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Rehabilitation of patients undergoing total hip arthroplasty

With focus on muscle strength, walking and aerobic endurance performance

Thesis for the degree of Philosophiae Doctor

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Norwegian University of Science and Technology
Faculty of Medicine
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Rehabilitering av pasienter operert med totalprotese i hofteleddet –
Med fokus på muskelstyrke, gangeffektivitet og aerob utholdenhetskapasitet

Dagens rehabilitering av pasienter operert med totalprotese i hofteleddet består hovedsakelig av øvelser med liten belastning og mange repetisjoner. Tidligere studier har vist at muskulær belastning må være minst 60-70% av 1 repetisjon maksimum (1RM) for å øke muskelstyrke, og at maksimal styrketrening med 85-95% av 1RM vil øke styrken optimalt. Rehabilitering etter dagens retningslinjer ser ikke ut til å være tilfredsstillende for å gjenvinne muskelstyrke, gangeffektivitet og aerob utholdenhetskapasitet hos pasienter operert med totalprotese i hofteleddet.

Hensikten med denne avhandlingen er å sammenligne fysisk kapasitet hos tidligere proteseopererte pasienter med friske forsøkspersoner, samt å sammenligne fysisk kapasitet hos pasienter operert i hhv. ett - eller begge hofteledd der en også evaluerer muskelstyrke i anatomisk rekonstruerte hofteledd. Videre sammenlignes tradisjonell rehabilitering med 4 ukers maksimal styrketrening i perioden 1-5 uker etter operasjon. Disse pasientene evalueres før operasjon, etter 1 og 5 uker, samt 6 og 12 måneder etter operasjon.

Evalueringsmetodene i denne avhandlingen er måling av maksimal muskelstyrke, arbeidsøkonomi, maksimalt oksygenopptak, ganganalyse, hofteskår og livskvalitet.

Avhandlingen viser at rehabiliterte pasienter har redusert muskelstyrke i det opererte beinet, nedsatt arbeidsøkonomi og aerob utholdenhetsprestasjon samt at de avlaster det opererte benet ved gange sammenlignet med friske personer. Pasienter operert i hhv. ett - og begge hofteledd viser ingen forskjell i arbeidsøkonomi, aerob utholdenhetskapasitet eller gangmønster. En god anatomisk rekonstruksjon av hofteleddet bedrer ikke styrken i de musklene som bidrar til utoverføring av beinet. Maksimal styrketrening initiert 1 uke etter operasjon resulterer i stor økning i muskelstyrke og kraftutviklingshastighet sammenlignet med tradisjonell rehabilitering og har effekt på arbeidsøkonomi 6 og 12 måneder etter operasjonen, samt på kraftutviklingshastighet 12 måneder etter operasjonen.

Samlet gir avhandlingen bedre innsikt i hva som er effektive treningsmetoder for pasienter operert med totalprotese i hofteleddet. Den setter også fokus på redusert muskelstyrke og gangeffektivitet hos denne pasientgruppen samt at den reduserte aerobe utholdenhetskapasiteten kan gi økt sykdomsrisiko.

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Veiledere: Jan Hoff (hovedveileder), Jan Helgerud og Otto Schnell Husby

Overnevnte avhandling er funnet verdig til å forsvares offentlig for graden philosophiae doctor i klinisk medisin. Disputas finner sted i Auditorium ØHA 11, Øya Helsehus Torsdag 08.04.10, kl 12.15

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Preface

The thesis is based on the 4 papers listed below. The papers are referred to by roman numbers in the text. The work has been carried out at the Department of Circulation and Medical Imaging, Faculty of Medicine, Norwegian University of Science and Technology during the years 2005-2009.

Paper I

Husby VS, Helgerud J, Bjørgen S, Husby OS, Benum P, Hoff J. **Reduced strength, work efficiency and maximal oxygen consumption 3-5 years after total hip arthroplasty.**
Submitted Am J Phys Med Rehab.

Paper II

Husby VS, Bjørgen S, Hoff J, Helgerud J, Benum P, Husby OS. **Unilateral vs. bilateral total hip arthroplasty – the influence of medial femoral head offset and effects on strength and aerobic endurance performance.**
Submitted Hip International.

Paper III

Husby VS, Helgerud J, Bjørgen S, Husby OS, Benum P, Hoff J. **Early maximal strength training is an efficient treatment for patients operated with total hip arthroplasty.**
Arch Phys Med Rehab 2009; 90:1658-67.

Paper IV

Husby VS, Bjørgen S, J Helgerud, Husby OS, Benum P, Hoff J. **Early postoperative maximal strength training improves work efficiency 6-12 months after osteoarthritis induced total hip arthroplasty in patients under 60 years old.**
Accepted for publication in Am J Phys Med Rehab.

List of abbreviations

ANOVA	Analysis of variance
ASA	American Society of Anaesthesiologists
[(a – v) O_2 difference]	Arterial-venous oxygen difference
BMI	Body mass index
CO	Cardiac output
FO	Medial femoral head offset
h	Hour
HR	Heart rate
HR_{max}	Maximal heart rate
HRQoL	Health related quality of life
HSD	Tukey`s honestly significant difference
Hz	Hertz
Kcal	Kilocalories
Kg	Kilogram
Km	Kilometre
$Km \cdot h^{-1}$	Kilometres · hour
L	Litre
m	Metre
M_b	Body mass
MCS	Mental component score
min	Minute(s)
mL	Millitre
$mL \cdot kg^{-1} \cdot min^{-1}$	Millilitres · $kilogram^{-1}$ · $minute^{-1}$
$mL \cdot kg^{-0.75} \cdot min^{-1}$	Millilitres · $kilogram^{-0.75}$ · $minute^{-1}$
$m_b \cdot kg^{-0.67}$	Body mass · $kilogram^{-0.67}$
N	Newton
$N \cdot sec^{-1}$	Newton · $second^{-1}$
OA	Osteoarthritis
O_2	Oxygen
p	P-value
PCS	Physical component score
PF	Peak force

r	Correlation coefficient
R	Respiratory exchange ratio
RFD	Rate of force development
RM	Repetition maximum
s	Second(s)
SD	Standard deviation
SEM	Standard error of the mean
SF-36	36-item Short-Form Health Survey
THA	Total hip arthroplasty
V_E	Minute ventilation
VO_2	Oxygen consumption
VO_{2max}	Maximal oxygen consumption
W	Watt
WHO	World Health Organization
WOMAC	Western Ontario and McMaster Universities OA index

Summary of the thesis

Patients having completed rehabilitation after undergoing THA demonstrate a 40 % reduced muscle strength, 26 % lower maximal oxygen consumption (VO_{2max}), 42 % reduced work efficiency and an asymmetric loading of the limbs 3-5 years after completed rehabilitation when compared to healthy age-matched subjects. The reduced VO_{2max} in THA patients implies increased risk for co-morbidity. The results indicate that the current rehabilitation programs are inefficient in restoring muscle strength and aerobic endurance performance in THA patients.

Unilaterally and bilaterally operated THA patients demonstrate similar outcome in VO_{2max}, work efficiency and gait patterns. A bilaterally operated group with normal medial femoral head offset (FO) in the hip joint was compared with a bilaterally operated group with FO < 5 mm of preoperative values. No differences in hip abductor muscle strength, VO_{2max}, work efficiency or gait patterns were found between the bilaterally operated groups.

Maximal strength training with few repetitions, heavy loads and maximal concentric contraction is an efficient and safe treatment in the early postoperative phase for patients undergoing THA. Maximal strength training improved rate of force development (RFD) by 65 %, hip abduction by 87 % and leg press by 65 % in the operated leg compared to conventional rehabilitation. The results of 4 weeks maximal strength training starting 1 week postoperatively compared with conventional rehabilitation programme, equalise those of THA patients operated 3-5 years ago.

6-12 months after THA, the early maximal strength training intervention resulted in improved work efficiency by 29 and 30 %, respectively and an increase in RFD by 74 % after 12 months compared with the conventional rehabilitation programme. Work efficiency and RFD are important functional parameters as the oxygen needed to perform a specific task is reduced and the risk for falling has shown to be lower with improved RFD.

1 Introduction

Total hip arthroplasty (THA) is a common procedure in orthopaedic surgery (175). THA is reported to relieve pain, improve function, increase mobility and psychosocial well-being. The success rate of THA is high and associated with high patient satisfaction (98). In 2004, the reported rates (per 100,000 population) for THA for the United States, Canada, Australia and New Zealand ranged from 70–150 (2, 92). In Norway, the total number of primary THA was 6.804 in 2008 (69). As the population lives longer, the incidence of obesity (4) and inactivity increases, it is anticipated that the number of THA will increase (172, 175). Since the first stainless steel acetabular and femoral component was implanted by the Englishman Philip Whiles in 1938, great developments have occurred concerning design of the prosthesis components, surgical technique and improvements in hygienic standards. Sir John Charnley was probably the first hip surgeon to introduce standardized procedures securing a successful outcome of THA (137).

Despite the development in surgical technique and implant design, relatively few changes in the postoperative rehabilitation programmes have occurred. Orthopaedic clinical research has been criticized for giving more attention to the construction and design of the hip implant than the functional adaptation of the patients (57). Early rehabilitation of the weakened musculature is anticipated to be of greater importance than the biomechanical reconstruction itself (33, 152). Studies of postoperative gait patterns, muscle strength and functional outcomes have suggested that rehabilitation of THA patients ought to include programs that particularly address strengthening of the hip abductor muscles (80). During the first 6 months postoperatively, improvement in hip abductor strength reaches only 50 % of normal values and leaves the hip relatively unguarded (139).

Current rehabilitation programs for THA patients seem to be inadequate in restoring muscle strength and aerobic endurance performance levels to those of healthy age-matched individuals (54). A higher demand on the quality of rehabilitation is expected as a consequence of the trend towards younger subjects to be scheduled for THA together with a predominance of the post-war generation in the population (172) with higher expectations to regain their normal activity level (66). The focus in future rehabilitation of the THA patients should be to restore the function level towards healthy subjects, a scenario possible within today's advances in effective training methods. Finally, full recovery may prevent co-morbidity (129).

1.1 Osteoarthritis of the hip and THA

The main cause for receiving THA is either idiopathic or secondary osteoarthritis (OA) of the hip. OA is a disease where the loss of articular cartilage in the normal load-bearing area of the joint is present (142). The prevalence of OA of the hip increases with age (49) and increased body mass index (BMI) (50). Heavy lifting, farming and athletic activity are activities that may increase the risk of developing OA. Trauma, osteonecrosis, sepsis, epifysiolysis, dysplasia coxae and rheumatoid arthritis are diseases that may lead to secondary OA (72). The disease is characterized by moderate to severe pain during physical activity as well as at rest, contracture of the hip joint, instability and hip abductor weakness that may result in a Trendelenburg gait pattern (84).

THA consists of 2 components; a femoral stem with a head and an acetabular cup. The most frequent materials used in femoral stem are stainless steal, titanium or cobalt-chromium. The femoral stems are designed as monoblock or modular. Monoblock prostheses consist of 1 component whereas a modular prosthesis allows for adjusting tension, leg length and lever arm of the hip abductors by using femoral heads with various neck lengths. The acetabular component has a modular or a monoblock design as well. The modular component have a metal shell with a liner attached to the inside of the shell and is fixed to the acetabulum with or without bone cement. The bearing surface of the artificial joint consists of steel, cobalt-chrome or ceramic on the femoral head and high-density polyethylene, ceramic or cobalt-chrome on the inner surface of the acetabular cup (28).

1.2 Biomechanics of the hip

Alterations in joint anatomy caused by surgical procedures can change the force acting across the joint and the stresses developed in the articular surfaces. Alterations to the moment arms of the hip muscles and the area of contact between the femur and the acetabulum are major anatomical considerations. A valgus neck angle decreases the moment arm whereas a varus neck angle/increased neck length increases the moment arm (84).

The hip abductor muscle group is crucial in order to stabilize the pelvis and to a normal gait without limping (33, 47, 133). The muscle group mainly consists of the gluteal muscles. In addition, the m. tensor fascia latae is known to contribute to the abduction movement in the hip joint. Laboratory studies have demonstrated the iliotibial tract to balance a significant tension of the proximal lateral aspect of the femur (195). Standing with equal weight on each leg, minor use of the hip abductor muscles is necessary. The resultant forces needed for one legged and two legged stance, respectively, can be calculated. The force is 1/3 of the body weight during two legged stance whereas the forces needed to perform one legged stance is larger than body weight. The body weight axes are medial to the centre of rotation of the hip, and to regain balance, the abductor force needs to be on the standing leg (183). The greatest contributor to the forces is the musculus gluteus medius (122). The reason for the enhanced force needed during one legged standing is that the abductor weight arm is shorter compared with the body weight arm. The ratio is approximately 1.8 (194). Weak hip abductors, and in particular the musculus gluteus medius, will result in a typical gait pattern, the Trendelenburg gait (8). Trendelenburg test is positive if, when standing on one leg, the pelvis drops on the side opposite to the stance leg (62).

Medial femoral head offset (FO) is a topic of interest in THA. The importance of a correct FO in THA surgery has been emphasized in the literature (13, 14, 33, 100, 119, 188). FO is defined as the as the perpendicular distance between the long axis of the femur and the centre of rotation of the femoral head. FO is one of the contributors to increase the hip abductor moment arm and thereby influence hip abductor strength. By increasing the FO during surgery, the hip abductor moment arm can be increased (38). A 5 mm reduction in FO compared to the normal FO of the patient leads to an increase in the hip abductor forces of approximately 17 Kg (170 N), corresponding to about 10 % increase in the hip abductor forces that is needed to stabilize the pelvis in a 75 Kg individual (84). FO has been reported to correlate positively with hip abductor strength and it has been suggested that greater FO after THA allows increased range of hip abduction and greater hip abductor strength. In addition, a large FO increases stability due to reduced risk of impingement and improved soft-tissue tension (119). Too large FO is stated to increase the small relative motion between the implant and the bone (micromotion) and affect implant stability (42). The clinical implications of a large FO for the patients is difference in leg length and a higher incidence of trochanter bursitis, leading to pain due to a tight iliotibial band (45).

1.3 Surgical approach

The surgical approach for THA is required to meet several demands. The approach needs to provide a wide exposure to the hip joint and be easy to extend if complications occur. Furthermore, nerves have to be avoided and protected (sciatic and femoral nerves) (127). The surgical approach have major impact on THA stability and hip abductor muscle function (113). Several surgical approaches are used for THA, each with positive and negative aspects. The choice of approach is frequently based upon the surgeon experience rather than clinical trials. The most common approaches are the lateral approach with trochanteric osteotomy, the direct lateral approach, the posterior approach in addition to the anterior approach (86).

1.3.1 Direct lateral approach (transgluteal approach)

The direct lateral approach is the most common approach for THA in Norway (69). Performing the direct lateral approach, the hip is exposed through a posterior curved, lateral skin incision. Thus the common muscle plate of the anterior 1/3 part of musculus vastus lateralis and musculus gluteus medius is dissected subperiostally from the greater trochanter (86). The advantage of the direct lateral approach is an excellent exposure of the acetabulum which may reduce the risk of dislocation since the positioning of the acetabulum cup is facilitated (16, 86). Furthermore, the risk of injuring the nervus ischiadicus is reduced. Disadvantages are increased risk of injury to the superior gluteal nerve, failed reattachment of the gluteus medius muscle resulting in limping, and a reduced exposure to the femur (86).

1.4 Aerobic endurance and maximal oxygen consumption

Aerobic endurance refers to the ability of a subject to perform large-muscle, whole body physical activity at moderate or high intensities for an extended period of time (136). Maximal oxygen consumption (VO_{2max}) is defined as the highest oxygen consumption an individual can attain during exercise at sea level using large muscle groups (196). Oxygen consumption (VO_2) is the product of cardiac output (CO) and arterial-venous oxygen difference ([(a – v) O_2 difference]) (151) and measures the ability of the body to transport oxygen from ambient air to the mitochondria. The transport of oxygen (O_2) may be limited by the central (pulmonal diffusing capacity, CO, O_2 carrying capacity of the blood) and peripheral factors (skeletal muscle capacity) (17).

VO_{2max}, running economy and lactate threshold are factors determining aerobic endurance performance. VO_{2max} is considered the single most important factor (136) and a high VO_{2max} is necessary for a success in e.g. middle- and long-distance running (17). Furthermore, VO_{2max} is reported to be a strong predictor of cardiovascular and all cause mortality (59, 88, 91, 111, 129).

1.5 Training for muscle strength and power

Muscle strength is frequently defined as the maximal force or torque developed by a muscle or a muscle group performing a particular joint movement whereas power is defined as the product of force and velocity (95). A majority of strength training programmes is based upon a system of exercise to one repetition maximum (1RM) presented in 1945 by DeLorme (41). Repeated testing in a particular movement at increasingly higher loads leads to a point where the subject is able to perform the movement only once. The mass lifted is described as the subjects 1RM for the particular movement (95). Increase in muscle strength can occur due to adaptations in the nervous system (neural adaptations) or in the muscle itself (hypertrophy) (20, 150).

1.5.1 Neural adaptations

Neural adaptations influence activation of muscle and/or the velocity and force of the nerve signal. The term neural adaptations involves several factors such as alterations in recruitment, rate coding, synchronization of motor units, reflex potentiation, co-contraction of antagonists and synergistic muscle activity (coordination) (19). In the high threshold motor units, the majority of muscle fibres are type II fibres (fast twitch fibres). Strength training performed with heavy loads (3-5 RM) recruits the high threshold motor units in contrast to light loads (12-15 RM) which predominantly recruit low threshold motor units. Peak power output of type II fibres is 4 times higher than that of type I fibres (97) and the time of the force production of the muscle is dependent of the magnitude of Type II fibres (61).

Neural adaptations are suggested to be predominant in the early stages (8-12 weeks) of strength training and is associated with muscle strength gains with no concomitant hypertrophy of the muscles and subsequent weight gains (19). Increase in muscle strength without hypertrophy is regarded as an evidence for neural involvement (55). Furthermore, increased muscle strength in an untrained leg, when training the contralateral leg, is suggested to be a result of central motor adaptations (6, 36, 173). Several studies demonstrate increased muscle strength without muscle hypertrophy (6, 73, 85). To achieve maximal muscle activation, it is important to stress all motor units, especially high threshold motor units. Maximal strength training including few repetitions (3-5) with high loads, maximal mobilization of force in the concentric phase and long resting periods is an appropriate way of ensuring optimal neural adaptations to occur. In addition, it is of importance to perform the exercise with heavy loads at the highest velocity possible (19-21). According to Behm and Sale (21), the intended, rather than the performed velocity of a specific task is most important to increase strength. Findings by Almåsbakk and Hoff (7) point at development of coordination as a crucial factor in early velocity-specific muscle strength gains.

Maximal strength training has been carried out successfully both in healthy subjects, patients with chronic obstructive pulmonary disease, coronary artery disease patients as well as in subjects above 80 years (37, 73, 75, 76, 87).

1.5.2 Hypertrophy

Skeletal muscle hypertrophy is described as an increased weight or cross-sectional area of the muscle after overload training and muscle force is reported to be proportional to the cross-sectional area of the muscle (118). It is generally believed that the increase in muscle volume is a result of an enlargement of the muscle fibres due to increased muscle contractile protein synthesis, increased size and number of myofibrils and addition of sarcomeres within each muscle fibre (171). Whether increased number of muscle fibres (hyperplasia) contributes to the hypertrophy in adults is debated. MacDougall (106) claims there is little evidence for an increase in muscle fibre numbers as a result of heavy resistance training. Longitudinal muscle fibre splitting has been demonstrated in avian muscle after chronic stretch overload (11) whereas human autopsy data have revealed increased number of muscle fibres in the anterior tibialis muscle in the dominant leg (162). Yet, the hyperplasia issue is controversial, and the general consensus is that muscle hypertrophy primarily is a result of increased muscle fibre size and connective tissue area (106).

Hypertrophy training traditionally consists of several sets of 6-12 repetitions with submaximal resistance (60-90 % of 1RM) performed with slow velocity until exhaustion. Increased 1RM muscle strength only is of advantage in power lifting sport where the main goal is to lift the weight load and where velocity of the movement is of minor importance (97). Tesch and Larsson (171) demonstrated increased proportion of Type I fibres (slow-twitch fibres) in body-builders, resembling the muscle fibre pattern of endurance athletes. Increased body mass has been reported to be a consequence of long-term training for hypertrophy (74).

1.5.3 Rate of force development

Rate of force development (RFD) is defined as the slope of the joint moment-time curve and expresses the subject's ability to develop muscle strength rapidly (191, 193). Usually, it takes in excess 0.3-0.4 seconds to generate maximum force in human skeletal muscles (191). The RFD parameter has important functional significance, from an athlete's performance in sprint or to prevent a fall in an elderly. The latter are performances characterized by a limited time to develop force (0-200 ms)(193). RFD has been reported to improve as a result of strength training based on the neural adaptation principles (37, 73, 76, 87, 141, 166, 192, 193). Furthermore, RFD has been identified as a contributor to improve work efficiency (73, 141). Improved RFD results in longer atonic periods between the contractions which in turn increase muscle perfusion and thereby improves work efficiency (192). Heavy resistance training with slow movements has been reported not to improve RFD (97). Häkkinen et al. (60) showed a decrease in RFD as a result of strength training with heavy loads and slow movements. A recent study demonstrated a more pronounced decrease in RFD compared to muscle strength in elderly subjects scheduled for THA (165), which is supported by others (78, 79). This finding highlights the importance of a strength training program that restores both muscle strength and RFD in this patient group.

