. Tartu, 2012, 96 p.
35. **Jelena Sokk.** Shoulder function in patients with frozen shoulder syndrome: the effect of conservative treatment and manipulation under general anaesthesia. Tartu, 2012, 125 p.
36. **Helena Liiv**. Anthropometry, body composition and aerobic capacity in elite DanceSport athletes compared with ballet and contemporary dancers. Tartu, 2014, 80 p.
37. **Liina Remmel**. Relationships between inflammatory markers, body composition, bone health and cardiorespiratory fitness in 10- to 11-year old overweight and normal weight boys. Tartu, 2014, 94 p.