1.6 Muscle strength and aerobic endurance performance

Work economy is defined as the oxygen needed to run/walk at a given, constant velocity (17) and can be expressed as ml · kg^{-1} · m^{-1} (68). Work efficiency reflects the percentage of total energy expended that contributes to external work, with the reminder lost as heat. Work efficiency is normally within the range of 20-25 % (114). Work efficiency is an important parameter in the performance of athletes, and may explain differences in performance despite similar VO_{2max} (18, 68, 126, 141, 154). Factors as mechanical skills or biomechanics, training velocity, muscle fibre type, VO_{2max}, substrate utilization, muscle power and flexibility have impact on work efficiency (23). Joint stiffness, limb size, abnormal gait patterns and/or inadequate coordination, gender, age and body size are factors contributing to differences in work efficiency between individuals as well (138). More elastic energy is used and the energy required in breaking forces are reduced as a result of explosive strength training (154). Subjects with a high work efficiency use less energy and thereby less oxygen performing a specific task (154). Several studies report maximal strength training to improve work efficiency (58, 73, 75, 76, 85, 87, 124, 141). It is suggested that heavy strength training may lead to a higher absolute force production in the muscle fibres which may allow the muscle fibres to work at a lower percentage of maximal strength (89). In contrast, a few studies report no significant improvements in work efficiency after heavy strength training (26, 71, 89).

1.7 Physical inactivity

Physical inactivity has demonstrated to be a risk factor for a large number of chronic conditions such as cardiovascular disease, Type-2 diabetes, colon and breast cancer, hypertension, obesity, osteoporosis and depression (1, 29, 31, 135, 169, 181). Several studies report a relationship between inactivity and mortality (112, 129, 149, 185). Myers et al. (129) stated peak exercise capacity to be one of the most powerful predictors of mortality, and being more important than other established risk factors for cardiovascular disease (e.g. hypertension, smoking and diabetes) in both healthy subjects and in subjects with cardiovascular diseases. A 12 % improved survival was achieved by improving VO_{2max} by 3.5 ml per kg body mass (129). Ruiz et al. (149) report muscle strength in large muscle groups to be associated with death and cancer in men when cardiorespiratory fitness had been accounted for. Immobilisation influences health tremendously; exemplified by McGuire et al. (120) demonstrating 3 weeks of bed rest to have larger influence on aerobic endurance performance than 30 years of ageing. Immobilisation induces loss of muscle strength. When immobilising an extremity in cast, the decline in muscle strength is most pronounced during the first days of immobilisation with a strength loss of 3-4 % per day during the first week (12). Weakened muscles are common side effects following major surgery (e.g. THA and knee surgery) (186). Wigerstad-Lossing et al. (186) demonstrated reduced muscle strength, muscle cross-sectional area, changed muscle fibre composition and area as well as reduced activity of muscle enzymes in the immobilised leg (cast) of patients undergoing knee surgery. THA patients have a co-morbidity health risk due to inactivity, especially because of pain induced inactivity before the hip replacement, but also after the replacement because of reduced function. An atrophy of type IIA and IIX fibres in the gluteus maximus, medius and tensor fascia lata muscles in THA patients as a result of disuse has been found preoperatively, and the findings persisted 5 months postoperatively despite physical therapy exercises (144). Co-morbidity for a group of 78 year old hip fracture patients were 65 % cardiovascular diseases, 22 % diabetes and 20 % respiratory diseases (143). This fact has received little attention in treatment and rehabilitation of THA patients.

According to the Norwegian Arthroplasty Register, mean age for patients undergoing primary THA in Norway was 69.4 years in 2008 (69). In addition to the frequently observed negative consequences from THA on muscle strength (153, 160), ageing furthermore compromises the issue. D`Antona et al. (39) found disuse to have impact on fibre force production in addition to ageing. Ageing is associated with sarcopenia, which is defined as an age-related loss of skeletal muscle mass, strength and function. The condition is both a process and an outcome and is initiated as early as in the forties (190). The decrease in muscle strength is however most pronounced after the 6th decade (105, 189) as a decrease of 1.5 % per year is expected (189). The decline in muscle strength correlates with the loss of muscle mass and the decline in the lower extremities is more pronounced compared to upper extremity muscle strength, indicating decreased activity. The proportion of type II fibres is reduced as a result of disuse and ageing (93, 131). Moreover, type II fibre size declines by 20-50 % while the corresponding percentage decline for type I fibres is 1-25 % (43). Sarcopenia can be minimized and reversed by both endurance and strength training (93), but no other intervention (e.g. hormone replacement, diet) has demonstrated to be as effective as strength training (43).

1.8 Rehabilitation of THA patients

As early as in 1945, DeLorme (41) recommended heavy resistance training in the rehabilitation after injury. The recommendation was based on the findings of larger strength gains after few repetitions with high loads and increased endurance following a large number of repetitions with low resistance. Still, most rehabilitation programmes consist of hip joint mobilization, strengthening of surrounding muscles with low-resistance weight, and gait training (81, 128, 147, 177). A study by Anderson et al. (9) demonstrated low levels of neuromuscular activation during conventional physical therapy exercises. Suetta et al. (164) found no improvement in muscle strength after conventional rehabilitation following THA. Minns Lowe et al. (125) reviewed several studies to evaluate the effectiveness of physical therapy exercises after THA and reported insufficient evidence for physical therapy exercises to be effective tools in the rehabilitation of the THA patients. Some studies have reported improvements after conventional rehabilitation programs, but have not compared the THA patients with healthy subjects (176, 179). It is, however, documented that training intensity must exceed 60 % of 1RM to improve muscle strength and that 80-90 % of 1RM seem to be the optimal load (15). Campos et al. (35) report higher strength gains for a group using few repetitions with high loads compared to an intermediate repetition group and a high repetition group. McDonagh and Davies (118) reviewed several resistance training studies and reported that loads less than 66% of 1RM produced little increase in muscle strength even if up to 150 contractions a day were performed. Using loads higher than 66% of 1RM, 10 contractions a day gave increases in muscle strength. The effectiveness of increasing muscle strength by means of few repetitions with heavy loads is confirmed by Berger (24), Dons et al. (44) and Hoff et al. (73, 75, 76). In the light of this information, it can be suggested that the traditional physical therapy exercises are not adequate in order to stimulate improvements in muscle strength in the THA patients.

Strong hip abductor muscles are important for a normal gait without limping (33, 84) and to secure the longevity of the implant (52). Weakened hip abductor muscles are a common finding after THA and postoperative rehabilitation (16, 46, 104, 107, 140, 153, 160, 175, 180). Patients with weak hip abductor muscles load the healthy side twice as much as normal, which increases energy expenditure during walking (33). Regaining normal walking patterns is one of the goals in rehabilitation of patients undergoing THA and naturally, gait patterns are frequently measured after THA (52, 103, 117, 123, 140, 160). Gait speed has been found to be recovered 12 months after surgery (123) while most studies have discovered slower walking speed and asymmetric loading of the legs to be present 6 months-3 years postoperatively (52, 103, 117, 140, 160, 168). The asymmetric loading of the legs may lead to development of OA in the healthy leg (167). Increased muscle strength in the THA patients reduces the risk for falls and fracture and has impact on functional aspects of their lives (93).

Strength training has the ability to increase the amount of fat-free body mass which is known to be the major determinant of resting metabolic rate. Thereby weight loss can be facilitated (83), which is beneficial for THA patients as a high BMI is one of the major contributing factors to OA of the hip (50).

1.9 Physical activity in THA patients: Pros and cons

It is an ongoing debate what might be too much activity after THA and which activities that are recommended to reduce polyethylene wear. Polyethylene wear is defined as the removal of materials, with the generation of wear particles, that occur due to relative motion between 2 opposing surfaces under load (156). Polyethylene has been the preferred material used in the acetabular cups (67) and physical activity after THA has been considered as a contributor to increase wear and subsequent loosening of the hip implant. Younger patients (50-60 years) and males have been associated with higher polyethylene wear (157). Load and the number of cycles rather than time since surgery are factors affecting rate of wear (158). Cross-linked polyethylene has shown to reduce wear approximately 80 % compared with conventional polyethylene in a short term (26 months) in-vivo study (67).

An adequate balance between the physical activity needed to maintain or improve aerobic endurance performance and the amount of activity which possibly could compromise longevity of the hip prosthesis should be obtained (66, 80). Recommendations for sport activities vary among orthopaedic surgeons. Nevertheless, there are some consensuses. High-impact activities such as football, handball, basketball soccer or hockey are not recommended whereas walking, swimming and cycling are activities which are considered safe. However, it is an established fact that THA in a sedentary patient will show less wear compared to an active patient. The advantages of physical activity are numerous as described earlier, and can even be beneficial to the artificial implant. Falling and injuries may be reduced due to improved muscle strength and coordination together with increased bone density and prosthesis ingrowth (98). A trend towards fewer restrictions in physical activity from orthopaedic surgeons is reported between 1999 and 2005 (66).

1.10 Health related quality of life and hip score systems

In the vast majority of the patients, OA of the hip influences quality of life. THA patients experience pain, stiffness and functional deficits at various degrees (82). According to the World Health Organization (WHO), physical, material, social and emotional wellbeing and individual development and daily activity should be included in quality of life measurements (5). Outcome measures of orthopaedic surgery and rehabilitation programmes have been measured by a variety of hip score systems which include physical aspects of health and the ability to perform activities of daily living. The Harris Hip Score (64) and the Merle D'Aubigné and Postel scoring system (40) are frequently used scoring systems. Patient-completed assessment is now looked upon as important to evaluate the outcome of THA. Health related quality of life (HRQoL) can be measured by disease-specific and/or generic health status questionnaires (48). THA is reported to improve HRQoL significantly (10, 82, 121, 161, 170).

2 Objective, aims and hypotheses of the studies

The main focus of the present thesis was to assess the physical outcome of the conventional rehabilitation program used for THA patients, to compare unilaterally and bilaterally operated THA patients with respect to normalisation of gait patterns, muscle strength, work efficiency and aerobic endurance performance and to investigate the influence of FO on hip abductor muscle strength in THA patients. Furthermore, we wanted to explore the feasibility and effects of maximal strength training in THA patients in the early postoperative phase and the effects the intervention implied after 6 and 12 months.

Paper I: Reduced strength, work efficiency and maximal oxygen consumption 3-5 years after total hip arthroplasty.

The aims of study I were 1) to determine to what extent patients operated with unilateral THA, completing 4 week institutional rehabilitation 3-5 years ago, regain muscle strength, work efficiency and walking skills compared to the healthy leg and compared to healthy age-matched controls, 2) to determine whether the patients show differences in work efficiency and VO_{2max} compared to healthy age-matched controls.

We hypothesised that the THA patients had lower muscle strength in the operated leg compared to the healthy leg and reduced muscle strength, work efficiency and VO_{2max} compared with a healthy age-matched control group.

Paper II: Unilateral vs. bilateral total hip arthroplasty – the influence of medial femoral head offset and effects on strength and aerobic endurance performance.

The aim of study II was to investigate whether bilaterally operated THA patients demonstrate lower muscle strength, aerobic endurance performance and different gait pattern compared to unilaterally operated THA patients, and to examine whether decreased FO influences hip abductor muscle strength.

We hypothesised that; 1) the bilaterally operated patients showed lower aerobic endurance performance, muscle strength and different gait pattern compared to the unilaterally operated patients, 2) the bilaterally operated patients with normal FO demonstrated superior hip abduction strength compared to the bilaterally operated patients with abnormal FO.

Paper III: Early maximal strength training is an efficient treatment for patients operated with total hip arthroplasty.

The aims of study III were to demonstrate the effects of maximal strength training compared to conventional rehabilitation and to confirm the safety of initiating maximal strength training 1 week after THA.

We hypothesised that the group who performed maximal strength training in addition to conventional rehabilitation would improve muscle strength, work efficiency and normalize gait patterns significantly compared to the group who performed conventional rehabilitation only. Furthermore, we hypothesised that it was feasible and safe to accomplish maximal strength training in the early postoperative phase in patients undergoing THA.

Paper IV: Early postoperative maximal strength training improves work efficiency 6-12 months after osteoarthritis induced total hip arthroplasty in patients under 60 years old.

The aim of study IV was to investigate how the maximal strength training intervention in the early postoperative phase after undergoing THA would influence strength and work efficiency 6 and 12 months postoperatively.

We hypothesized that the short term improvements previously documented in the early postoperative phase after undergoing THA would influence work efficiency 6 and 12 months postoperatively.

3 Methods

3.1 Subjects

54 THA patients and 10 healthy age-matched subjects were included in the thesis (Table 1). Inclusion and exclusion criteria are described in detail in the papers.

In paper I, 10 unilaterally operated THA patients and 10 healthy age-matched control subjects completed the study. In paper II, 20 bilaterally operated THA patients were divided into 2 groups. One group had normal FO whereas the other group had abnormal low FO. Abnormal FO was defined as <5 mm compared to healthy side or preoperative values. The groups were compared with 10 unilaterally operated THA patients. In paper III, 12 unilaterally operated THA patients performing a maximal strength training program in addition to the conventional rehabilitation programme were compared with 12 unilaterally operated THA patients attending a conventional rehabilitation programme only. Paper IV is a follow-up study of the patients in paper III.

Table 1, Overview of the subjects included in the thesis

		Control subjects
Paper I	10 patients unilaterally operated with THA	10 healthy subjects
Paper II	20 patients bilaterally operated with THA	10 patients unilaterally operated with THA[i]
Paper III	12 patients unilaterally operated with THA	12 patients unilaterally operated with THA
Paper IV	12 patients unilaterally operated with THA[ii]	12 patients unilaterally operated with THA[ii]

3.2 Test procedures and materials

The subjects conducted the testing procedures in the same order at all tests (I-IV). The subjects performed 10 minutes warm-up as stationary cycling (III and IV) or treadmill walking (I-II) with exercise intensity allowing conversation without breathlessness. The tests were supervised by 2 experienced exercise physiologists.

[i] The unilaterally operated patients in paper I are used as control group in paper II

[ii] The same patients are subjects in paper III and IV as paper IV is a follow-up study

3.2.1 1RM leg press

In paper I-IV, bilateral and single leg 1RM leg press was determined in a seated position in a leg press ergometer (Technogym, Italy) with a knee joint angle of 90° between femur and tibia and a 90° joint angle in the hip joint to avoid luxation (Figure 1). The initial weight load was based on a subjective estimation of the patient's capacity to prevent the fitter patients from starting at too low an intensity. The subjects used 4-5 attempts to determine 1RM. Weight load was increased by 5-10 kg at each ramp, and the test was terminated when the subjects no longer managed to perform the leg press movement.

Figure 1, Leg press during training

3.2.2 Rate of force development and peak force

Force development, determined as RFD and peak force (PF), was calculated /measured in paper I-IV. Data was collected at 2000 Hertz (Hz) using a force platform with software specifically developed for the platform (Bioware, Kistler, Switzerland). The force platform consists of an aluminium top plate placed on top of 3-component force sensors that allows measurements of force and torque in three axes i.e. vertical, left- and right horizontal. The subjects performed the test of RFD and PF in a seated position in a leg press ergometer (Technogym, Italy) with a knee joint angle of 90º. The weight load was 40 kg during bilateral testing for all subjects. In paper III and IV, RFD and PF were tested in each leg separately and the weight load used was 10 kg for all subjects. The Kistler force platform was mounted in front of the legs and placed in a vertical position on the leg press ergometer. PF is the highest force attained during one repetition of maximal contraction (73). RFD was determined as 10-90 % of PF during the concentric action.

3.2.3 1RM hip abduction

In paper I-IV, 1RM hip abduction was measured using a custom-made apparatus (Figure 2). The subjects were tested in a supine position. To enable maximum stabilization, the pelvis was stabilized by an adjustable clamp arch against the iliac crest. The subjects performed 1RM hip abduction of the right and left leg, respectively. One leg was resting in a sling while the other leg was tested. The testing leg was placed in a 15 cm wide sling and horizontally mounted to the pulling apparatus with a rope. The lower edge of the sling was placed at caput fibulae. Weight load was increased by 5 kg at each ramp and the test was terminated when the subjects no longer managed to perform the hip abduction movement. The subjects were instructed to perform the movement with the arms placed on the chest and to keep the performing leg extended with the foot pointing forward using a horizontal movement.

Figure 2, Hip abduction during testing

3.2.4 Maximal oxygen consumption

In paper I-IV, VO_{2max} was measured while the patients performed treadmill walking (Technogym, Runrace 1200 HC, Italy). VO_{2max} was determined by increasing speed and inclination each minute until exhaustion. Continuous respiratory measurements were performed and the mean of the 3 highest 10 seconds continuous respiratory measurements determined $VO_{2max.}$ All ventilatory parameters and pulmonary gas exchange were measured using Cortex Metamax I portable metabolic test system (Cortex Biophysik GmbH, Germany). For measurements of heart rate (HR), short-range radio telemetry with Polar accurex watches (Polar Electro Oy, Finland) was used. The highest HR recorded during the last minute of the test was used as maximal HR (HR_{max}).

VO_2 in the maximal incremental tests is presented as VO_{2max} throughout the thesis. There were differences between subjects and differences between tests whether the subjects managed to reach their true $VO_{2max,}$ but the variable VO_{2max} has been chosen.

3.2.5 Allometric scaling

Traditionally, V_{O2} is divided by body mass. When expressing V_{O2} as ml · kg^{-1} · min^{-1}, a linearity between body mass and V_{O2} is assumed (196). Thus, the VO2 of light subjects will be overestimated and that of heavy subjects will be underestimated (68). When comparing different subjects in running and walking performance, V_{O2} expressed as ml · $kg^{-0.75}$ · min^{-1} is suggested to be the most correct method of comparisons between subjects of various body mass (25). When comparing muscle strength in different subjects, the weight lifted should be expressed as kg · $m_b^{-0.67}$ (196). Allometric scaling was used to normalize V_{O2} and weight lifted to body size and mass in order to compare different subject groups, sexes and to compare each subject at different time periods. Both sexes were represented in papers I-IV.

3.2.6 Work efficiency and work economy

In paper I-IV, work efficiency was calculated between 3.30-4.30 min during the 5 min standardized workload test. The subjects walked on a treadmill for 5 minutes (Technogym, Runrace 1200 HC, Italy) at a standardized workload corresponding to 40 Watts (W). In paper I and II, work economy was calculated between 3.30-4.30 min during the standardized workload and expressed as mL · $kg^{-0.75}$ · m^{-1}. All ventilatory parameters and pulmonary gas exchange was measured using Cortex Metamax I portable metabolic test system (Cortex Biophysik GmbH, Germany). For measurement of HR, short-range radio telemetry with Polar accurex watches (Polar Electro Oy, Finland) was used.

The following equation was used to define the walking speed corresponding to 40 W on the treadmill:

(1)

$$V = \frac{workload}{[m_b \cdot g] \cdot \sin(\theta)} \cdot 3.6$$

V= velocity [km · h^{-1}]

Work load = 40 W [Nm · s^{-1}]

g = gravitational constant [9.8 m · s^{-2}]

m_b = body mass [kg]

θ = treadmill inclination [deg]

3.6 = converting velocity expressed in [m · s^{-1}] to [km · h^{-1}]

(2) Net efficiency was calculated by the following equation:

$$\frac{\text{Load (W) of exercise} \cdot 0.01433 \left(\text{Kcal} \cdot \text{min}^{-1}\right)}{\text{Energy expenditure during exercise} - \text{REE} \left(\text{Kcal} \cdot \text{min}^{-1}\right)} \cdot 100$$

REE; resting energy expenditure

Resting energy expenditure was calculated from standardised values of 3.5 ml · kg^{-1} · min^{-1}. Both VO_2 and W were converted to kilocalories (Kcal) to allow the calculation of percent work efficiency (114).

3.2.7 Gait patterns

In paper I-IV gait patterns was recorded with subjects walking at a standardized velocity of 4 km·h^{-1} on a horizontal treadmill (Technogym, Runrace 1200 HC, Italy). A Pedar-X dynamic pressure distribution measure system for capacitive sensors was used (Novel Pedar-X System, Germany). Step length, peak force heel/toe, stance time and impulse were calculated. Flexible insoles with sensors were placed in both shoes. Pressure ranges were logged during walking and analyzed at a later stage. Before recording, the subjects walked with the measuring equipment for 2 minutes to ensure a steady state of walking, without being informed about the recording period. The recording measurement duration was 30 seconds and the recorded steps from 11-20 in each subject were used in the analysis of gait parameters. The Pedar measurement system has been proven to be a valid and reliable measure of contact area and peak pressure (77, 90).

3.2.8 Borg scale

In paper I-IV, the subjects gave a subjective evaluation of perceived exertion by end-exercise leg effort and breathlessness using the Borg ratio scale after completing the VO_{2max} test. The scale ranges from 6-20, where 20 represents the highest degree of exertion (32).

3.2.9 Health related quality of life

In paper III and IV, the generic 36-item Short-Form Health Survey (SF-36) was used to determine HRQoL after each test. The survey contains an evaluation of both physical component score (PCS) and mental component score (MCS). The scale ranges from 0-100 where 100 indicates optimal health (182). The SF-36 is a widely used and validated survey and has been translated and validated for Norwegian conditions (102).

3.2.10 Surgical procedures

Only the direct lateral approach, described by Hardinge and modified by Frndak (53, 63), was used in all patients in paper I-IV. In paper I-II, surgery was performed by several orthopaedic surgeons. Under reconstruction of the hip abductor muscles in the patients in paper I and II, the common muscle plate was refixed to the greater trochanter with a double resorbable osteosutures (Vicryl, No 2, Johnson & Johnson, NJ, USA). Furthermore, this fixation was reinforced with a continuously sewed resorbable suture, leaving no gap between the muscle plate and the anterior part of the greater trochanter (Vicryl, No 2, Johnson & Johnson, NJ, USA). In paper III (and IV), all surgery was performed by 1 orthopaedic surgeon. Reconstruction of the hip abductor muscles of the patients was modified from previous procedures. Under reconstruction of the hip abductor muscles, the common muscle plate was reinserted to the greater trochanter with 2 non resorbable osteosutures (PremiCron, B.Braun Medical Ltd, Germany). Furthermore, this fixation was reinforced with a continuously sewed slowly resorbable looped monofilament suture (MonoPlus, B. Braun Medical Ltd, Germany). Skin was closed with unresorbable suture (I-IV) (Dafilon, B.Braun Medical Ltd, Germany).

3.2.11 Clinical function score of the hip

In paper I-IV, the Merle D'Aubigné and Postel scoring system was used for clinical evaluation of hip function. The scoring system evaluates pain, joint mobility and gait function with a range from 3-18. The sum of the 3 separate scores represent the total score where 18 indicates optimal function of the hip (40).

3.2.12 Radiological assessments

Anteroposterior pelvic radiographs were taken prior to inclusion in the studies, using a 28 mm magnification marker, located at the level of the symphysis. All radiographs were digitized and a computer analysing program (SectraPACS) was used for all measurements including calibration of the radiographs. The parameters were measured by 2 observers.

3.2.13 Calculation and measurement of biomechanical values

In paper I-IV, FO was measured as the perpendicular distance between the longitudinal axis of the femur and the centre of the femoral head (38). In paper II, the following values were calculated: FO ratio was calculated by measuring the distance between the centres of the femoral heads divided by FO (188). The greater trochanter tangent was a line drawn 70º to the centre to centre line, and tangential to the most lateral part of the greater trochanter. The acetabular lever arm was defined as the perpendicular distance from the femoral head centre to the greater trochanter tangent. Hip lever arm ratio was calculated as the abductor lever arm divided by the body weight lever arm (134) (Figure 3). Hip abductor power was calculated as recorded dynamic hip abductor strength ($kg \cdot m_b^{-1}$) multiplied by leg length from the spina iliaca anterior superior to the tuberositas tibia (measured in vivo) divided by length of the hip abductor lever arm (133).

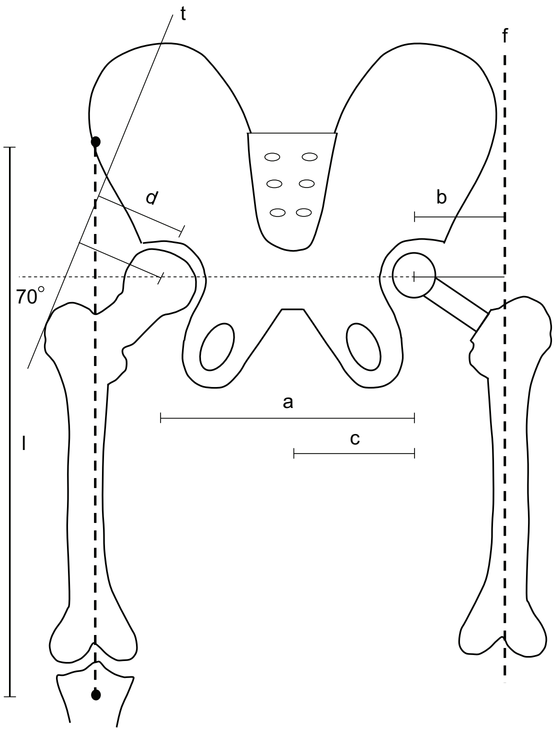

Figure 3, Calculation and measurement of biomechanical parameters
a = distance between centres of femoral heads
b = length of femoral offset
c = length of body weight lever arm
d = length of abductor lever arm
f = longitudinal axis of the femur
l = length of leg
t = greater trochanter tangent

3.2.14 Cadaveric test of muscle reattachment strength

The strength of the reattachment of the hip abductor muscles was tested in 1 intact cadaver pelvis. 2 threaded 4 mm pins were inserted 20 mm into the iliac crest. The standard lateral approach to the hip joint was performed. The anterior part of the capsule was resected. The common muscle plate of the anterior part of the musculus gluteus medius and musculus vastus lateralis was sutured back to the anterior part of the greater trochanter by first using a double osteosuture. Furthermore, a slowly resorbable loop suture duplicated the muscle plate to the greater trochanter. A continuous close of the fascia latae was performed. In order to test the pull-out strength of the sutures, the muscle attachment of the hip abductor muscles were released by separating the iliac wing from the pelvis by using a Giggly saw. A connection between the 2 threaded pins was established and a load cell was linked to the connection. A longitudinal force angulated 30º in the frontal plane was applied. A load of 25 kg was applied. After the test, the reattachment of the muscles and sutures was inspected and found to be intact. The test was approved by the regional ethics committee and consent from relatives was obtained.

3.2.15 Statistical analysis

The software program Statistical Package of the Social Sciences version 16-17 (SPSS Inc. Chicago, IL) was used for all statistical analysis. Results are presented as mean ± SD throughout the study, except from in figures where results are presented as mean ± SEM. Q-Q plots were used to determine normal distribution of the parameters. In paper I, one-way analysis of variance (ANOVA) was used to determine differences in parameters between the groups whereas paired-sample t tests were used to determine strength differences between the legs within each group. In paper II, one-way ANOVA and Tukey`s honestly significant difference (HSD) post-hoc tests were performed to determine differences in parameters between the groups. The relationship between variables was determined by simple correlation analysis (Pearson's r). In paper III preoperative data was compared by two-sample t tests. Submaximal oxygen consumption and work efficiency were measured by two-sample t tests at all tests due to missing variables at the test 1 week postoperatively. Postoperative FO of the groups was compared by two-sample t tests. Variables obtained 1 week postoperatively and 5 weeks postoperatively were analysed by two-way ANOVA for repeated measurements with time as within-factor and STG vs. CRG as grouping factor. When a significant interaction between main effects was found, a two-sided multiple contrast test within each group and between groups at each point in time were performed with the appropriate adjustments of the degrees of freedom (187). In paper IV, two-sample t tests and Mann Whitney-U tests were used to determine differences in parameters between groups whereas paired-sample t tests and Wilcoxon signed rank tests were used to determine within group differences. Additionally, two-sample t tests were used to compare data from paper I and III, and paired-samples t tests were used to compare differences between the legs in the patients in paper III and IV. A p value ≤ 0.05 was considered significant for all measurements.

3.3 Training procedures and materials

In paper III, all patients were enrolled in a 4 week inpatient rehabilitation facility. The STG performed leg press and hip abduction in addition to the conventional rehabilitation. The CRG performed the conventional rehabilitation only. In paper IV, all patients performed self-adjusted rehabilitation and were referred to physical therapy twice a week until 6 months postoperatively.

3.3.1 Maximal strength training

One week postoperatively, maximal strength training was initiated with 5 training bouts a week for 4 weeks. Each training session started with a 10 minute warm up period of stationary cycling at an intensity corresponding to 50 % of VO_{2max} followed by the maximal dynamic strength training regime of leg press and hip abduction. Maximal strength training was performed in 4 series of 5 repetitions maximum involving the operated leg only. The series were separated by resting periods of 2 minutes.

Leg press was performed in a leg press ergometer in a seated position with a knee joint angle of 90º and a flexion angle of maximum 90º in the hip joint (to avoid hip luxation) with range of motion of 90-45º in the hip joint and 90-0º in the knee joint. The training load was 5RM, corresponding to approximately 85 % of 1RM (6). When the patients managed to perform 6RM, the load was increased by 5 kg.

Hip abduction was performed using a standard pulling apparatus. The patients were standing in an upright position stabilized by parallel bars with a 15 cm wide sling placed at the medial malleolus of the trained leg (Figure 4). The patients were instructed to stand in an upright position and to keep the foot pointing forward during the hip abduction exercise. Range of motion was 0-25º in the hip joint. When the patients managed to perform 6RM, the load was increased by 1 kg. The training sessions were supervised by 2 exercise physiologists with experience from a hospital orthopaedic hip joint unit.

Figure 4, Hip abduction during training

3.3.2 Conventional rehabilitation

The conventional rehabilitation for all patients attending inpatient treatment in a rehabilitation centre consisted of individual sling exercise therapy in hip abduction/adduction, hip flexion/extension, exercises with low resistance (>12-15 repetitions (94)) or no resistance and exercises performed in water when sutures had been removed. Each session lasted 1 hour and was performed 5 days a week for 4 weeks. The patients attended educational classes twice a week. The 2 patients in the CRG who choose to return home after being discharged from the hospital received outpatient treatment supervised by a physician 3 times a week with instructions to carry out prescribed exercises at home 2 times a week.

4 Summary of results

Paper I: Reduced strength, work efficiency and maximal oxygen consumption 3-5 years after total hip arthroplasty

1. 1RM leg press was reduced in the operated leg of the unilaterally operated THA patients (UNO-group) by 40 % compared with the right leg of the healthy controls (C-group) (122±31 vs. 87±25 kg).
2. 1RM leg press difference between the legs was significantly higher in the UNO-group than in the C-group by 425 %.
3. 1RM hip abduction strength difference between the legs was significantly higher in the UNO-group compared with the C-group by 105 %.
4. Gait patterns revealed a significant higher peak pressure in the healthy forefoot of the UNO-group compared with the C-groups left forefoot by 41 %.
5. Work efficiency and work economy were significantly lower in the UNO-group compared with the C-group by 42 % and 17 %, respectively.
6. VO_{2max} was significantly lower in the UNO-group by 26 % compared with the C-group (38.8±9.0 vs. 30.7±7.4 ml · kg · min^{-1}).

Paper II: Unilateral vs. bilateral total hip arthroplasty – the influence of medial femoral head offset and effects on strength and aerobic endurance performance

1. Bilateral leg press in kg · m_b^{-1} was significantly higher in the unilaterally operated THA patients (UNO) compared with the bilaterally operated THA patients with abnormal low FO (BDO) and the bilaterally operated THA patients with normal FO (BNO) by 38 % and 31 %, respectively.
2. Leg press healthy leg in kg · m_b^{-1} in the UNO was significantly higher compared with the left leg of the BNO by 46 %. Leg press healthy leg in kg · m_b^{-1} in the UNO was significantly higher compared with the normal FO leg of the BDO by 33 %.
3. Hip abduction strength of the healthy leg of the UNO was significantly higher compared with the normal FO leg of the BDO by 79 %. The corresponding result

for the left leg of the BNO compared with the healthy leg of the UNO in kg · m_b^{-1} was 58.2 %.

4. A positive correlation was found between FO and hip abduction strength (kg · m_b^{-1}) and between FO and calculated hip abduction strength in the abnormal low FO side of the BDO (r= 0.866 and 0.893, respectively).
5. No differences between the unilaterally and bilaterally operated groups were revealed in VO_{2max}, work efficiency or gait patterns.
6. No differences in hip abduction strength were found between the BNO and BDO.

Paper III: Early maximal strength training is an efficient treatment for patients operated with total hip arthroplasty

1. 1RM bilateral leg press improved in both the strength training group (STG) and the conventional rehabilitation group (CRG), with a more pronounced improvement in the STG by 41 % (193±54 vs. 137±42 kg).
2. 1RM leg press in the operated leg increased in both groups, but more clearly in the STG being 65 % higher compared with the CRG (76±20 vs. 46±16 kg).
3. RFD in the operated leg improved in both groups with an improvement being 65 % higher in the STG compared with the CRG.
4. Hip abduction strength in the operated leg increased in both groups, but more pronounced in the STG by 87 % vs. the CRG (43±15 vs. 23±9 kg). In the healthy leg, only the STG increased hip abduction strength from 1-5 weeks. At the 5 weeks test hip abduction strength in the healthy leg of the STG was 49 % higher compared with the CRG.
5. No significant difference in gait patterns, VO_{2max} or work efficiency was found between the groups.
6. The mental component score (MCS) from the SF-36 survey was 22 % higher in the STG compared to the CRG 1 week after the operation. In the CRG the score increased by 17 % reaching levels not significantly different from STG 5 weeks after the operation.
7. Physical component score (PCS) increased in both groups 1-5 weeks postoperatively, averaging 22 % with no difference between groups.

Paper IV: Early postoperative maximal strength training improves work efficiency 6-12 months after osteoarthritis induced total hip arthroplasty in patients under 60 years old

1. Work efficiency was 29 % higher in the strength training group (STG) compared with the conventional rehabilitation group (CRG) in the test after 6 months (18.5±4.5 vs. 14.3±4.2 %).
2. No significant difference in muscle strength was found between the groups 6 months postoperatively.
3. Rate of force development (RFD) in the operated leg was significantly higher by 74 % in the STG compared with the CRG 12 months postoperatively.
4. Leg press in the healthy leg ($kg \cdot m_b^{-0.67}$) was significantly higher by 36 % in the STG compared with the CRG 12 months postoperatively.
5. After 12 months, work efficiency was 30 % higher in the STG compared with the CRG (16.9±3.2 vs. 13.0±3.9 %).
6. No differences in gait patterns or VO_{2max} were found between the groups.
7. No significant differences between the groups in health related quality of life was found 6 and 12 months after surgery.

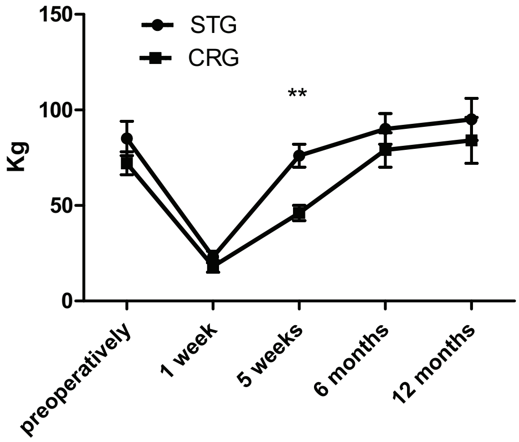

Figure 5, Leg press operated leg
Data are presented as mean ± SEM. Leg press in kg from preoperatively to 12 months postoperatively in the STG and CRG (Paper III and IV). ** Significant differences between the groups p<0.01.

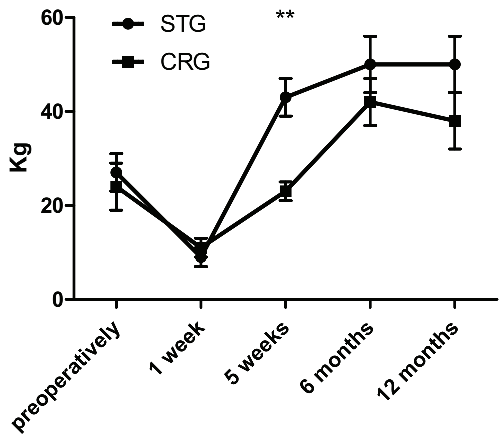

Figure 6, Hip abduction operated leg
Data are presented as mean ± SEM. Hip abduction in kg from preoperatively to 12 months postoperatively in the STG and CRG (Paper III and IV). ** Significant differences between the groups p<0.01.

5 Discussion

The present thesis demonstrates that THA patients are not fully recovered 3-5 years after THA. Furthermore, the conventional rehabilitation offered the THA patients does not seem to restore muscle strength and VO_{2max} compared with normative data (I). The outcome of bilaterally operated THA patients, either with normal or abnormal FO, did not differ with respect to muscle strength, gait patterns, work efficiency or VO_{2max}. No differences were revealed between unilaterally and bilaterally operated THA patients in work efficiency, gait patterns or VO_{2max} (II). Maximal strength training improved muscle strength and power in the lower extremities of THA patients more than conventional rehabilitation (III) and maximal strength training initiated in the early postoperative phase improved work efficiency 6-12 months postoperatively (IV).

5.1 Muscle strength in THA patients

In the present thesis, muscle strength was obtained by leg press and hip abduction (I-IV). In paper I, leg press muscle strength in the operated leg of the unilaterally operated THA patients (UNO-group) was 68 % of the leg press muscle strength in the healthy leg. The corresponding result in hip abduction was 61 %. In leg press, muscle strength in the operated leg in the UNO-group was reduced by 40 % compared to healthy subjects. The strength deficits between the legs found in paper I are in line with the findings of others (159, 160, 174). The large difference in muscle strength both in leg press and in hip abduction in paper I may to some extent be due to a highly reduced preoperative strength of the affected extremity or/and an inefficient rehabilitation programme. Preoperative muscle strength in the lower extremities is reported to be reduced in THA patients (159, 175) which is consistent with the findings in paper III where a significant difference between the affected and healthy leg was found preoperatively in the strength training group (STG) by 24 % ($p=0.001$) and in the conventional rehabilitation group (CRG) by 39 % ($p=0.004$).

In paper II, no differences in muscle strength after THA between the bilaterally operated group with normal FO (BNO) and the bilaterally operated group with abnormal FO (BDO) were found. The importance of a correct FO in the THA surgery has been emphasized (13, 14, 33, 119, 188) since a correct FO primes the ability of the patient to regain muscle strength of the hip abductor muscles postoperatively. Despite optimal biomechanical reconstruction of the hip joints in the BNO, muscle strength in these patients were inadequate compared to the healthy leg of the unilaterally operated group with normal FO (UNO). The traditional postoperative rehabilitation which was conducted in the studied patients in paper I and II has probably not been sufficient to optimally restore muscle strength. Conventional physiotherapy exercises are reported to have small effects on muscle strength in THA patients (9, 125, 164). Another aspect related to muscle strength in the THA patients, is to what extent it is feasible to fully restore muscle strength in the affected limb when comparing to healthy controls, particularly when the direct lateral approach is used (I-IV). The direct lateral approach is considered to be the approach that compromises hip abductor muscles the most (86). Yet, conclusions can not be drawn about the feasibility of restoring muscle strength in the lower extremities since an efficient rehabilitation program for the THA patients has not been established.

In paper III, maximal strength training with few repetitions and explosive movements (or with the intention to perform explosive movements) in the concentric phase of the movement improved muscle strength considerably in the STG. Maximal strength training was well tolerated by the patients in the STG and no adverse events (luxation of the hip joint or rupture of the reattachment of the musculus gluteus medius) occurred during training or testing. An important advantage of maximal strength training is a rapid improvement in muscle strength without a concomitant increase in body mass (85) which is of advantage since transportation of an increased body mass is an unfavourable side effect. After 4 weeks of maximal strength training (20 training sessions), hip abduction and leg press in the operated leg were 87 % and 65 % higher, respectively in the STG compared with the CRG. After the training intervention, the STG improved hip abduction muscle strength in the healthy leg when training the operated leg only, which is suggested to be a result of neural adaptations (6, 36, 173). In contrast, improvements in the healthy leg of the CRG were not found. Heavy strength training (70-90 % of 1RM) in leg press has been initiated 6-8 weeks postoperatively (65) and 1 week postoperatively with loads of 50 % of 1RM the first week increasing to 80 % of 1RM 6 weeks postoperatively (164). The improvements in the above-mentioned studies were less (122 % and 28 %, respectively) compared with the results in paper III (230 % increase in leg press in the operated leg), and training the hip abductors or measuring hip abduction muscle strength were not conducted. In paper III, maximal strength training was added to the conventional rehabilitation programme in the STG. The STG and the CRG received different amounts of training since the STG received both maximal strength training and conventional rehabilitation. Thus, the amount of training conducted in the 2 groups was not matched according to frequency and total work.

Significant differences between the legs in leg press and hip abduction were present in the STG and the CRG 5 weeks postoperatively. In the STG, hip abduction muscle strength of the operated leg was 78 % (p=0.012) of the hip abduction muscle strength in the healthy leg. The corresponding result in leg press was 74 % (p<0.001). In the CRG, hip abduction muscle strength of the operated leg was 62 % (p=0.001) of the hip abduction muscle strength in the healthy leg. The corresponding result in leg press was 52 % (p<0.001). In the STG, differences in leg press 6 months postoperatively (81 % of healthy leg muscle strength, p=0.004) and in leg press and hip abduction 12 months postoperatively (83 % of healthy leg muscle strength, p=0.024 and 83 % of healthy leg muscle strength, p=0.003, respectively) were present. 6 and 12 months postoperatively, no muscle strength differences between the legs were found in the CRG. Differences between the groups were not statistically significant. Muscle strength differences between the legs were significantly less in the STG in paper III and IV compared with the UNO-group in paper I when comparing 5 weeks, 6 and 12 months results of the STG (p<0.001). An explanation may be that at an incomplete rehabilitation of the affected leg in the UNO-group may have resulted in a greater reliance on the healthy leg. Thus muscle strength in the healthy leg may have improved at the cost of restoring muscle strength in the operated leg. Nevertheless, in light of the significantly less difference between the legs in the STG compared with the UNO-group, one may speculate that the rehabilitation of the STG have resulted in improved reliance on the operated leg.

To our knowledge, no studies have initiated maximal strength training in leg press and hip abduction 1 week postoperatively in THA patients. Weak hip abductor muscles have impact on the THA patients functional level, as these impairments may affect their capacity of e.g. walking stairs or descending slopes (130). Thus, it is of importance to incorporate training that strengthens the hip abductor muscles after THA. When comparing the unilaterally operated THA patients in paper I with the STG in paper III, only hip abduction in the healthy leg reached significant differences between the groups (p=0.001). It is an interesting finding that the results of 4 weeks of maximal strength training equals those of THA patients operated 3-5 years ago which highlight the effectiveness of maximal strength training. Questions can be raised whether maximal strength training is advisable 1 week after THA. The strength of the reattachment of the musculus gluteus medius to the greater trochanter when the lateral approach is used may be challenged when initiating maximal strength training as early as 1 week postoperatively. In order to mimic the load on the reattachment of the musculus gluteus medius in the immediate postoperative phase, a muscle strength test in a cadaveric pelvis was performed. The load applied was 25 kg and the test was repeated twice. Visual inspection after the test revealed an intact reattachment of the muscles and the sutures. As reported in paper III, 1RM in hip abduction was 9 and 11 kg, respectively in the CRG and the STG at the test 1 week postoperatively which is a load far less than the load used in the cadaveric test. Biomechanical calculations have demonstrated a torsion moment in caput femoris of 37 Nm in a 75 Kg person if normal FO in single leg stance, such as stair climbing (96), which corresponds to approximately 90 kg. The weight load mimics the leg press intervention in paper III. In paper III, Merle D'Aubigné and Postel mean score was 17 in both groups after 5 weeks, indicating a normal gait without limping and a sufficient reattachment of the musculus gluteus medius to the trochanter major.

Comparing muscle strength of the STG in paper III to the healthy subjects in paper I, leg press and hip abduction muscle strength in the STG is reduced, verifying the need for a longer maximal strength training programme to fully restore muscle strength. In paper IV, no differences in leg press or hip abduction were revealed between the STG and the CRG. The finding is not surprising, since the maximal strength training programme was not continued in the STG. After 5 weeks, all patients were referred to current rehabilitation course which consisted of outpatient physical therapy twice a week until 6 months postoperatively. In paper IV, the effects of free living were determined, and the amount of training was not systematically recorded. An overview of leg press and hip abduction strength results in the STG and CRG from preoperatively to 12 months postoperatively (paper III and IV) is presented in summary of results (Figure 5 and 6, respectively).

5.2 Muscle power in THA patients

In paper I, RFD was equal in the healthy control group compared to the UNO-group despite differences in muscle strength. The results from paper II demonstrated similar results: No differences in RFD between the groups were found despite higher muscle strength in the healthy leg of the unilaterally operated group compared to the bilaterally operated groups. This finding is not controversial since increased muscle strength not automatically improves RFD (97, 171). Moreover, RFD is reported to decrease as a result of heavy strength training with slow moments (60, 97). To increase RFD, the high threshold muscle fibres (Type II fibres) must be recruited, which is ensured in maximal strength training performed with high velocity. In paper III, when the maximal strength training was added to the conventional rehabilitation programme, RFD improved by 65 % in the STG compared to the CRG. Improved RFD as a result of maximal strength training is in line with the findings in several studies (37, 73, 76, 166, 192). No difference in RFD was demonstrated between the STG in paper III and the UNO-group in paper I despite of the great discrepancy between the groups in time elapsed since surgery. A longer training period for the STG may have resulted in a higher RFD in the STG compared to the UNO-group. In paper IV, RFD in the operated leg was higher in the STG compared to the CRG after 12 months by 74 % despite no differences in muscle strength in the operated leg. Training with light or heavy loads, respectively, has been reported to give equal improvements in RFD despite differences in 1RM (7), demonstrating that RFD may be improved without a concomitant improvement in 1RM.

For patients undergoing major surgery, such as THA patients, levels of muscle strength and RFD are expected to be lower ahead of surgery and immediately after surgery as disuse is one of the major contributors to skeletal muscle atrophy (163). Maximal strength training (3-5 repetitions) recruits the high threshold motor units which predominantly consist of type II fibres (97) and thereby contributes to an increased reliance on type II fibres in THA patients. During fast movements with a short contraction time (<300 ms) maximal force is difficult to achieve, so that any increase in RFD will be important (193). Low levels of RFD are associated with limitations in activities of daily living, risk of falling and hip fractures (51, 99, 105, 193). Thus it seems crucial to improve RFD in patients undergoing THA.

5.3 Aerobic endurance performance in THA patients

Patients with OA of the hip frequently show decreased aerobic endurance performance. The degree of deconditioning correlates with the severity of OA and it is anticipated that inactivity caused by pain leads to the reduced aerobic endurance performance (145, 146). Paper I demonstrated clearly that VO_{2max} in the THA patients (UNO-group) was decreased after THA as well compared to the healthy control group. The difference of 26 % in VO_{2max} (corresponding to 8.1 $mL \cdot kg^{-1} \cdot min^{-1}$) is noticeable as increased risk for developing cardiovascular disease and Type 2 diabetes is associated with inactivity and reduced VO_{2max} (30, 101). According to the secondary law/regulative of Norway concerning compensation for permanent injury, unilateral THA produces 15-35 % degree of disability dependent on functional level. Bilateral THA results in 15-35 % further decrease in disability dependent on the degree of disability in the contralateral hip. Based on the above mentioned regulative, it is anticipated that a bilateral procedure is more disabling to the patients than a unilateral procedure of THA (3). In paper II, no differences in VO_{2max} between unilaterally or bilaterally THA patients were detected despite differences in muscle strength. The results in paper III display similar findings as no differences in VO_{2max} were found although differences in muscle strength were present. In consistency with the findings in paper III, several studies report no alterations in VO_{2max} as an effect of strength training only (70, 110, 116, 141). In paper IV, no difference in VO_{2max} between the STG and CRG was present even if work efficiency was higher in the STG. Differences in aerobic endurance performance despite similar VO_{2max} may be explained by the impact of work efficiency (126).

Maximal strength training is frequently reported to improve aerobic endurance performance (73, 75, 76, 85, 87, 141, 155) by increasing work efficiency. In paper I, the healthy control group displayed a 42 % higher work efficiency compared to the UNO-group which may be explained by an increased walking performance in the healthy controls. In paper III, work efficiency was not significantly increased in the STG compared to the CRG despite vast differences in muscle strength and RFD. In line with the findings in paper III, Kelly et al. (89) discovered no significant differences in work efficiency between a group adding heavy strength training to an endurance programme or a group performing the endurance programme only. Since maximal strength training has not been performed in THA patients previously, comparing the effects of maximal strength training on work efficiency with other studies is not feasible. Another element is that THA patients undergoing major surgery in the lower limbs may respond differently to maximal strength training concerning effects on work efficiency. The reason might be that the low amount of walking activity has reduced the transfer of muscle strength from leg press to efficient walking, which is in line with the findings from Almåsbakk and Hoff, highlighting specificity of training (7). According to the findings in paper III and IV, the effect of the maximal strength training on work efficiency seems to be delayed. In paper IV, work efficiency was higher in the STG with a difference of 29 % and 30 % 6 and 12 months after THA surgery. The improved work efficiency in the STG group was reflected by reduced VO_2 and HR at the submaximal oxygen test. Compared to the CRG, a 14 % reduction in VO_2 (ml · kg$^{-0.75}$ · min^{-1}) was found after 6 months whereas VO_2 in ml · kg^{-1} · min^{-1} and in ml · kg$^{-0.75}$ · min^{-1} were lowered by 30 % and 29 %, respectively followed by a 13 % reduced HR 12 months postoperatively. Yet, the work efficiency value of the STG (19 % and 16 % after 6 and 12 months, respectively) was still not within the range of normal value which is considered to be 20-25 % (114). Nankaku et al. (130) found reduced work efficiency in THA patients compared to healthy controls after a 4 week rehabilitation period and the reduced work efficiency was mainly explained by increased lateral trunk displacement caused by weakened hip abductor muscles. Similar finding is reported by Brown et al. (34) discovering lower work efficiency in the THA patients 1 year after surgery compared to that of healthy subjects. Work efficiency reflects the THA patient's functional performance level (184) and an increased work efficiency may allow the THA patients to be more physically active at a higher intensity which is favourable in order to improve VO_{2max}. As VO_{2max} is known to be a predictor of mortality (129), a high VO_{2max} is important.

Measuring gait patterns in paper I revealed that the forefoot pressure during walking was significantly higher in the healthy leg than in the operated leg in the unilaterally operated THA patients. This seems to be an attempt to reduce load of the operated leg and thus to an asymmetric loading of the limbs which in turn increases energy expenditure (33) and thereby affects work efficiency negatively. Talis et al. (168) and McCrory et al. (117) demonstrated similar findings: Unilaterally operated THA patients loaded the healthy leg more than the operated leg. The results of paper II, III and IV revealed no differences between the groups in the different gait variables. Walking on a relatively slow pace (4 km · h^{-1}) on a horizontal treadmill for 2-3 minutes only, may enable the patients to mask possible weak hip abductor muscles. A positive correlation between hip abductor strength and maximal walking speed has been reported (109, 178) and related to paper III, where hip abductors were stronger in the STG, maximal gait speed would have been assumed higher in the STG compared to the CRG. However, gait speed was not measured in the studies I-IV.

5.4 Biomechanical considerations

Normal FO in adult individuals is averagely 43 mm (± 6.8 mm)(132). In paper I, all patients had normal FO in the operated leg (mean 43.7 mm) compared to their healthy side (mean 42.5 mm). Comparing with healthy subjects in paper I, muscle strength was reduced and muscle strength differences between the legs were present in the UNO-group despite optimal anatomical reconstruction of the hip joint. In paper II, FO was 38.8 and 48.8 mm in the abnormal and normal side, respectively in the BDO. The expected difference in hip abduction strength between the BNO and BDO failed to appear. The contribution to hip abduction strength of the tensor fascia lata (195) combined with an adequate hip lever arm ratio (> 0.5 in all groups), a too small sample size, too small discrepancies in FO or an inefficient rehabilitation may explain the lack of significant muscle strength differences despite dissimilarities of FO in paper II. In paper III (and IV), all THA patients had normal FO compared to preoperative values and hip abductor strength was considerably higher in the STG compared to the CRG as a result of maximal strength training. A correct anatomical reconstruction of the hip joint after THA has several advantages. However, it is believed that an early rehabilitation of the muscles after THA surgery is of greater importance than the reconstruction of the mechanics of muscle pull (33, 152). Thereby, an insufficient rehabilitation may be one of the factors explaining the findings in paper I and II.

5.5 Hip score systems

Several hip scores systems are used in the orthopaedic practice, but the validity of the different score systems has been questioned and the results may be biased by the fact that surgeons evaluate their own results. Moreover, the hip scores systems are criticized for not including a patient satisfaction part (56). In paper I, the patients obtained a hip score value of 17 points measured by Merle D'Aubigné and Postel scoring system. However, functional physical tests revealed strength deficits, reduced walking efficiency and aerobic endurance performance compared to healthy subjects. In paper II, functional hip score demonstrates values close to optimal score (17-18 points) for all 3 patient groups. The corresponding value in paper III was 17 points in both groups although vast muscle strength differences were present between the STG and CRG. In paper IV, the scores were 17 and 18 points in the STG and CRG, respectively, not accounting for increased work efficiency and RFD in the STG compared to the CRG. The results in the present thesis indicate hip score systems to bee insufficient in determining physical performance of the THA patients. The hip score system do not seem to be sufficient sensitive to detect the true physical level of the patients. An example is the term “normal gait function” in the Merle D’Aubigné and Postel scoring system which gives maximal score without providing information about walking speed or distance.

5.6 Health related quality of life

In paper III and IV, HRQoL was measured by the SF-36 short form survey. Paper III revealed an increase in the physical component score (PCS) in both the STG and the CRG from 1-5 weeks postoperatively averaging 21.5 % with no differences between the groups. Mental component score (MCS) was 21.7 % and significantly higher in the STG compared to the CRG 1 week after the operation and may be explained by the effect of the extra follow-up time in the STG. 12 months after surgery (paper IV), PCS values were 47 and 48 in the STG and the CRG, respectively. The PCS values in both groups in paper IV are higher compared to those of Mahomed et al. (108) who found a PCS value of 39 12 months postoperatively. MCS score was 52 and 50 in the STG and the CRG, respectively whereas the corresponding value in the Mahomed study was 45. No differences between the groups in the HRQoL variables were detected after 5 weeks, 6 or 12 months postoperatively. The improved work efficiency in the STG would have been expected to be accompanied by differences in HRQoL. An explanation may be that generic instruments, as the SF-36, may often lack the sensitivity to detect differences between treatment methods compared in clinical trials. Disease-specific scales may have revealed differences among the groups since they generally are reported to be more responsive than generic health status measures (48). Western Ontario and McMaster Universities OA index (WOMAC) is a disease-specific questionnaire used to assess pain, function and stiffness of hip and knee (22). The SF-36 as well as the WOMAC questionnaires are reported to detect alterations in pain in THA patients undergoing rehabilitation after surgery while the WOMAC have demonstrated better ability to detect functional improvements (10). Mahomed et al. (108) report large inter-group improvements in the SF-36 and the WOMAC from before to 3 months after surgery. No differences between the groups were revealed at 12 months after surgery by the use of SF-36 or WOMAC in the Mahomed study, which is in line with the findings in paper IV.

5.7 Risk of muscle strength training

Rupture of the reattachment of the musculus gluteus medius and luxation of the hip joint during hip abduction and leg press training and testing were considered adverse events in paper III and IV. In order to avoid possible luxation of the hip joint in the leg press exercise, the angle in the hip joint was carefully adjusted to be 90°. Reconstruction of the hip abductor muscles of the patients was modified from previous procedures by using 2 non resorbable osteosutures and a continuously sewed slowly resorbable looped monofilament suture. Furthermore, the strength of the modified suturing technique was adequate when tested in an intact cadaveric pelvis. No adverse events occurred during training and testing in the THA patients (III and IV). Increased muscle strength may be favourable to the hip implant and important in order to improve coordination and to prevent falls (98). Considering the relationship between VO_{2max} and mortality (112, 129, 149, 185), the risk of inactivity caused by reduced muscle strength ought to be considered higher.

5.8 Limitations

The low number of participants can be considered a limitation in the studies as minor differences may not be observed. Despite the low number of subjects, significant differences were found which strengthen the results. A higher number of participants might however secure a greater generalisation of the results to the patient group, although it is not believed that there is unintentional bias in the population used in the present experiments. In paper III (and IV) a longer duration of the maximal strength training programme (10-12 weeks) might have revealed differences in muscle strength at 6 and 12 months (paper IV) as well. A limitation in the gait analysis part in the present thesis is that the variables maximum walking speed, a 6 min walking test or walking distance should have been added. These tests may have resulted in differences between the groups and comparisons with other studies would have been applicable. In paper IV, physical activity was not systematically recorded in the THA patients. Such registration would have been beneficial in order to state whether improved work efficiency actually resulted in increased physical activity in the STG or otherwise; to confirm that the improved work efficiency was a result of increased physical activity.

5.9 Perspectives

THA is one of the most successful medical innovations developed in the 20th century (66). THA has been documented to relieve pain, improve function, correct deformity, increase social functioning, reduce the individual's reliance on others, and contribute to psychological well-being as well as being cost-effective to society and improve quality of life. In the US, the prevalence of THA is expected to increase by 174 % from 2005-2030 (66). Current rehabilitation does not seem to restore functional abilities in the THA patients compared with healthy subjects. Weakened abductor muscles, reduced walking speed and asymmetric loading of the limbs, reduced work efficiency and diminished aerobic endurance performance are frequently reported after the rehabilitation period (33, 115, 168). Thus it seems crucial to implement an effective rehabilitation program to the THA patients both in terms of reducing health risks, increasing patient satisfaction and protecting the hip implant.

The present thesis shows that VO_{2max}, muscle strength and work efficiency are reduced compared to healthy subjects and that aerobic endurance performance is reduced to the same extent in unilaterally and bilaterally operated THA patients. Maximal strength training in hip abduction and leg press is demonstrated to be highly effective in order to improve muscle strength in THA patients and to have a positive impact on work efficiency after 6 and 12 months. VO_{2max} and work efficiency did not reach recommended levels in the CRG and the STG at the end of follow-up. Thus, a combination of a prolonged maximal strength training programme (10-12 weeks) followed by a programme enhancing aerobic endurance performance would be beneficial in future rehabilitation programmes for THA patients. Considering prosthetic wear, interval training performed as cycling or uphill walking should minimize wear, but still tax the circulatory system sufficiently to improve VO_{2max}. Interval training performed as 4 x 4 minutes of aerobic intervals at 85-95 % of HR_{max} with 3 minutes active rest between the intervals has been carried out successfully in both coronary artery disease patients and chronic obstructive lung disease patients with an improvement in VO_{2max} of approximately 0.5 % per training session (27, 148).

It seems safe to state that current rehabilitation for the THA patients is insufficient. By using well documented training methods such as the maximal strength training, rehabilitation of the THA patients can be improved.

6 Conclusions

Patients undergoing THA 3-5 years prior to physical tests demonstrated reduced muscle strength, VO_{2max}, work efficiency and asymmetric loading of the limbs compared to healthy age-matched subjects. The results indicate that current rehabilitation programs are inefficient in restoring muscle strength and aerobic endurance performance.

Unilaterally and bilaterally operated THA patients demonstrate similar results in VO_{2max}, work efficiency and gait measurements. In the bilaterally operated patients, an optimal biomechanical reconstruction of the hip joint did not result in differences in hip abduction muscle strength.

Maximal strength training with few repetitions, heavy loads and maximal concentric contraction is an efficient and safe treatment in an early postoperative phase for patients undergoing THA. Compared to the conventional rehabilitation program, the maximal strength training resulted in larger improvements in RFD, hip abduction and leg press.

Maximal strength training for 4 weeks starting 1 week postoperatively in THA patients, improved work efficiency 6 and 12 months postoperatively and RFD 12 months postoperatively compared to the conventional rehabilitation programme.

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PAPER I

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PAPER II

Unilateral vs. bilateral total hip arthroplasty – the influence of medial femoral head offset and effects on strength and aerobic endurance capacity

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Running head; Biomechanical and physiological outcome of unilateral and bilateral THA

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Abstract

The purpose of the present study was to determine whether unilaterally operated total hip arthroplasty patients were superior to bilaterally operated THA patients with respect to aerobic endurance performance, muscle strength and gait patterns 3-5 years after surgery, and to what extent medial femoral head offset influenced hip abductor strength. 10 unilaterally operated THA patients with normal FO (UNO), 10 bilaterally operated THA patients with normal FO (BNO) and 10 bilaterally operated THA patients with abnormal low offset (BDO) participated in the study. Improved muscle strength in the healthy leg of the UNO did not result in differences compared to the BNO and the BDO in work efficiency, gait patterns or maximal oxygen consumption. A reduced FO in the BDO did not result in lower hip abduction strength compared to the BNO. A correlation between reduced FO and low hip abduction strength was found in the BDO ($r=0.866$, $p=0.001$). Future focus should be in the quality of the rehabilitation.

Key words: total hip arthroplasty, VO_{2max}, strength, work efficiency, medial femoral head offset

Introduction

Studies of physical performance after total hip arthroplasty (THA) include a majority of patients with unilateral disability. However, 15-25 % of adults with hip diseases need bilateral surgery (1). Studies on bilateral THA have focused on the one-stage versus two-stage surgical procedure issue with particular focus on complication rate, mortality and cost effectiveness (2, 3, 4, 5). A few studies have compared gait patterns and walking efficiency measured by oxygen consumption (VO_2) between unilaterally and bilaterally operated THA patients (6, 7, 8, 9).

Aerobic endurance capacity is one of the most important factors determining physical performance (10). Pate and Kriska (11) report maximal oxygen consumption (VO_{2max}), lactate threshold and work economy as major factors contributing to aerobic endurance performance (11) and where VO_{2max} is regarded as the single most important factor (10). Myers et al. (12) report peak exercise capacity to be a stronger predictor of death compared to other risk factors in healthy subjects as well as in subjects with cardiovascular disease. Thus, it is essential to address this issue in the treatment of THA patients as well. Patients undergoing unilateral THA demonstrate an abnormal gait pattern (13) decreased walking efficiency (6) and lower muscle strength (14, 15, 16) after surgery and rehabilitation compared to healthy subjects. A relationship between muscle strength and work efficiency has been found, (17, 18, 19, 20) indicating strengthening of the muscles to be of importance in order to perform physical activities in an efficient manner.

Weakness of the hip abductor muscles is a common finding after THA (21, 22, 23). Normal function of the hip abductor muscles is crucial for a normal gait pattern without limping (24). Medial femoral head offset (FO) is one of the contributors to increase the hip abductor moment arm and thereby influence hip abductor strength. By increasing the FO during surgery, the hip abductor moment arm can be increased (25). FO has been reported to correlate positively with hip abductor strength and it has been suggested that greater FO after THA allows increased range of hip abduction and greater hip abductor strength. Furthermore, a large FO increases stability due to reduced risk of impingement and improved soft-tissue tension (26).

The aim of the study was to investigate whether bilaterally operated THA patients show lower muscle strength, aerobic endurance performance and different gait pattern compared to unilaterally operated THA patients, and to examine whether decreased FO influences hip abductor muscle strength. We hypothesized that; 1) the bilaterally operated THA patients had lower aerobic endurance performance and muscle strength and different gait pattern compared to the unilaterally operated THA patients 2) the bilaterally operated patients with normal FO would be superior to the bilaterally operated patients with abnormal FO with respect to hip abduction strength.

Material and methods

Subjects

30 fully recovered patients operated with THA performed either unilaterally or bilaterally, were recruited from the Orthopaedic department at St. Olav's University Hospital in Trondheim, Norway. The patients were divided into subgroups postoperatively. All patients were consecutively selected from a series of patients operated with uncemented, well documented prosthesis attending the routine follow-up rehabilitation program. Inclusion criteria were age <65 years and THA(s) performed between 3-5 years prior to the study. Exclusion criteria were disease that might influence physical testing performance, heart or lung disease and malign disease. Anthropometric data are presented in table 1. The study was approved by the Ethical Committee at the Faculty of Medicine at NTNU, Trondheim, Norway and conducted in accordance with the Helsinki declaration. Prior to the study, all patients were informed about the project and gave written informed consent.

Surgical procedure

Surgery was performed by different orthopaedic surgeons. All patients had THA surgery performed through the same approach and surgical procedures were performed in accordance with the routines of the orthopaedic department. The hip was approached through a posterior curved, lateral incision. The m. tensor fascia latae, the m. gluteus medius and the m. vastus lateralis were distally incised direct laterally. Proximally, a slight posterior curvation of the incision in the m. tensor fascia latae and the m. gluteus medius were performed. The common muscle plate of the anterior part of m. vastus lateralis and m. gluteus medius was dissected subperiostally from the greater trochanter. After arthrotomy and dislocation, the femoral canal was entered through fossa piriformis. The acetabular component as well as the femoral component was inserted following the surgical procedures of the manufacturers. During reconstruction of the hip abductor muscles, the common muscle plate was refixed to the greater trochanter with a double unresorbable osteosuture. Furthermore, this fixation was reinforced with a continuously sewed slowly resorbable suture, leaving no gap between the muscle plate and the anterior part of the greater trochanter (Vicryl, No2, Johnson & Johnson, NJ, USA).

Study design

3 different groups were compared in the study. One group consisted of 10 unilaterally operated THA patients, either right- or left hip joint with a normal FO based on the measurement of FO in the healthy leg (UNO). The bilaterally operated patients had surgery performed as two-stage surgery and were divided into 2 groups: 10 bilaterally operated patients where one hip joint of the patients had abnormal low FO whereas the other hip joint had normal FO compared to preoperative values (BDO), and 10 bilaterally operated patients where both hip joints had normal FO compared to preoperative values (BNO). Abnormal FO in the present study was defined as a FO difference >5 mm compared to preoperative values or healthy leg values. After discharge from the hospital, all patients had inpatient treatment in a rehabilitation centre for 4 weeks and performed exercises supervised by physical therapists. The exercises consisted of individual sling exercise therapy in hip abduction/adduction, hip flexion/extension, exercises with low resistance (>12-15 repetitions) or no resistance and exercises performed in water when sutures had been removed. After discharge to their homes, the patients were referred to outpatient physical therapy twice a week until 6 months postoperatively. Different physical therapists supervised the patients during training, though receiving identical exercise instructions from the orthopaedic surgeons. Prior to exercise testing, the patients were examined by an orthopaedic surgeon who approved the physical tests. All patients met for testing once and the duration was approximately 1 hour.

Testing procedures

The testing procedures were performed in the same order as listed below for all patients. Prior to testing, the patients performed 10 minutes treadmill walking with exercise intensity allowing conversation without breathlessness. All tests were supervised by the 2 exercise physiologists.

Muscle strength measurements.

The physical tests started with determining bilateral 1 repetition maximum (1RM) dynamic leg press followed by testing the right and left leg separately. The patients performed the strength tests in a seated position in a leg press ergometer (Technogym, Italy) with a knee joint angle of 90° between femur and tibia and a 90° joint angle in the hip joint. The initial weight load was based on a subjective estimation of the patient's capacity to prevent the fitter patients from starting at too low an intensity. The patients used 4-5 attempts to determine 1RM. Weight load was increased by 5-10 kg at each ramp, and the test was terminated when the patients no longer managed to perform the leg press movement. Force development, determined as rate of force development (RFD) and peak force (PF), was measured with data collected at 2000 Hz using a force platform with a software specifically developed for the platform (Bioware, Kistler, Switzerland). The force platform consists of an aluminium top plate placed on top of 3-component force sensors that allows measurements of force and torque in three axes i.e. vertical, left- and right horizontal. The patients performed the test of RFD and PF in a seated position in a leg press ergometer (Technogym, Italy) with a knee joint angle of 90º. The weight load was 40 kg for all patients. The Kistler force platform was placed in a vertical position on the leg press ergometer. PF is the highest force attained during the movement. RFD is determined as 10-90 % of PF during the concentric action.

1RM dynamic hip abduction was measured using a custom-made table. The patients were tested in a supine position. To enable maximum stabilization, the pelvis was stabilized by an adjustable clamp arch against the ala ossis ileii. The patients performed 1RM hip abduction of the right and left leg respectively. One leg was resting in a sling while the other leg was tested. The testing leg was placed in a 15 cm wide sling and horizontally mounted to the pulling apparatus with a rope. The lower edge of the sling was placed at tuberositas tibiae. Weight load was increased by 5 kg at each ramp and the test was terminated when the patients no longer managed to perform the hip abduction movement. The patients were instructed to perform the movement with the arms placed on the chest and to keep the performing leg extended with the foot pointing forward using a horizontal movement.

Gait patterns

Gait patterns were recorded while the patients were walking at a standardized velocity of 4 $km \cdot h^{-1}$ on a horizontal treadmill (Technogym, Runrace 1200 HC, Italy). A Pedar-X dynamic pressure distribution measure system was used for capacitive sensors (Novel Pedar-X System, Germany). Data was collected at 50 Hz. Step length, peak force (PF) and peak pressure (PP) heel/toe, stance time and impulse were calculated. The Pedar measurement system has been proven to be a valid and reliable measure of contact area and peak pressure (27, 28). Two flexible insoles with sensors were placed in the right and left shoe respectively. Pressure ranges during walking were logged and analyzed. Before recording, the patients walked with the measuring equipment for 2 minutes to ensure a steady state of walking, without being informed about the recording period. The recording measurement duration lasted 30 seconds and the recorded steps from 11-20 in each subject were used in the analysis of gait parameters.

Work efficiency and work economy

The patients performed treadmill for 5 minutes (Technogym, Runrace 1200 HC, Italy) at a standardized workload corresponding to 40 Watts (W). Work efficiency was calculated between 3.30-4.30 min during the 5 min standardized workload test. Work economy was determined as the oxygen cost at 40 Watts. All ventilatory parameters and pulmonary gas exchange was measured using Cortex Metamax I portable metabolic test system (Cortex Biophysik GmbH, Germany). For measurements of heart rate (HR), short-range radio telemetry with Polar accurex watches were used (Polar Electro Oy, Finland). Net efficiency was calculated by the following equation:

$$\frac{\text{Load (W) of exercise} \cdot 0.01433\ (\text{Kcal} \cdot \text{min}^{-1})}{\text{Energy expenditure during exercise} - \text{REE}\ (\text{Kcal} \cdot \text{min}^{-1})} \cdot 100$$

REE; resting energy expenditure

Resting energy expenditure was calculated from standardised values of 3.5 ml · kg^{-1} · min^{-1}. Both VO_2 and W were converted to kilocalories (Kcal) to allow the calculation of percent work efficiency. Work efficiency reflects the percentage of total energy expended that contributes to external work, with the reminder lost as heat (29).

VO_{2max}

VO_{2max} was tested by treadmill walking (Technogym, Runrace 1200 HC, Italy). VO_{2max} was determined by increasing speed and inclination each minute until exhaustion. All ventilatory parameters and pulmonary gas exchange were measured using Cortex Metamax I portable metabolic test system (Cortex Biophysik GmbH, Germany). For measurements of HR, short-range radio telemetry with Polar accurex watches were used (Polar Electro Oy, Finland). VO_{2max} was calculated as the 3 highest continuous 10 second measurements. The highest HR recorded during the last minute of the test was determined as maximal HR (HR_{max}). VO_{2max} is defined as the highest VO_2 the individual can reach during exercise involving large muscle groups (10). After the VO_{2max} test, the patients gave a subjective evaluation of perceived exertion by end-exercise leg effort and breathlessness using the Borg ratio scale. The scale ranges from 6-20, where 20 represent the highest degree of exertion (30).

Radiological assessments

Anteroposterior pelvic radiographs were taken prior to examination, using a 28 mm magnification marker, located at the level of the symphysis. All radiographs were digitized and a computer analysing program (SectraPACS) was used for all measurements including calibration of the radiographs. All parameters were measured by 2 independent observers.

Calculation and measurement of biomechanical values

FO was measured as the perpendicular distance between the longitudinal axis of the femur and the centre of the femoral head (25). The greater trochanter tangent was a line drawn 70º to the centre to centre line, and tangential to the most lateral part of the greater trochanter. The acetabular lever arm was defined as the perpendicular distance from the femoral head centre to the greater trochanter tangent. Hip lever arm ratio was calculated as the hip abductor lever arm divided by the body weight lever arm (31) (Figure 1). Calculated hip abductor strength was recorded dynamic hip abductor strength ($kg \cdot m_b^{-1}$) multiplied by leg length from the spina iliaca anterior superior to the tuberositas tibia (measured in vivo) divided by length of the hip abductor lever arm (32).

Clinical function score of the hip

For clinical evaluation of hip function, the Merle D'Aubigné and Postel scoring system was used. The scoring system evaluates pain, joint mobility and gait function with a range from 3-18 where 18 indicates optimal function of the hip (33).

Statistical analysis

The software program SPSS 17.0 (Statistical Package for the Social Sciences, SPSS Inc. Chicago, IL) was used for statistical analysis. Data are presented as mean ± standard deviation (SD). The parameters were found normally distributed by the use of Q-Q plot. One-way analysis of variance (ANOVA) with Tukey`s honestly significant difference post-hoc tests were used to determine differences in parameters between the groups. The relationship between variables was determined by Pearson`s p correlation analysis. A p-value < 0.05 was considered significant for all measurements. With a power of 0.80 and a two sided α value of

0.05 and an expected difference of 20 kg in hip abduction between the BNO and BDO, the calculated number of patients needed in each group was 9.

Results

Anthropometric data (Table 1)

Right leg FO of the BNO was significantly larger compared to the abnormal FO leg of the BDO by 23 % (p=0.002). Differences in FO between the legs were larger in the BDO both when compared to the BNO and to the UNO (by 623 %, p<0.001 compared to both groups). No differences in hip score were found between the groups.

Muscle strength measurements (Table 2)

Bilateral leg press in kg · m_b^{-1} demonstrated significantly higher values in the UNO compared to the BDO by 38 % (p=0.032). Bilateral leg press in kg · m_b^{-1} was significantly higher in the UNO compared to the BNO by 31 % (p=0.015). Leg press healthy leg in kg · m_b^{-1} and kg · $m_b^{-0.67}$ in the UNO revealed significantly higher values compared to the left leg of the BNO by 46 % (p=0.005) and 35 % (p=0.023) respectively. Leg press healthy leg in kg · m_b^{-1} and kg · $m_b^{-0.67}$ in the UNO revealed significantly higher values compared to the normal FO leg of the BDO by 33 % (p=0.010) and 38 % (p=0.020) respectively. Leg press difference between the legs was significantly larger in the UNO compared to the BDO and BNO by 320 % (p=0.003) and 300 % (p=0.003) respectively.

Hip abduction strength of the healthy leg of the UNO in kg, kg · m_b^{-1} and kg · $m_b^{-0.67}$ demonstrated significantly higher values compared to the normal FO leg of the BDO by 79 % (p=0.007), 92 % (p=0.002) and 89 % (p=0.003) respectively. The corresponding results for the healthy leg of the UNO compared to the left leg of the BNO in kg · m_b^{-1} and kg · $m_b^{-0.67}$ was 58 % (p=0.20) and 51 % (p=0.032) respectively. Hip abduction strength difference between the legs was significantly larger in the UNO compared to the BDO and BNO by 153 % (p=0.015) and 187 % (p=0.008) respectively.

Biomechanical measurements and calculations (Table 3)

Hip lever arm ratio was larger in the operated leg of the UNO compared to the abnormal offset leg of the BDO by 17 % (p=0.048). Calculated hip abduction strength was greater in the healthy leg of the UNO compared to the left leg of the BNO and the normal FO leg of the

BDO by 61 % (p=0.027) and 111 % (p=0.002) respectively. Abductor lever arm was larger in the right leg of the BNO compared to the abnormal FO leg of the BDO by 20 % (p=0.017). A positive correlation was found between FO and calculated hip abduction strength in the abnormal offset side of the BDO (r=0.893, p=0.001) as well as between FO and hip abduction strength ($kg \cdot m_b^{-1}$) (r=0.866, p=0.001). A negative correlation was found between FO and calculated hip abduction strength and between FO and hip abduction strength (kg) in the operated leg of the UNO (r=-0.707, p=0.022 and r=-0.636, p=0.048, respectively).

Maximal oxygen uptake, work efficiency and work economy (Tables 4 and 5)

No differences between the groups were revealed in VO_{2max}, work efficiency and work economy.

Gait patterns

No difference in the various gait variables was found between UNO and the bilaterally operated groups, or between the BDO and BNO.

Discussion

The present study shows that despite greater muscle strength in the healthy leg of the UNO, this did not to result in increased work efficiency or VO_{2max} or differences in gait patterns compared to the BDO and the BNO. Differences in FO between the BNO and the BDO did not result in hip abduction strength differences between the groups. A positive correlation between hip abductor strength and FO in the abnormal FO leg was found in the BDO.

The importance of a correct FO in the THA surgery has been emphasized in the literature (22, 26, 34, 35, 36). A correct FO primes the ability of the patient to regain strength of the hip abductor muscles postoperatively. Despite optimal biomechanical reconstruction of the hip joint, the overall result for the patient does not seem to bee adequate. It has been questioned whether the current rehabilitation programmes fulfil the needs of the patients (14, 15). Adequate strengthening of the musculature surrounding the hip is of importance to secure the longevity of the implant (37). Some authors state early rehabilitation of the weakened musculature to be of greater importance than the biomechanical reconstruction itself (22, 38). The latter can explain the findings in the present study where no significant differences in muscle strength were found between the bilaterally operated groups with normal and abnormal FO values respectively. Another possible explanation may be the contribution to hip abductor strength of the m. tensor fascia latae and the iliotibial tract. The m. tensor fascia latae is known to be one of the contributors to the abduction movement in the hip joint. Laboratory studies have demonstrated the iliotibial tract to balance a significant tension of the proximal lateral aspect of the femur (39). The hip lever arm ratio of the BDO is > 0.5 and shows that the discrepancy in FO may be too small to give significant hip abductor muscle strength differences among the BNO and BDO. The contribution to hip abduction strength of the tensor fascia lata combined with an adequate hip lever arm ratio may explain the lack of significant muscle strength differences despite dissimilarities of FO in the present study.

Based on the findings of McGrory et al.(26), a correlation between hip abduction strength and FO would have been expected in all groups in the present study. The study of McGrory and co-workers demonstrated correlations between FO and both hip abduction strength and the length of the hip abductor lever arm. The reason for not finding positive correlation between FO and hip abductor strength in the present study may be due to a too small discrepancy in FO (>5 mm). However, the bilateral group with abnormal FO demonstrated correlation between reduced FO and low hip abductor strength which is in line with the findings of above-mentioned study. The finding of a negative correlation between FO and both calculated hip abduction strength and hip abduction in kg in the operated leg of the UNO group may indicate lower hip abductor strength levels than expected.

Few recent studies have addressed the aerobic endurance capacity and work efficiency of patients operated with THA, and it is an interesting finding in the present study that there is no difference in work efficiency or VO_{2max} between unilaterally and bilaterally operated THA patients. Brown et al.(6) measured walking efficiency in 29 unilaterally and bilaterally operated THA patients. The number of bilaterally operated patients in that study was small, as only 2 patients were included in the study, and the unilateral and bilateral groups were not compared. The findings of the study by Brown and co-workers was that despite large improvements in walking efficiency postoperatively, patients fitted with THA still have a higher energy cost of walking compared to healthy subjects. McBeath et al.(8) studied walking efficiency in unilateral and bilateral THA patients. A 187 % and 65 % increase in walking efficiency was found 4 years postoperatively in the unilateral and bilateral groups, respectively. Walking efficiency was expressed as $ml \cdot kg^{-1} \cdot m^{-1}$. The increase in percent in walking efficiency was greater in the unilateral operated group, but because the decrease in walking efficiency was more pronounced in the unilateral group at the 6 months test, firm conclusions about the most improving group are difficult to make. Unfortunately, the groups in the study were not compared statistically. Mattson and co-workers (7) report a trend towards a higher oxygen cost of walking for bilaterally operated THA patients compared with unilaterally THA patients 6-12 months after surgery. Thus, it seems to be no consensus concerning this issue.

Walking speed reached similar levels in both unilateral and bilateral groups 1 year postoperatively in a study of McBeath et al. (8) with greater increase in the bilateral operated group presumable due to lower preoperative walking speed in this group. The results of the McBeath study have resemblance to the present study where no differences in gait patterns between unilateral and bilateral THA patients were revealed. Walking speed was not measured in the present study. However, a correlation between gait velocity and walking efficiency was found in the McBeath study as well which justifies comparison. Correlation between hip abductor strength and gait velocity has been reported previously (40) and since hip abductor strength did not differ between the groups in the present study, one may anticipate gait velocity to be equal. Berman et al. (41)evaluated gait patterns in unilaterally and bilaterally operated (two-stage) total knee replacement patients and found the largest improvements in the bilaterally operated group. The finding could be explained by the negative effect from asymptomatic arthritis of the healthy knee in the unilaterally operated group (41). Although the study involved total knee replacement patients, one may speculate the same phenomenon to occur in THA patients. 2 of the unilaterally operated patients in the present study had radiographic evidence of arthritis in the contralateral hip joint and mild symptoms of arthritis which might have influenced physical performance negatively. The incidence of bilateral osteoarthrosis of the hip in the present study is in accordance with literature referred previously. In disagreement with the results in the present study, Wykman and Olsson (9) reported unilaterally operated THA patients to be superior to bilaterally operated THA patients with respect to gait patterns including walking speed. Free walking speed was measured in the above-mentioned study which may have resulted in that the patients were able to walk at a slow pace and thereby mask an abnormal gait pattern.

In the present study, VO_{2max} did not differ between the groups either they underwent unilateral or bilateral THA. VO_{2max} averaged 29 mL · kg^{-1} · min^{-1} in the 3 groups which is lower than recommended levels (29). Ries et al. (42) reported improved cardiovascular fitness after THA. However, VO_{2max} was 16.1 mL · kg^{-1} · min^{-1} 2 years after surgery which is even lower compared to the present study allowing for testing performed as stationary cycling in the study by Ries et al. Since VO_{2max} is a strong predictor of mortality (12), it is crucial to offer the THA patients a rehabilitation programme that incorporates endurance training in addition to strength training. Expectations to physical fitness level in THA patients seem to be relatively low, since restrictions in physical activity have been emphasized from the orthopaedic surgeons and a majority of the patients have been satisfied by the relief of pain. In the future, the patients will probably have higher expectations to physical capacity after THA as the post-war generation predominate population. This generation is anticipated to have higher demands and will probably accept few limitations in physical activity (43).

Functional hip score as measured by Merle D'Aubigné and Postel scoring system demonstrated values close to optimal score for all 3 patient groups. Garrelick et al. (44) claim traditional hip score systems to be insufficient to evaluate the outcome of THA. The main complaints are lack of subjective evaluation of the patients and the variety of hip score systems making comparison between studies difficult. In addition, the sensitivity of the hip score system do not seem to be present in order to detect the true physical level of the patients. An example is the term "normal gait function" in the Merle D'Aubigné and Postel scoring system which gives maximal score without providing information about walking speed or distance. Orthopaedic research has been claimed to pay too much attention to the technical aspects of surgery rather than focusing on the overall physical outcome for the patients (42, 45). Technically well performed THA does not necessarily lead to a success concerning physical performance of the patient unless follow-up and rehabilitation have the same standard as surgery itself.

A limitation of the study is the low number of participants which makes it difficult to generalise the present findings to the whole population of THA patients. The expected differences in hip abduction strength between the groups were not present which might have been avoided with a larger sample size. Further research should implement larger number of unilaterally and bilaterally operated THA patients to state whether muscle strength and aerobic endurance capacity is equal. In one of the groups the male-female ratio was 2:8 which could be a possible bias in the findings in aerobic endurance capacity and muscle strength. However, no differences were detected between the gender balanced groups in the parameters mentioned above.

Conclusion

The present study demonstrates no differences between unilaterally and bilaterally operated THA patients concerning work efficiency, gait patterns and VO_{2max}. There were no differences in hip abduction strength between the BNO and the BDO despite differences in FO. A positive correlation between reduced FO and low hip abduction strength was observed in the abnormal FO side of the BDO. However, low FO does not seem to influence the overall physical outcome of the THA patients and future focus should be more on the quality of the rehabilitation process.

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Table 1. Individual anthropometric data for the bilaterally operated group with normal FO (BNO), the bilaterally operated group with abnormal FO (BDO) and the unilaterally operated group with normal FO (UNO).

Variables	Bilateral operated normal FO (BNO) n=10	Bilateral operated abnormal FO (BDO) n=10	Unilateral operated normal FO (UNO) n=10
Sex (men/women)	2/8	5/5	5/5
Age (years)	57 ± 8	60 ± 6	57 ± 8
Height (cm)	172 ± 10	173 ± 11	170 ± 8
Mass (m_b)	88.5 ± 10.1	87.4 ± 16.9	79.9 ± 12.7
BMI ($kg \cdot m^{-2}$)	30 ± 5	29 ± 4	27 ± 3
FO right/abnormal/operated leg (mm)	47.8 ± 8.8‡‡	38.8 ± 4.2	43.7 ± 4.3
FO left/normal/healthy leg (mm)	47.4 ± 9.3	48.7 ± 5.3	42.5 ± 4.2
Differences in FO (mm)	1.3 ± 2.7‡‡‡	9.4 ± 4.6	1.3 ± 2.1$^{\#\#\#}$
Merle D`Aubigné-Postel (3-18)	17 ± 1	17 ± 1	17 ± 1

Data is presented as mean ± SD for each variable. BMI; body mass index, FO; the perpendicular distance between the longitudinal axis of the femur and the centre of the femoral head. Difference in FO is the individual difference between each leg in each of the subjects. ‡‡ Significant difference between BNO and BDO p< 0.01, ‡‡‡significant difference between BNO and BDO p< 0.001, $^{\#\#\#}$significant difference between UNO and BDO p<0.001.

Table 2. Muscle strength parameters for the bilaterally operated group with normal FO (BNO), the bilaterally operated group with abnormal FO (BDO) and the unilaterally operated group with normal FO (UNO).

Variables	**Bilateral operated normal FO (BNO) n=10**	**Bilateral operated abnormal FO (BDO) n=10**	**Unilateral operated normal FO (UNO) n=10**
1RM leg press both legs (kg)	195 ± 40	195 ± 48	225 ± 47
1RM leg press both legs ($kg \cdot m_b^{-1}$)	2.2 ± 0.3	2.1 ± 0.7	2.9 ± 0.7$^{*,\#}$
1RM leg press both legs ($kg \cdot m_b^{-0.67}$)	9.6 ± 1.5	9.9 ± 2.7	12.1 ± 2.7
1RM leg press right/abnormal FO/operated leg (kg)	96 ± 31	99 ± 27	87 ± 25
1RM leg press right/abnormal FO/operated leg ($kg \cdot m_b^{-1}$)	1.1 ± 0.3	1.2 ± 0.4	1.1 ± 0.3
1RM leg press right/abnormal FO/operated leg ($kg \cdot m_b^{-0.67}$)	4.7 ± 1.3	5.0 ± 1.5	4.7 ± 1.4
1RM leg press left/normal FO/healthy leg (kg)	100 ± 26	100 ± 23	128 ± 34
1RM leg press left/normal FO/healthy leg ($kg \cdot m_b^{-1}$)	1.1 ± 0.2	1.2 ± 0.3	1.6 ± 0.5$^{**,\#}$
1RM leg press left/normal FO/healthy leg ($kg \cdot m_b^{-0.67}$)	5.1 ± 1.3	5.0 ± 1.1	6.9 ± 1.8$^{*,\#}$
1RM leg press diff. between the legs (kg)	11 ± 9**	10 ± 9$^{\#\#}$	42 ± 31
RFD both legs ($N \cdot s^{-1}$)	2738 ± 1230	2865 ± 937	3424 ± 1306
PF both legs (N)	883 ± 237	966 ± 262	1153 ± 411
1RM hip abduction right/abnormal FO/operated leg (kg)	66 ± 45	50 ± 25	61 ± 35
1RM hip abduction right/abnormal FO/operated leg ($kg \cdot m_b^{-1}$)	0.73 ± 0.48	0.58 ± 0.29	0.77 ± 0.45
1RM hip abduction right/abnormal FO/operated leg ($kg \cdot m_b^{-0.67}$)	3.2 ± 2.1	2.5 ± 1.2	3.3 ± 1.9
1RM hip abduction left/normal FO/healthy leg (kg)	71 ± 34	56 ± 26	100 ± 30$^{\#\#}$
1RM hip abduction left/normal FO/healthy leg ($kg \cdot m_b^{-1}$)	0.79 ± 0.37	0.65 ± 0.33	1.25 ± 0.37$^{*,\#\#}$
1RM hip abduction left/normal FO/healthy leg ($kg \cdot m_b^{-0.67}$)	3.5 ± 1.6	2.8 ± 1.4	5.3 ± 1.5$^{*,\#\#}$
1RM hip abduction diff. between the legs (kg)	15 ± 24**	17 ± 15$^{\#}$	43 ± 18

Data is presented as mean ± SD for each variable. 1RM; one repetition maximum, RFD; rate of force development, PF; peak force. *Significant difference between UNO and BNO $p<0.05$, **significant difference between UNO and BNO $p<0.01$, $^{\#}$significant difference between UNO and BDO $p<0.05$, $^{\#\#}$significant difference between UNO and BDO $p<0.01$.

Table 3. Biomechanical calculations for the bilaterally operated group with normal FO (BNO), the bilaterally operated group with abnormal FO (BDO) and the unilaterally operated group with normal FO (UNO).

Variables	Bilateral operated normal FO (BNO) n=10	Bilateral operated abnormal FO (BDO) n=10	Unilateral operated normal FO (UNO) n=10
Distance between centres of femoral heads (cm)	181.2 ± 10.4	176.1 ± 15.2	173.2 ± 8.1
Abductor lever arm right/abnormal/operated leg (mm)	62.3 ± 9.9‡	52.1 ± 5.9	59.9 ± 6.9
Abductor lever arm left/normal/healthy leg (mm)	62.1 ± 8.7	65.0 ± 5.3	60.0 ± 5.8
Calc. abductor strength right/abnormal/operated leg	0.658 ± 0.423	0.608 ± 0.299	0.727 ± 0.459
Calc. abductor strength left/normal/healthy leg	0.729 ± 0.346	0.555 ± 0.284	1.171 ± 0.430*, ##
Hip lever arm ratio right/abnormal/operated leg	0.687 ± 0.093	0.595 ± 0.079	0.694 ± 0.094#
Hip lever arm ratio left/normal/healthy leg	0.685 ± 0.085	0.741 ± 0.073	0.695 ± 0.080

Data is presented as mean ± SD for each variable. *Significant difference between UNO and BNO $p<0.05$, ‡significant difference between BNO and BDO $p< 0.05$, #significant difference between UNO and BDO $p<0.05$, ##significant difference between UNO and BDO $p<0.01$.

Table 4. Work efficiency and work economy for the bilaterally operated group with normal FO (BNO), the bilaterally operated group with abnormal FO (BDO) and the unilaterally operated group with normal FO (UNO).

Variables	Bilateral operated normal FO (BNO) n=10	Bilateral operated abnormal FO (BDO) n=10	Unilateral operated normal FO (UNO) n=10
VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	17.7 ± 1.9	17.5 ± 2.7	17.7 ± 2.0
VO_2 ($L \cdot min^{-1}$)	1.57 ± 0.20	1.52 ± 0.33	1.40 ± 0.17
VO_2 ($mL \cdot kg^{-0.75} \cdot min^{-1}$)	54.3 ± 5.5	53.1 ± 8.0	52.7 ± 5.0
Work efficiency (%)	14.0 ± 2.8	15.6 ± 5.0	16.5 ± 2.5
Work economy ($mL \cdot kg^{-0.75} \cdot m^{-1}$)	0.74 ± 0.06	0.84 ± 0.19	0.76 ± 0.07
V_E ($L \cdot min^{-1}$)	42.8 ± 9.4	38.7 ± 10.2	34.0 ± 3.6
HR ($b \cdot min^{-1}$)	110 ± 15	117 ± 18	120 ± 16

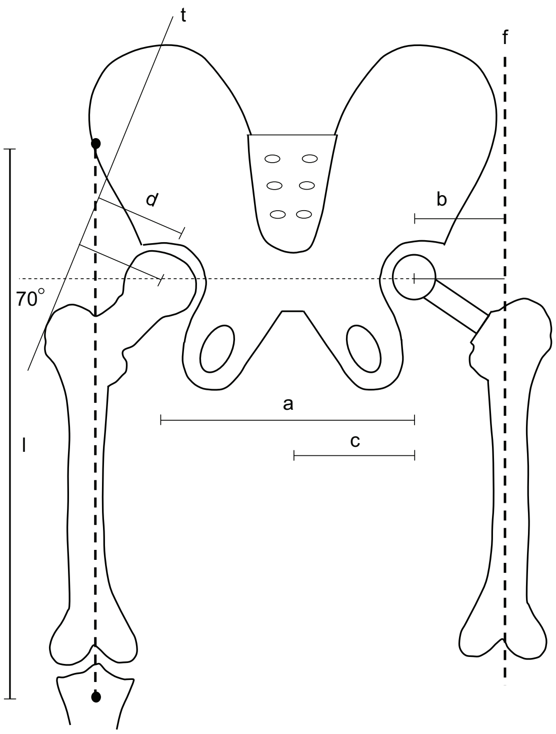
Data is presented as mean ± SD for each variable. VO_2; oxygen consumption, V_E; ventilation, HR; heart rate.

Table 5. Maximal oxygen consumption for the group bilaterally operated group with normal FO (BNO), the bilaterally operated group with abnormal FO (BDO) and the unilaterally operated group with normal FO (UNO).

Variables	Bilateral operated normal FO (BNO) n=10	Bilateral operated abnormal FO (BDO) n=10	Unilateral operated normal FO (UNO) n=9
VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	27.6 ± 6.3	28.4 ± 6.5	30.7 ± 7.4
VO_{2max} ($L \cdot min^{-1}$)	2.45 ± 0.65	2.45 ± 0.55	2.43 ± 0.57
VO_{2max} ($mL \cdot kg^{-0.75} \cdot min^{-1}$)	84.8 ± 19.8	86.8 ± 18.6	91.4 ± 22.3
V_E ($L \cdot min^{-1}$)	81.9 ± 25.8	74.2 ± 27.8	76.3 ± 25.3
HR_{max} ($b \cdot min^{-1}$)	157 ± 24	152 ± 26	164 ± 26
R (CO_2/O_2)	1.05 ± 0.04	1.03 ± 0.07	1.04 ± 0.07
Borg scale (6-20)	16 ± 2	16 ± 1	17 ± 1

Data is presented as mean ± SD for each variable. VO_{2max}; maximal oxygen consumption, V_E; ventilation, HR_{max}; maximal heart rate, R; respiratory exchange ratio, Borg scale; subjective evaluation of perceived exertion.

Figure 1. Figure showing biomechanical parameters



a = distance between centres of femoral heads

b = length of femoral offset

c = length of body weight lever arm

d = length of abductor lever arm

f = longitudinal axis of the femur

l = length of leg

t = greater trochanter tangent

PAPER III

ORIGINAL ARTICLE

Early Maximal Strength Training Is an Efficient Treatment for Patients Operated With Total Hip Arthroplasty

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ABSTRACT. Husby VS, Helgerud J, Bjørgen S, Husby OS, Benum P, Hoff J. Early maximal strength training is an efficient treatment for patients operated with total hip arthroplasty. Arch Phys Med Rehabil 2009;90:1658-67.

Objective: To compare muscle strength, work efficiency, gait patterns, and quality of life in patients undergoing total hip arthroplasty (THA) randomly assigned to either maximal strength training or a conventional rehabilitation program.

Design: A randomized controlled study.

Setting: Research laboratory, rehabilitation center, and physical therapy clinic.

Participants: Patients (N=24) with osteoarthritis as the main reason for THA were randomly assigned to perform maximal strength training (n=12) or conventional rehabilitation (n=12).

Interventions: The maximal strength training group (STG) performed maximal strength training in leg press and abduction with the operated leg only 5 times a week for 4 weeks in addition to the conventional rehabilitation program. The conventional rehabilitation group (CRG) received supervised physical therapy 3 to 5 times a week for 4 weeks.

Main Outcome Measures: 1-repetition maximum (1RM) leg press strength, 1RM abduction strength, rate of force development (RFD), work efficiency, gait patterns, and quality of life.

Results: 1RM increased in the bilateral leg press ($P<.002$) and in the operated leg separately ($P<.002$) in the STG compared with the CRG. 1RM abduction strength in the operated leg ($P<.002$) and the healthy leg ($P<.002$) increased in the STG compared with the CRG. RFD increased in the STG compared with the CRG ($P_g=.030$), followed by a trend towards increased peak force in the STG ($P_g=.053$) (P_g = probability for differences between groups). Work efficiency tended to improve in the STG compared with the CRG ($P=.065$). No differences in gait patterns were revealed between the groups after the training intervention.

Conclusions: Early maximal strength training 1 week postoperatively is feasible and an efficient treatment to regain muscular strength for patients who have undergone THA, demonstrated by a significantly larger increase in muscular strength and a trend towards a better work efficiency in the STG compared with the CRG.

Key Words: Arthroplasty; Hip; Rehabilitation.

TOTAL HIP ARTHROPLASTY is a common procedure in orthopedic practice.[1] In 2004, the reported rates (per 100,000 population) for primary THA in the United States, Canada, Australia, and New Zealand ranged from 70 to 150.[2,3] The number is expected to increase as the population ages, more people live longer, and a greater percentage of the population is obese.[1,4] The main purpose of THA, besides pain relief, is to restore hip biomechanics leading to a minimal functional deficit, and to secure the longevity of the implant.[5]

A large group of patients who underwent THA still have mild to moderate long-term impairments postoperatively.[6] The impairments include reduced walking efficiency,[7] pain, muscle weakness of the hip abductors, contracture of the hip, gait disorders, and weakness of the hip extensors and flexors.[8,9] These problems may, in turn, lead to complications such as loosening of the implant and joint instability.[10,11] A major concern after THA is abductor weakness, particularly when the lateral approach is used. An unsuccessful reattachment or a denervation of the anterior gluteal flap may occur with the lateral approach.[12] Several studies report postoperative abductor weakness.[1,12-14]

Adequate strength of the muscles of the lower extremity and, in particular, the abductor muscles is required for a satisfactory gait pattern without limping[15] and to prevent falls.[14] To improve muscle strength, training intensity should exceed 60% of 1RM, and 80% to 90% of 1RM seems to be the optimal load.[16,17] McDonagh and Davies[18] reviewed several resistance training studies and reported that loads less than 66% of 1RM produce little increase in strength even if up to 150 contractions a day were performed. Maximal strength training is traditionally performed with high loads of 85% to 95% of 1RM, few repetitions, and with explosive movements.[19] Several studies

List of Abbreviations

ASA	American Society of Anesthesiologists
CRG	conventional rehabilitation group
MCS	mental component score
PCS	physical component score
PF	peak force
REE	resting energy expenditure
RFD	rate of force development
RM	repetition(s) maximum
SF-36	Medical Outcomes Study 36-Item Short-Form Health Survey
STG	strength training group
THA	total hip arthroplasty
$\dot{V}O_2$	oxygen consumption
$\dot{V}O_2max$	maximum oxygen consumption

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demonstrate maximal strength training to be an efficient training method to improve muscle strength as well as work efficiency. The training method has been carried out successfully in healthy subjects as well as patients with chronic obstructive pulmonary disease, and in patients with coronary artery disease.[20-24]

Most patients are offered rehabilitation after surgery, either in a rehabilitation center or by outpatient physiotherapy. Traditionally, rehabilitation programs consist of hip joint mobilization, strengthening of surrounding muscles with low-resistance weight, and gait training.[6,25-27] Small increases in maximal muscle strength of the operated leg are demonstrated after standard rehabilitation following THA.[1,28] Andersen et al[29] found low levels of neuromuscular activity after conventional physical therapeutic exercises in the rehabilitation of patients with knee injuries. Studies implementing higher training loads have been initiated 6 to 8 weeks[30] or 4 months[1] after THA surgery.

The efficiency of the rehabilitation programs after THA has been questioned.[8,31,32] Further investigation is needed to improve current rehabilitation. To our knowledge, early maximal strength training in patients undergoing THA has not been carried out previously.

We hypothesized that it is feasible to accomplish maximal strength training in an early postoperative phase in patients undergoing THA. Furthermore, we hypothesized that the group who performed maximal strength training in addition to conventional rehabilitation would improve strength, gait measurements, and work efficiency significantly compared with the group who performed conventional rehabilitation only.

METHODS

Study Design

The study was designed as a randomized controlled study. We randomly assigned the patients manually by drawing lots. The procedure was performed by 2 persons not familiar with the different treatment options. We randomly assigned the patients to either the group performing maximal strength training in addition to the conventional rehabilitation program (STG), or to the group that participated in the conventional rehabilitation program only (CRG). Patients in the STG received inpatient treatment at the same rehabilitation center for 4 weeks. In the CRG, 2 patients stayed at home and received outpatient physical treatment, 8 patients attended the same rehabilitation center as the STG, while the remaining 2 patients received inpatient treatment at other rehabilitation centers. The patients were tested preoperatively, 1 week postoperatively, and 5 weeks postoperatively. The trial profile of the study is displayed in figure 1.

Patients

We recruited 24 patients from patients scheduled for THA in the orthopedic department at St. Olav's University Hospital in Trondheim, Norway. The STG consisted of 5 men and 7 women, whereas the CRG consisted of 4 men and 8 women. Inclusion criteria were age less than 70 years, a diagnosis of primary osteoarthritis as the main cause for elective THA surgery, and an ASA score of PI. This classification system gives a summary of the preoperative status of the patient and the risk the surgery implies for the patient. An ASA score of PI indicates a healthy patient.[33] Exclusion criteria included muscular or skeletal disease that might influence the training and physical testing performance, heart or lung diseases, and diabetes mellitus.

The study was approved by the regional ethics committee and conducted in accordance with the Helsinki Declaration. Each subject reviewed and signed consent forms that included detailed information about the study. The consent form was approved by the regional ethics committee.

Surgical Procedure

Only the direct lateral approach was used. Following a posterior curved, lateral incision, the hip was exposed through a direct lateral approach as described by Frndak et al[34] and modified by Hardinge.[35] Thus the common muscle plate of the anterior one-third of musculus vastus lateralis and musculus gluteus medius was dissected subperiosteally from the greater trochanter. The acetabular component and the femoral component were inserted following the surgical procedures of the manufacturers. The femoral component was uncemented, customized porous and hydroxyapapatite-coated[a] with a 28-mm ceramic head.[b] The acetabular component was an uncemented Trilogy cup with a cross-linked polyethylene liner.[c] Under reconstruction of the abductor muscles, the common muscle plate was reinserted to the greater trochanter with 2 nonresorbable osteosutures (Premi-Cron[d]). Furthermore, this fixation was reinforced with a continuously sewed, slowly resorbable looped monofilament suture (MonoPlus[d]). Skin was closed with unresorbable suture (Dafilon[d]). All surgical procedures were performed by the same orthopedic surgeon specializing in THA surgery with 25 years of experience. By using a combination of nonresorbable and slowly resorbable sutures, the use of heavier loads in the postoperative training program is justified. The postoperative medical prescription included full weight-bearing. Training started 1 week postoperatively.

Hip offset was defined as the perpendicular distance between the long axis of the femur and the center of rotation of the femoral head.[36] Postoperatively, measurements of the operated and healthy hip were compared.

Training Protocol

All patients received a medical prescription from the orthopedic surgeon who also gave exercise instructions for the conventional rehabilitation program. The conventional rehabilitation for all patients having inpatient treatment in a rehabilitation center consisted of individual sling exercise therapy in hip abduction/adduction, hip flexion/extension, exercises with low resistance (>12–15 repetitions[37]), or no resistance and exercises performed in water when sutures had been removed. Each session lasted 1 hour and was performed 5 days a week for 4 weeks. The patients attended educational classes twice a week. The 2 patients in the CRG who stayed home after being discharged from the hospital received outpatient treatment supervised by a physician 3 times a week with instructions to carry out prescribed exercises at home 2 times a week.

In addition to the conventional rehabilitation program, all patients in the STG performed, from 1 week after the operation, 5 training bouts a week for 4 weeks consisting of a 10-minute warmup period performed by stationary cycling at an intensity corresponding to 50% of $\dot{V}O_2max$. The maximal dynamic strength training regimen consisted of 2 exercises, leg press and hip abduction, that included 4 series of 5RM involving the operated leg only. 5RM corresponds to approximately 85% of 1RM.[38] When the patients managed to perform 6RM, the load was increased by 5kg. The series were separated by resting periods of 2 minutes. Leg press was performed in a leg press ergometer in a seated position with a knee joint angle of 90° and a flexion angle of 90° maximum in the hip joint (to avoid hip luxation), with a range of motion of 90° to 45° in the hip joint and 90° to 0° in the knee joint (fig 2). Hip abduction was performed using a standard pulling apparatus. The patients

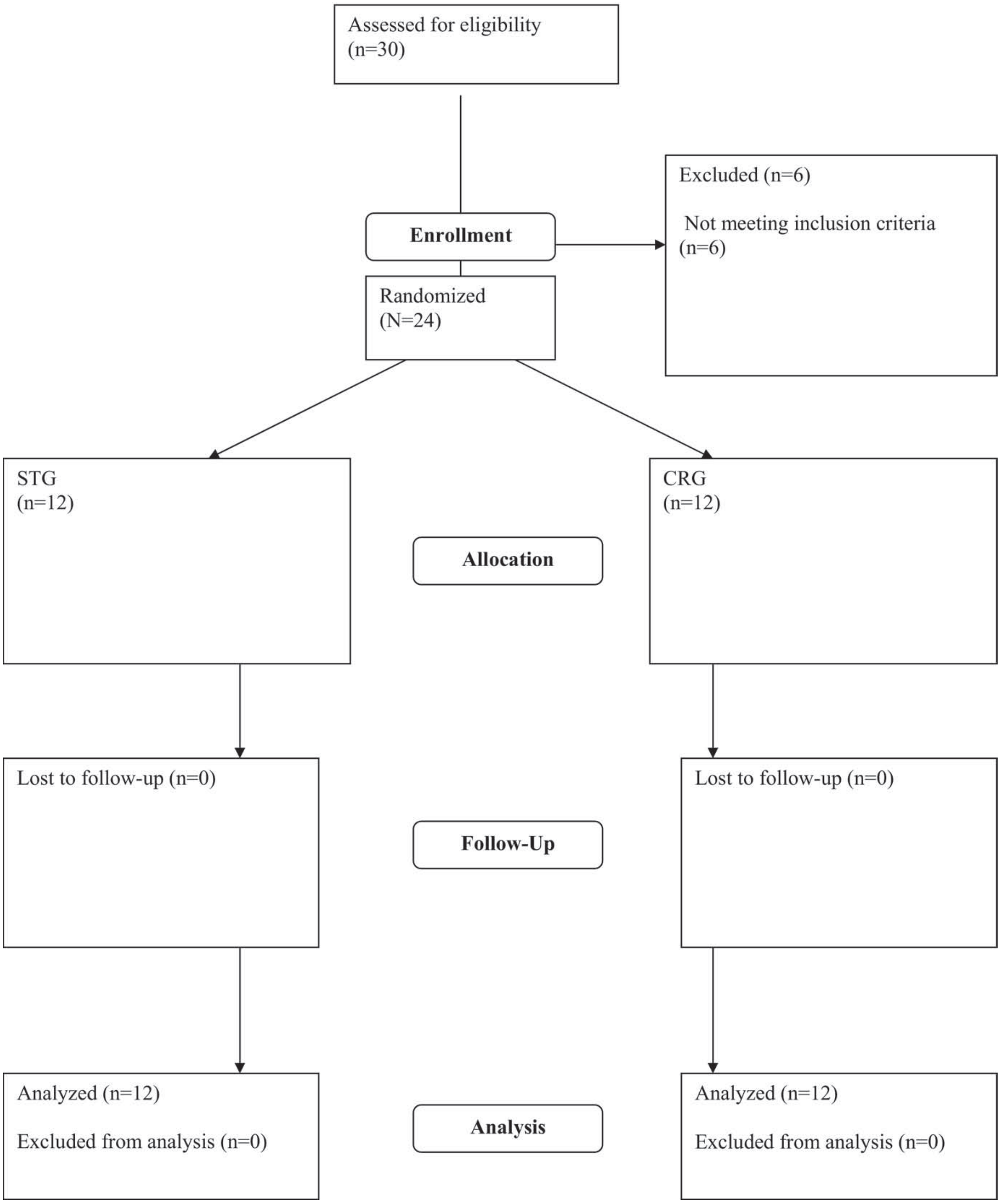

Fig 1. Flow chart of the study.

Fig 2. Leg press exercise during training.

were standing in an upright position stabilized by parallel bars with a 15-cm broad sling placed at the medial malleolus of the trained leg (fig 3). The patients were instructed to stand in an upright position and to keep the foot pointing forward during the abduction exercise. Range of motion was 0° to 25° in the hip joint. When the patients managed to perform 6RM, the load was increased by 1kg. The training sessions were supervised by 2 exercise physiologists with experience from a hospital orthopedic hip joint unit.

Testing Procedures

Before testing procedures, the patients performed 10 minutes of treadmill walking at a given inclination and speed, or stationary cycling with an exercise intensity corresponding to 50% of $\dot{V}O_2$max. At the preoperative test, where $\dot{V}O_2$max was unknown, the intensity was kept at a level where the patients were able to talk effortlessly. The patients performed the testing procedures in the same order at all tests.

Strength measurements. The physical tests started with determining bilateral 1RM leg press followed by testing the right and left leg separately. The patients performed the strength tests in a seated position in a leg press ergometer[e] with a knee joint angle of 90° between the femur and tibia and a 90° joint angle in the hip. The initial weight load was based on a subjective estimation of the patient's capacity to prevent the fitter patients from starting at too low an intensity. The patients used 4 to 5 attempts to determine 1RM. We increased the weight load by 5 to 10kg at each ramp and terminated the test when the patients no longer managed to perform the leg press movement.

We measured force development, determined as RFD and PF, with data collected at 2000Hz using a force platform with software specifically developed for the platform.[f] The force platform consists of an aluminum top plate placed on top of 3-component force sensors that allows measurements of force and torque in 3 axes, that is, vertical, left, and right horizontal. The patients performed the test of RFD and PF in a seated position in a leg press ergometer[e] with a knee joint angle of 90°. The weight load was 40kg during bilateral testing and 10kg during single leg testing for all patients. We mounted the Kistler force platform in front of the leg, placed in a vertical position on the leg press ergometer. RFD expresses the ability of the patient to develop muscle strength rapidly. PF is the highest force attained during the movement. RFD is determined as 10% to 90% of PF obtained from the maximum slope of the force-time curve.[39] The RFD parameter has important functional significance, such as an athlete's performance in the sprint[39] or preventing a fall in an elderly person.[40]

We measured 1RM abduction using a custom-made table. The patients were tested in a supine position. To enable maximum stabilization, we stabilized the pelvis by using an adjustable clamp arch against the ala ossis ilii. The patients performed 1RM abduction of the right and left leg. One leg was resting in a sling while the other leg was tested. We placed the testing leg in a 15-cm broad sling horizontally mounted to the pulling apparatus with a rope. We placed the lower edge of the sling at caput fibulae. We increased the weight load by 5kg at each ramp and terminated the test when the patients no longer managed to perform the abduction movement. We instructed the patients to perform the event with the arms placed on the chest and to keep the performing leg extended with the foot pointing forward using a horizontal movement. Range of motion in the abduction movement was 0° to 25°.

Gait patterns. We recorded gait patterns while the patients were walking at a standardized velocity of 4km/h on a horizontal treadmill (Runrace 1200 HC[e]). We used a Pedar-X dynamic pressure distribution measure system for capacitive sensors.[g] The Pedar measurement system has been proven to be a valid and reliable measure of contact area and peak pressure.[41,42] Data were collected at 50Hz. Force was calculated as the sum of pressure multiplied by areal for all 99 sensors in each insole. We calculated step length, PF heel/toe, stance time, and impulse. Step length was defined as the interval between initial contact of each foot.[43]

Two flexible insoles with sensors were placed in the right and left shoe, respectively. We logged pressure ranges during walking and analyzed them. Before recording, the patients walked with the measuring equipment for 2 minutes to ensure a steady state of walking, without being informed about the recording period. The recording measurement duration was 30 seconds, and we used the recorded steps from 11 to 20 in each subject in the analysis of gait parameters.

Fig 3. Abduction exercise during training.

Work efficiency. The patients walked on a treadmill for 5 minutes at a standardized workload corresponding to 40W. We calculated work efficiency from 3.30 to 4.30 minutes during the 5-minute standardized workload test.[44] We measured all ventilatory parameters and pulmonary gas exchange using the Cortex Metamax I portable metabolic test system.[h] For measurements of heart rate, we used short-range radio telemetry with Polar accurex watches.[i] Net efficiency was calculated by the following equation:

$$\frac{Load\ (watt)\ of\ exercise \cdot 0.01433\ (kcal \cdot \min^{-1})}{Energy\ expenditure\ during\ exercise -\ REE\ (kcal \cdot \min^{-1})} \cdot 100$$

REE was calculated from standardized values of $3.5 mL \cdot kg^{-1} \cdot min^{-1}$. Both V_{O_2} and watts were converted to kilocalories to allow the calculation of percent work efficiency. Work efficiency reflects the percentage of total energy expended that contributes to external work, with the reminder lost as heat.[45]

Maximum oxygen consumption. We tested $\dot{V}_{O_2}max$ by treadmill walking. We determined $\dot{V}_{O_2}max$ by increasing speed and inclination each minute until the patients decided to terminate the test. We measured all ventilatory parameters and pulmonary gas exchange using the Cortex Metamax I portable metabolic test system. For measurements of heart rate, we used short-range radio telemetry with Polar accurex watches. The highest heart rate recorded during the last minute of the test was used as the maximum heart rate. $\dot{V}_{O_2}max$ is defined as the highest $\dot{V}_{O_2}$ the person can attain during exercise involving large muscle groups.[46]

After the $\dot{V}_{O_2}max$ test, the patients gave a subjective evaluation of perceived exertion by end-exercise leg effort and breathlessness using the Borg ratio scale. The scale ranges from 6 to 20, where 20 represents the highest degree of exertion.[47]

Health-related quality of life. We used the SF-36 to determine health-related quality of life after each test. The survey contains an evaluation of both PCS and MCS. The scale ranges from 0 to 100, where 100 indicates optimal health.[48] The SF-36 is a widely used and validated survey and has been translated and validated for Norwegian conditions.[49]

Clinical function score of the hip. For clinical evaluation of hip function we used the Merle D'Aubigné and Postel scoring system preoperatively and after 5 weeks. The scoring system evaluates pain, joint mobility, and gait function with a range from 3 to 18, where 18 indicates optimal function of the hip.[50]

Statistical Analysis

With a power of .80 and an expected increase in 1RM in the operated leg by 20kg after the intervention period,[22] 9 patients were needed in each group. We used the software program SPSS 16.0[j] for statistical analysis. Data are presented as mean ± SD. We tested variables for normality by Q-Q plot. Preoperatively, we compared the groups by 2-sample *t* tests. We measured work efficiency by 2-sample *t* tests at all tests because of missing variables at the test 1 week postoperatively. We compared postoperative hip offset between the groups by 2-sample *t* tests. We studied variables obtained 1 week and 5 weeks postoperatively by 2-way analysis of variance for repeated measurements with time as within factor and STG versus CRG as grouping factor. When a significant interaction between main effects was found, a 2-sided multiple contrast test within each group and between groups at each point in time were performed with the appropriate adjustments of the degrees of freedom.[51] We considered a *P* value less than .05 as significant for all measurements.

Table 1: Preoperative Anthropometric Data for the STG and the CRG

Subject Characteristics	STG (n=12)	CRG (n=12)	*P*
Sex (M/W), n	5/7	4/8	.689
Age (y)	58±5	56±8	.343
Mass (kg)	84.6±11.2	80.9±18.4	.552
Height (cm)	174±9	170±11	.348
BMI (kg/m^2)	28.1±2.9	28.2±6.5	.967
Merle D'Aubigné Postel (3–18)	10±1	10±1	.445

NOTE. Values are mean ± SD unless otherwise indicated.
Abbreviation: BMI, body mass index; M, men; W, women.

RESULTS

One week postoperatively, we excluded submaximal V_{O_2} tests from analysis because of severe difficulties for the patients to walk without support for the time necessary to perform the test adequately. The variety of body mass normalization procedures (dimensional scaling) did not affect the results and are not presented in the Results section.

Anthropometric Data

Body mass significantly decreased from the 1- to 5-week postoperative tests, averaging 2.2% ($P<.001$). Differences in offset between the operated and healthy leg were 1.1±2.7 and 2.6±2.5 in the STG and CRG, respectively, which was not significantly different between the groups ($P=.223$). The Merle D'Aubigné and Postel score was not significantly different between the groups either preoperatively or 5 weeks postoperatively.

Preoperatively, the Merle D'Aubigné and Postel score was 10±1 in both STG and CRG ($P=.445$). Five weeks postoperatively, the corresponding value was 17±1 in both groups ($P=.207$). No significant group differences in age, mass, height, or body mass index were found. Preoperative anthropometric data of the patients are presented in table 1.

Strength Measurements

At 1 week after the operation, there was no difference between groups in 1RM bilateral leg press strength. At the 5-week test, a significant increase was found in 1RM bilateral leg press for both groups. The improvement was more pronounced, 40.9%, in the STG compared with the CRG ($P<.002$). The same pattern of change was found in corresponding results from the operated leg; 1RM was not different 1 week after the operation and increased in both groups, but increased more in the STG, being 65.2% higher compared with the CRG after 4 weeks of training ($P<.002$). After the operation, RFD in the operated leg was 64.5% higher in the STG compared with the CRG ($P_g=.030$) and increased in both groups between the first and the fifth postoperative week ($P_w<.001$).

Neither the bilateral PF nor healthy leg PF differed between groups 1 week after the operation. Both variables improved significantly in the STG compared with the CRG after 4 weeks of training: 61.7% for both legs ($P<.002$) and 48.3% ($P<.02$) for the healthy leg, respectively. Neither bilateral PF nor healthy leg PF increased significantly in the CRG 1 to 5 weeks postoperatively. There was a trend towards a higher PF in the operated leg in the STG compared with the CRG ($P_g=.053$). At 1 week after the operation, abduction strength did not differ between groups either in the operated or in the healthy leg. Abduction strength in the operated leg increased with training in both groups, but the increase was more pronounced in the STG, by 87%,

Table 2: Strength Measurements for the STG and the CRG

Measure	STG (n=12) T1	STG (n=12) T2	STG (n=12) T3	CRG (n=12) T1	CRG (n=12) T2	CRG (n=12) T3	ANOVA Main Effects
Leg press strength (kg)							
1RM both legs	193±71	103±36	193±54†‡	171±49	89±26	137±42§	P_w<.001, P_g=.035, P_i=.001
1RM operated leg	85±31	23±9	76±20†‡	72±22	18±11	46±14§	P_w<.001, P_g=.001, P_i=.001
1RM healthy leg	105±38	91±32	103±28	99±33	81±32	88±30	P_w<.023, P_g=.288, P_i=.605
Force development ($N\cdot s^{-1}$)							
RFD both legs	2572±1508	1321±948	2632±1435	2713±2117	1036±828	2060±1398	P_w<.001, P_g=.340, P_i=.482
RFD operated leg	1422±723	568±698	1680±816	1293±897	233±162	1021±601	P_w<.001, P_g=.030, P_i=.244
RFD healthy leg	1581±780	1679±955	2080±924	1573±795	1304±892	1748±1291	P_w=.025, P_g=.364, P_i=.902
Maximal force (N)							
PF both legs	1005±422*	587±234	967±379†‡	714±200	451±194	598±194	P_w<.001, P_g=.026, P_i=.045
PF operated leg	565±238	278±150	526±180	412±146	190±86	380±202	P_w<.001, P_g=.053, P_i=.636
PF healthy leg	608±250	501±245	654±230†‡	529±224	414±192	441±199	P_w<.005, P_g=.156, P_i=.028
Abduction strength (kg)							
1RM operated leg	27±15	9±7	43±15†‡	24±16	11±5	23±9§	P_w<.001, P_g=.019, P_i<.001
1RM healthy leg	37±17	31±17	55±18†‡	32±16	31±15	37±13	P_w<.001, P_g=.142, P_i=.003

NOTE. Values are mean ± SD for each variable.
Abbreviations: ANOVA, analysis of variance; T1, test preoperatively; T2, test 1 week postoperatively; T3, test 5 weeks postoperatively.
*Differences between the groups preoperatively by 2-sample *t* tests. P_w, P_g, and P_i=probability for difference within and between groups and for interaction, respectively.
†Differences between the groups at T3 by post hoc multiple contrast tests.
‡Different from T2 in the STG group.
§Different from T2 in the CRG group.

versus the CRG ($P<.002$). In the healthy leg, only the STG increased strength from 1 to 5 weeks. At the 5-week test, abduction strength in the healthy leg was 48.6% higher compared with the CRG ($P<.002$). Strength measurements are presented in table 2.

Gait Parameters

No significant differences between the groups were found at the 1- and 5-week tests. All gait parameters improved in the STG and the CRG 1 to 5 weeks postoperatively. The different gait parameters are presented in table 3.

Work Efficiency

No significant difference between the groups was found after 1 week. Five weeks postoperatively there was a significantly lower heart rate in the STG by 11.4% ($P=.041$). There was a trend towards a better work efficiency in the STG after 5 weeks by 32.3% ($P=.065$). The results are presented in table 4.

Maximum Oxygen Consumption

No significant differences between the groups were found in the $\dot{V}O_2max$ tests. The $\dot{V}O_2max$, heart rate, and respiration

Table 3: Gait Patterns at 4km/h for the STG and the CRG

Measure	STG (n=12) T1	STG (n=12) T2	STG (n=12) T3	CRG (n=12) T1	CRG (n=12) T2	CRG (n=12) T3	ANOVA Main Effects
Step length OL (cm)	63.4±8.9	51.1±13.9	67.3±6.7	61.6±17.2	50.6±11.4	67.5±6.6	P_w<.001, P_g=.961, P_i=.862
Step length HL (cm)	64.9±8.2	56.3±11.3	68.9±5.3	64.0±18.2	54.2±13.1	70.0±8.6	P_w<.001, P_g=.886, P_i=.417
PF OL (N)	714±134	517±136	653±118	672±196	501±120	589±103	P_w<.001, P_g=.391, P_i=.194
PF HL (N)	713±72.0	559±94	659±65	702±204	553±134	617±113	P_w<.001, P_g=.551, P_i=.269
PP OL ($N\cdot cm^{-2}$)	24.50±6.98	18.25±7.15	22.54±3.46	25.42±11.17	18.84±7.40	22.75±6.70	P_w=.020, P_g=.845, P_i=.908
PP HL ($N\cdot cm^{-2}$)	25.11±7.06	19.27±3.46	22.67±3.97	27.10±11.66	22.55±7.48	25.69±8.83	P_w=.019, P_g=.175, P_i=.920
PP OL heel ($N\cdot cm^{-2}$)	16.15±5.09	9.37±2.92	16.44±4.41	15.73±4.90	9.13±2.82	14.85±2.48	P_w<.001, P_g=.389, P_i=.414
PP HL heel ($N\cdot cm^{-2}$)	17.61±6.44	14.18±4.43	18.59±4.14	16.82±5.69	15.21±6.22	17.83±8.79	P_w=.005, P_g=.995, P_i=.429
PP OL forefoot ($N\cdot cm^{-2}$)	24.20±7.37	16.77±5.83	22.08±4.05	25.73±11.19	18.79±7.40	23.18±7.40	P_w=.005, P_g=.454, P_i=.773
PP HL forefoot ($N\cdot cm^{-2}$)	24.88±6.89	17.10±3.76	22.10±4.01	27.57±11.52	21.62±6.60	24.23±7.43	P_w=.006, P_g=.102, P_i=.354
Stance time OL (s)	0.592±0.047	0.790±0.097	0.602±0.064	0.615±0.071	0.757±0.128	0.658±0.080	P_w<.001, P_g=.709, P_i=.068
Stance time HL (s)	0.605±0.035	0.885±0.113	0.620±0.047	0.639±0.077	0.813±0.150	0.686±0.110	P_w<.001, P_g=.932, P_i=.025*
Impulse, OL (N·s)	298±74	243±100	268±59	294±100	222±81	268±67	P_w=.018, P_g=.723, P_i=.437
Impulse, HL (N·s)	290±41	319±92	264±56	304±100	316±102	278±74	P_w=.011, P_g=.843, P_i=.609

NOTE. Values are mean ± SD for each variable. P_w, P_g, and P_i=probability for difference within and between groups and for interaction, respectively. Step length, cm between steps; stance, contact pressure; impulse, force by time.
Abbreviations: HL, healthy leg; OL, operated leg; PP, peak pressure; T1, test preoperatively; T2, test 1 week postoperatively; T3, test 5 weeks postoperatively.
*No significant difference after post hoc multiple contrast tests.

Table 4: $\dot{V}O_2$max and Work Efficiency for the STG and the CRG

Measure	STG (n=12) T1	STG (n=12) T2	STG (n=12) T3	CRG (n=12) T1	CRG (n=12) T2	CRG (n=12) T3	ANOVA Main Effects/*t* test
$\dot{V}O_2$max test							
VO_2max ($mL\cdot kg^{-1}\cdot min^{-1}$)	29.4±7.9	21.4±7.0	29.8±6.3	28.0±12.3	19.2±4.7	25.5±9.8	P_w<.001, P_g=.222, P_i=.426
Max HR ($beats\cdot min^{-1}$)	160±11	136±19	163±13	160±20	139±25	157±23	P_w<.001, P_g=.800, P_i=.515
R (VCO_2/VO_2)	1.06±0.1	0.99±0.07	1.14±0.09	1.06±0.1	0.98±0.06	1.05±0.07	P_w=.003, P_g=.081, P_i=.101
Borg scale* (6–20)	16±1	16±2	17±1	16±1	16±1	16±2	P_w=.180, P_g=.784, P_i=.410
Work efficiency test							
Work efficiency (%)	16.2±5.9	ND	17.6±7.7	14.0±3.9	ND	13.3±5.8	.065
VO_2 ($mL\cdot kg^{-1}\cdot min^{-1}$)	17.4±2.5	ND	16.3±3.2	18.7±3.0	ND	18.3±3.0	.129
HR ($beats\cdot min^{-1}$)	118±15	ND	114±15†	123±13	ND	127±15	.041

NOTE. Values are mean ± SD for each variable. P_w, P_g, and P_i, probability for difference within and between groups and for interaction, respectively.
Abbreviations: ANOVA, analysis of variance; HR, heart rate; ND, no data; R, respiration coefficient; T1, test preoperatively; T2, test 1 week postoperatively; T3, test 5 weeks postoperatively; VCO_2, carbon dioxide consumption.
*Borg scale, subjective evaluation of perceived exertion.
†Differences between the groups at T3 by 2-sample *t* tests.

coefficient increased significantly in both groups 1 to 5 weeks postoperatively. The Borg scale did not differ significantly in either group 1 to 5 weeks postoperatively. The results are presented in table 4.

Health-Related Quality of Life

The MCS score from the SF-36 was 21.7% higher ($P<.005$) in the STG (56±8) compared with the CRG (46±11) 1 week after the operation. In the CRG, the score increased by 17.4% ($P<.005$), reaching levels not significantly different from the STG 5 weeks after the operation. The PCS increased in both groups 1 to 5 weeks postoperatively: from 32±6 to 37±8 in the STG and from 30±4 to 38±5 in the CRG, averaging 21.5% ($P_w<.001$), with no difference between the groups ($P_g=.897$).

DISCUSSION

The main finding in this study is that the STG shows significantly higher performance in leg press, RFD, and hip abduction after the 4-week training intervention compared with the CRG. There was a trend towards higher walking efficiency in the STG 5 weeks postoperatively. The study demonstrates that it is both feasible and safe to carry out maximal strength training 1 week after undergoing THA.

The patients in the STG performed training with a load corresponding to 80% to 90% of 1RM. Maximal strength training induced a great increase in strength both in leg press and hip abduction in the STG compared with the CRG 5 weeks postoperatively. Muscle strength in the operated leg increased by 230% (leg press) in the STG in the present study, indicating maximal strength training to be highly effective. The strength outcome and the concomitant increase in RFD are in line with the findings of Hoff,[22] Karlsen,[23] and colleagues. Suetta et al.[28] demonstrated increased leg muscle strength by 22% to 28% after a 12-week resistance training intervention after THA. The resistance training started at approximately day 7 with an intensity of 50% of 1RM the first week, increasing to 80% of 1RM 6 weeks postoperatively. The increase in strength was less compared with the strength achieved in the present study, and the strength improvement occurred between 5 and 12 weeks when the training load was higher than 70% of 1RM. Abduction exercises were not conducted in the study by Suetta et al.[28] Because strength of the abductor muscles is crucial for walking without limping and preventing falls, as mentioned earlier, it would be natural to include specific training of these muscles.

Trudelle-Jackson and Smith[1] report strength and stability benefits from a weight-bearing program initiated 4 months postoperatively. Hauer et al[30] show increased strength and functional performance in patients undergoing hip surgery after intensive strength training starting 6 to 8 weeks postoperatively. Compared with the present study, the strength training was initiated relatively late. Initiating the massive strength training as soon as possible after the surgery is of great importance because major surgery and subsequent hospitalization are known to cause a severe decline in muscle mass and muscle strength.[28,52] Muscle strength declines 3% to 4% a day during the first week of immobilization.[53] Furthermore, because of activity-related pain and contracture of the hip, most patients experience a period of inactivity before surgery.

In the present study, work efficiency was expected to be significantly improved in the STG compared with the CRG after the intervention period, reflecting the greater muscle strength and the increased RFD in the operated leg in the STG. Several studies report a correlation between increased strength, RFD, and improved work efficiency.[20-22,24] However, Bishop,[54] Nakao,[55] and colleagues failed to discover improvement in endurance performance despite increased 1RM in leg strength, which is in line with the findings in the present study. It is reasonable to assume that a longer follow-up period would have demonstrated a higher effect on walking efficiency from the increased 1RM in leg press and abduction. That is, 5 weeks postoperatively, the patients seem not able to fully benefit from the gained muscular strength to increase work efficiency.

No significant differences between the groups concerning gait variables were displayed after the intervention period. Loizeau et al[56] found that patients fitted with THA walked more slowly and had a longer stance time and a shorter stride length compared with healthy subjects. Sicard-Rosenbaum et al[14] compared patients undergoing THA 9 months to 6 years earlier with an age-and sex-matched control group. Maximum walking speed was higher in the control group, but gait parameters such as step and stride length, stance time, support base, step, swing, and single and double support time were not significantly different between the groups. Detecting differences in walking speed but not in other gait parameters is in line with the findings in the present study, except maximum gait speed, which we did not measure. However, Vaz et al[57] demonstrated abductor strength to be related to distance walked during a 6-minute walk test, confirming the importance of abductor strength in walking speed. Weak hip abductors may suffice for walking at a self-selected pace,[14] and it can be speculated whether a faster walking speed than 4km/h would have revealed differences in some of the gait variables among the groups in the present study. Weaker abductor musculature on the operated side in the CRG may have contributed to poor trunk control during body weight transfer from the operated to the healthy leg.[56] The poor trunk control in the CRG may have been more pronounced with faster walking speeds.[14]

For decades, partial weight-bearing versus full weight-bearing in uncemented THA during the first 8 weeks has been discussed. Several authors now report no adverse effects of full weight-bearing immediately after surgery.[58-60] Instead, full weight-bearing is documented to reduce hospital stay and improve the rehabilitation process.[59] Questions can be asked about whether maximal strength training is recommended for patients immediately after THA. The reason for the problem to be addressed is whether the strength of the reattachments of the musculus gluteus medius to the greater trochanter when the lateral approach is used. In the present study, the Merle D'Aubigné and Postel mean score was 17 in both groups after 5 weeks, indicating a normal gait without limping and a sufficient reattachment of the gluteus medius to the trochanter major. Furthermore, biomechanical calculations demonstrate a torsion moment in the caput femoris of 37Nm in a 75-kg person if normal offset in single leg stance, such as stair climbing,[61] which corresponds to 90kg. The weight load mimics the leg press intervention in the present study.

Quality-of-life measurements demonstrated a higher MCS in the STG at the test 1 week after surgery. This may be explained by the effect of being the intervention part of a study and the fact that the participants knew they would get extra follow-up time. No differences in the quality-of-life variables were detected 5 weeks postoperatively. An explanation may be that generic instruments, such as the SF-36, may often lack the sensitivity to detect differences between treatment policies that are compared in clinical trials. Disease-specific scales may have revealed differences among the groups because they generally are more responsive than generic health status measures.[62]

Two of the patients in the CRG had outpatient treatment. The physical outcomes of the 2 patients, however, did not differ from the other participants in the CRG. Recent studies demonstrate no differences in functional outcomes, pain, or patient satisfaction between groups allocated to inpatient or outpatient rehabilitation,[63] or to home- or center-based exercise programs.[64]

In the present study, the training duration was relatively short. A longer duration of the training period (10–12wk) may have revealed differences between the groups in work efficiency as well as gait patterns. Future studies would benefit from a larger sample size and a longer training period for the participants. Adding the variables maximum walking speed or a 6-minute walking test may result in differences between the groups in gait variables. A higher work load than 40W may have been favorable in demonstrating differences in work efficiency.

Study Limitations

The sample size of the study was small based on strength differences in a maximal strength training intervention. Work efficiency and gait pattern data were not available for the patient group, and a higher sample size is required to detect statistical differences. Although different physicians supervised the patients in the study and 2 of the patients received outpatient treatment, the significant results show that early maximal strength training increases lower extremity strength after THA.

CONCLUSIONS

The present study demonstrates that maximal strength training is an appropriate treatment in an early postoperative phase after THA. Furthermore, maximal strength training improves muscular strength to a higher extent in the STG compared with the CRG, together with a trend towards higher work efficiency. No difference in gait patterns or quality-of-life measurements between the groups was detected after the intervention period.

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98. Gerd Inger Ringdal: QUALITY OF LIFE IN CANCER PATIENTS.
99. Torvid Kiserud: THE DUCTUS VENOSUS IN THE HUMAN FETUS.
100. Hans E. Fjøsne: HORMONAL REGULATION OF PROSTATIC METABOLISM.
101. Eylert Brodtkorb: CLINICAL ASPECTS OF EPILEPSY IN THE MENTALLY RETARDED.
102. Roar Juul: PEPTIDERGIC MECHANISMS IN HUMAN SUBARACHNOID HEMORRHAGE.
103. Unni Syversen: CHROMOGRANIN A. Phsysiological and Clinical Role.

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104. Odd Gunnar Brakstad: THERMOSTABLE NUCLEASE AND THE *nuc* GENE IN THE DIAGNOSIS OF *Staphylococcus aureus* INFECTIONS.
105. Terje Engan: NUCLEAR MAGNETIC RESONANCE (NMR) SPECTROSCOPY OF PLASMA IN MALIGNANT DISEASE.
106. Kirsten Rasmussen: VIOLENCE IN THE MENTALLY DISORDERED.
107. Finn Egil Skjeldestad: INDUCED ABORTION: Timetrends and Determinants.
108. Roar Stenseth: THORACIC EPIDURAL ANALGESIA IN AORTOCORONARY BYPASS SURGERY.
109. Arild Faxvaag: STUDIES OF IMMUNE CELL FUNCTION *in mice infected with* MURINE RETROVIRUS.

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110. Svend Aakhus: NONINVASIVE COMPUTERIZED ASSESSMENT OF LEFT VENTRICULAR FUNCTION AND SYSTEMIC ARTERIAL PROPERTIES. Methodology and some clinical applications.
111. Klaus-Dieter Bolz: INTRAVASCULAR ULTRASONOGRAPHY.
112. Petter Aadahl: CARDIOVASCULAR EFFECTS OF THORACIC AORTIC CROSS-CLAMPING.
113. Sigurd Steinshamn: CYTOKINE MEDIATORS DURING GRANULOCYTOPENIC INFECTIONS.
114. Hans Stifoss-Hanssen: SEEKING MEANING OR HAPPINESS?
115. Anne Kvikstad: LIFE CHANGE EVENTS AND MARITAL STATUS IN RELATION TO RISK AND PROGNOSIS OF CANCER.
116. Torbjørn Grøntvedt: TREATMENT OF ACUTE AND CHRONIC ANTERIOR CRUCIATE LIGAMENT INJURIES. A clinical and biomechanical study.
117. Sigrid Hørven Wigers: CLINICAL STUDIES OF FIBROMYALGIA WITH FOCUS ON ETIOLOGY, TREATMENT AND OUTCOME.
118. Jan Schjøtt: MYOCARDIAL PROTECTION: Functional and Metabolic Characteristics of Two Endogenous Protective Principles.
119. Marit Martinussen: STUDIES OF INTESTINAL BLOOD FLOW AND ITS RELATION TO TRANSITIONAL CIRCULATORY ADAPATION IN NEWBORN INFANTS.
120. Tomm B. Müller: MAGNETIC RESONANCE IMAGING IN FOCAL CEREBRAL ISCHEMIA.
121. Rune Haaverstad: OEDEMA FORMATION OF THE LOWER EXTREMITIES.
122. Magne Børset: THE ROLE OF CYTOKINES IN MULTIPLE MYELOMA, WITH SPECIAL REFERENCE TO HEPATOCYTE GROWTH FACTOR.
123. Geir Smedslund: A THEORETICAL AND EMPIRICAL INVESTIGATION OF SMOKING, STRESS AND DISEASE: RESULTS FROM A POPULATION SURVEY.

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124. Torstein Vik: GROWTH, MORBIDITY, AND PSYCHOMOTOR DEVELOPMENT IN INFANTS WHO WERE GROWTH RETARDED *IN UTERO*.
125. Siri Forsmo: ASPECTS AND CONSEQUENCES OF OPPORTUNISTIC SCREENING FOR CERVICAL CANCER. Results based on data from three Norwegian counties.
126. Jon S. Skranes: CEREBRAL MRI AND NEURODEVELOPMENTAL OUTCOME IN VERY LOW BIRTH WEIGHT (VLBW) CHILDREN. A follow-up study of a geographically based year cohort of VLBW children at ages one and six years.
127. Knut Bjørnstad: COMPUTERIZED ECHOCARDIOGRAPHY FOR EVALUTION OF CORONARY ARTERY DISEASE.
128. Grethe Elisabeth Borchgrevink: DIAGNOSIS AND TREATMENT OF WHIPLASH/NECK SPRAIN INJURIES CAUSED BY CAR ACCIDENTS.
129. Tor Elsås: NEUROPEPTIDES AND NITRIC OXIDE SYNTHASE IN OCULAR AUTONOMIC AND SENSORY NERVES.
130. Rolf W. Gråwe: EPIDEMIOLOGICAL AND NEUROPSYCHOLOGICAL PERSPECTIVES ON SCHIZOPHRENIA.
131. Tonje Strømholm: CEREBRAL HAEMODYNAMICS DURING THORACIC AORTIC CROSSCLAMPING. An experimental study in pigs.

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132. Martinus Bråten: STUDIES ON SOME PROBLEMS REALTED TO INTRAMEDULLARY NAILING OF FEMORAL FRACTURES.
133. Ståle Nordgård: PROLIFERATIVE ACTIVITY AND DNA CONTENT AS PROGNOSTIC INDICATORS IN ADENOID CYSTIC CARCINOMA OF THE HEAD AND NECK.

134. Egil Lien: SOLUBLE RECEPTORS FOR **TNF** AND **LPS**: RELEASE PATTERN AND POSSIBLE SIGNIFICANCE IN DISEASE.
135. Marit Bjørgaas: HYPOGLYCAEMIA IN CHILDREN WITH DIABETES MELLITUS
136. Frank Skorpen: GENETIC AND FUNCTIONAL ANALYSES OF DNA REPAIR IN HUMAN CELLS.
137. Juan A. Pareja: SUNCT SYNDROME. ON THE CLINICAL PICTURE. ITS DISTINCTION FROM OTHER, SIMILAR HEADACHES.
138. Anders Angelsen: NEUROENDOCRINE CELLS IN HUMAN PROSTATIC CARCINOMAS AND THE PROSTATIC COMPLEX OF RAT, GUINEA PIG, CAT AND DOG.
139. Fabio Antonaci: CHRONIC PAROXYSMAL HEMICRANIA AND HEMICRANIA CONTINUA: TWO DIFFERENT ENTITIES?
140. Sven M. Carlsen: ENDOCRINE AND METABOLIC EFFECTS OF METFORMIN WITH SPECIAL EMPHASIS ON CARDIOVASCULAR RISK FACTORES.

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141. Terje A. Murberg: DEPRESSIVE SYMPTOMS AND COPING AMONG PATIENTS WITH CONGESTIVE HEART FAILURE.
142. Harm-Gerd Karl Blaas: THE EMBRYONIC EXAMINATION. Ultrasound studies on the development of the human embryo.
143. Noèmi Becser Andersen:THE CEPHALIC SENSORY NERVES IN UNILATERAL HEADACHES. Anatomical background and neurophysiological evaluation.
144. Eli-Janne Fiskerstrand: LASER TREATMENT OF PORT WINE STAINS. A study of the efficacy and limitations of the pulsed dye laser. Clinical and morfological analyses aimed at improving the therapeutic outcome.
145. Bård Kulseng: A STUDY OF ALGINATE CAPSULE PROPERTIES AND CYTOKINES IN RELATION TO INSULIN DEPENDENT DIABETES MELLITUS.
146. Terje Haug: STRUCTURE AND REGULATION OF THE HUMAN UNG GENE ENCODING URACIL-DNA GLYCOSYLASE.
147. Heidi Brurok: MANGANESE AND THE HEART. A Magic Metal with Diagnostic and Therapeutic Possibilites.
148. Agnes Kathrine Lie: DIAGNOSIS AND PREVALENCE OF HUMAN PAPILLOMAVIRUS INFECTION IN CERVICAL INTRAEPITELIAL NEOPLASIA. Relationship to Cell Cycle Regulatory Proteins and HLA DQBI Genes.
149. Ronald Mårvik: PHARMACOLOGICAL, PHYSIOLOGICAL AND PATHOPHYSIOLOGICAL STUDIES ON ISOLATED STOMACS.
150. Ketil Jarl Holen: THE ROLE OF ULTRASONOGRAPHY IN THE DIAGNOSIS AND TREATMENT OF HIP DYSPLASIA IN NEWBORNS.
151. Irene Hetlevik: THE ROLE OF CLINICAL GUIDELINES IN CARDIOVASCULAR RISK INTERVENTION IN GENERAL PRACTICE.
152. Katarina Tunòn: ULTRASOUND AND PREDICTION OF GESTATIONAL AGE.
153. Johannes Soma: INTERACTION BETWEEN THE LEFT VENTRICLE AND THE SYSTEMIC ARTERIES.
154. Arild Aamodt: DEVELOPMENT AND PRE-CLINICAL EVALUATION OF A CUSTOM-MADE FEMORAL STEM.
155. Agnar Tegnander: DIAGNOSIS AND FOLLOW-UP OF CHILDREN WITH SUSPECTED OR KNOWN HIP DYSPLASIA.
156. Bent Indredavik: STROKE UNIT TREATMENT: SHORT AND LONG-TERM EFFECTS
157. Jolanta Vanagaite Vingen: PHOTOPHOBIA AND PHONOPHOBIA IN PRIMARY HEADACHES

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158. Ola Dalsegg Sæther: PATHOPHYSIOLOGY DURING PROXIMAL AORTIC CROSS-CLAMPING CLINICAL AND EXPERIMENTAL STUDIES
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160. Christina Vogt Isaksen: PRENATAL ULTRASOUND AND POSTMORTEM FINDINGS – A TEN YEAR CORRELATIVE STUDY OF FETUSES AND INFANTS WITH DEVELOPMENTAL ANOMALIES.
161. Holger Seidel: HIGH-DOSE METHOTREXATE THERAPY IN CHILDREN WITH ACUTE LYMPHOCYTIC LEUKEMIA: DOSE, CONCENTRATION, AND EFFECT CONSIDERATIONS.
162. Stein Hallan: IMPLEMENTATION OF MODERN MEDICAL DECISION ANALYSIS INTO CLINICAL DIAGNOSIS AND TREATMENT.

163. Malcolm Sue-Chu: INVASIVE AND NON-INVASIVE STUDIES IN CROSS-COUNTRY SKIERS WITH ASTHMA-LIKE SYMPTOMS.
164. Ole-Lars Brekke: EFFECTS OF ANTIOXIDANTS AND FATTY ACIDS ON TUMOR NECROSIS FACTOR-INDUCED CYTOTOXICITY.
165. Jan Lundbom: AORTOCORONARY BYPASS SURGERY: CLINICAL ASPECTS, COST CONSIDERATIONS AND WORKING ABILITY.
166. John-Anker Zwart: LUMBAR NERVE ROOT COMPRESSION, BIOCHEMICAL AND NEUROPHYSIOLOGICAL ASPECTS.
167. Geir Falck: HYPEROSMOLALITY AND THE HEART.
168. Eirik Skogvoll: CARDIAC ARREST Incidence, Intervention and Outcome.
169. Dalius Bansevicius: SHOULDER-NECK REGION IN CERTAIN HEADACHES AND CHRONIC PAIN SYNDROMES.
170. Bettina Kinge: REFRACTIVE ERRORS AND BIOMETRIC CHANGES AMONG UNIVERSITY STUDENTS IN NORWAY.
171. Gunnar Qvigstad: CONSEQUENCES OF HYPERGASTRINEMIA IN MAN
172. Hanne Ellekjær: EPIDEMIOLOGICAL STUDIES OF STROKE IN A NORWEGIAN POPULATION. INCIDENCE, RISK FACTORS AND PROGNOSIS
173. Hilde Grimstad: VIOLENCE AGAINST WOMEN AND PREGNANCY OUTCOME.
174. Astrid Hjelde: SURFACE TENSION AND COMPLEMENT ACTIVATION: Factors influencing bubble formation and bubble effects after decompression.
175. Kjell A. Kvistad: MR IN BREAST CANCER – A CLINICAL STUDY.
176. Ivar Rossvoll: ELECTIVE ORTHOPAEDIC SURGERY IN A DEFINED POPULATION. Studies on demand, waiting time for treatment and incapacity for work.
177. Carina Seidel: PROGNOSTIC VALUE AND BIOLOGICAL EFFECTS OF HEPATOCYTE GROWTH FACTOR AND SYNDECAN-1 IN MULTIPLE MYELOMA.

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178. Alexander Wahba: THE INFLUENCE OF CARDIOPULMONARY BYPASS ON PLATELET FUNCTION AND BLOOD COAGULATION – DETERMINANTS AND CLINICAL CONSEQUENSES
179. Marcus Schmitt-Egenolf: THE RELEVANCE OF THE MAJOR hISTOCOMPATIBILITY COMPLEX FOR THE GENETICS OF PSORIASIS
180. Odrun Arna Gederaas: BIOLOGICAL MECHANISMS INVOLVED IN 5-AMINOLEVULINIC ACID BASED PHOTODYNAMIC THERAPY
181. Pål Richard Romundstad: CANCER INCIDENCE AMONG NORWEGIAN ALUMINIUM WORKERS
182. Henrik Hjorth-Hansen: NOVEL CYTOKINES IN GROWTH CONTROL AND BONE DISEASE OF MULTIPLE MYELOMA
183. Gunnar Morken: SEASONAL VARIATION OF HUMAN MOOD AND BEHAVIOUR
184. Bjørn Olav Haugen: MEASUREMENT OF CARDIAC OUTPUT AND STUDIES OF VELOCITY PROFILES IN AORTIC AND MITRAL FLOW USING TWO- AND THREE-DIMENSIONAL COLOUR FLOW IMAGING
185. Geir Bråthen: THE CLASSIFICATION AND CLINICAL DIAGNOSIS OF ALCOHOL-RELATED SEIZURES
186. Knut Ivar Aasarød: RENAL INVOLVEMENT IN INFLAMMATORY RHEUMATIC DISEASE. A Study of Renal Disease in Wegener’s Granulomatosis and in Primary Sjögren’s Syndrome
187. Trude Helen Flo: RESEPTORS INVOLVED IN CELL ACTIVATION BY DEFINED URONIC ACID POLYMERS AND BACTERIAL COMPONENTS
188. Bodil Kavli: HUMAN URACIL-DNA GLYCOSYLASES FROM THE UNG GENE: STRUCTRUAL BASIS FOR SUBSTRATE SPECIFICITY AND REPAIR
189. Liv Thommesen: MOLECULAR MECHANISMS INVOLVED IN TNF- AND GASTRIN-MEDIATED GENE REGULATION
190. Turid Lingaas Holmen: SMOKING AND HEALTH IN ADOLESCENCE; THE NORD-TRØNDELAG HEALTH STUDY, 1995-97
191. Øyvind Hjertner: MULTIPLE MYELOMA: INTERACTIONS BETWEEN MALIGNANT PLASMA CELLS AND THE BONE MICROENVIRONMENT
192. Asbjørn Støylen: STRAIN RATE IMAGING OF THE LEFT VENTRICLE BY ULTRASOUND. FEASIBILITY, CLINICAL VALIDATION AND PHYSIOLOGICAL ASPECTS

193. Kristian Midthjell: DIABETES IN ADULTS IN NORD-TRØNDELAG. PUBLIC HEALTH ASPECTS OF DIABETES MELLITUS IN A LARGE, NON-SELECTED NORWEGIAN POPULATION.
194. Guanglin Cui: FUNCTIONAL ASPECTS OF THE ECL CELL IN RODENTS
195. Ulrik Wisløff: CARDIAC EFFECTS OF AEROBIC ENDURANCE TRAINING: HYPERTROPHY, CONTRACTILITY AND CALCUIM HANDLING IN NORMAL AND FAILING HEART
196. Øyvind Halaas: MECHANISMS OF IMMUNOMODULATION AND CELL-MEDIATED CYTOTOXICITY INDUCED BY BACTERIAL PRODUCTS
197. Tore Amundsen: PERFUSION MR IMAGING IN THE DIAGNOSIS OF PULMONARY EMBOLISM
198. Nanna Kurtze: THE SIGNIFICANCE OF ANXIETY AND DEPRESSION IN FATIQUE AND PATTERNS OF PAIN AMONG INDIVIDUALS DIAGNOSED WITH FIBROMYALGIA: RELATIONS WITH QUALITY OF LIFE, FUNCTIONAL DISABILITY, LIFESTYLE, EMPLOYMENT STATUS, CO-MORBIDITY AND GENDER
199. Tom Ivar Lund Nilsen: PROSPECTIVE STUDIES OF CANCER RISK IN NORD-TRØNDELAG: THE HUNT STUDY. Associations with anthropometric, socioeconomic, and lifestyle risk factors
200. Asta Kristine Håberg: A NEW APPROACH TO THE STUDY OF MIDDLE CEREBRAL ARTERY OCCLUSION IN THE RAT USING MAGNETIC RESONANCE TECHNIQUES

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201. Knut Jørgen Arntzen: PREGNANCY AND CYTOKINES
202. Henrik Døllner: INFLAMMATORY MEDIATORS IN PERINATAL INFECTIONS
203. Asta Bye: LOW FAT, LOW LACTOSE DIET USED AS PROPHYLACTIC TREATMENT OF ACUTE INTESTINAL REACTIONS DURING PELVIC RADIOTHERAPY. A PROSPECTIVE RANDOMISED STUDY.
204. Sylvester Moyo: STUDIES ON STREPTOCOCCUS AGALACTIAE (GROUP B STREPTOCOCCUS) SURFACE-ANCHORED MARKERS WITH EMPHASIS ON STRAINS AND HUMAN SERA FROM ZIMBABWE.
205. Knut Hagen: HEAD-HUNT: THE EPIDEMIOLOGY OF HEADACHE IN NORD-TRØNDELAG
206. Li Lixin: ON THE REGULATION AND ROLE OF UNCOUPLING PROTEIN-2 IN INSULIN PRODUCING ß-CELLS
207. Anne Hildur Henriksen: SYMPTOMS OF ALLERGY AND ASTHMA VERSUS MARKERS OF LOWER AIRWAY INFLAMMATION AMONG ADOLESCENTS
208. Egil Andreas Fors: NON-MALIGNANT PAIN IN RELATION TO PSYCHOLOGICAL AND ENVIRONTENTAL FACTORS. EXPERIENTAL AND CLINICAL STUDES OF PAIN WITH FOCUS ON FIBROMYALGIA
209. Pål Klepstad: MORPHINE FOR CANCER PAIN
210. Ingunn Bakke: MECHANISMS AND CONSEQUENCES OF PEROXISOME PROLIFERATOR-INDUCED HYPERFUNCTION OF THE RAT GASTRIN PRODUCING CELL
211. Ingrid Susann Gribbestad: MAGNETIC RESONANCE IMAGING AND SPECTROSCOPY OF BREAST CANCER
212. Rønnaug Astri Ødegård: PREECLAMPSIA – MATERNAL RISK FACTORS AND FETAL GROWTH
213. Johan Haux: STUDIES ON CYTOTOXICITY INDUCED BY HUMAN NATURAL KILLER CELLS AND DIGITOXIN
214. Turid Suzanne Berg-Nielsen: PARENTING PRACTICES AND MENTALLY DISORDERED ADOLESCENTS
215. Astrid Rydning: BLOOD FLOW AS A PROTECTIVE FACTOR FOR THE STOMACH MUCOSA. AN EXPERIMENTAL STUDY ON THE ROLE OF MAST CELLS AND SENSORY AFFERENT NEURONS

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216. Jan Pål Loennechen: HEART FAILURE AFTER MYOCARDIAL INFARCTION. Regional Differences, Myocyte Function, Gene Expression, and Response to Cariporide, Losartan, and Exercise Training.
217. Elisabeth Qvigstad: EFFECTS OF FATTY ACIDS AND OVER-STIMULATION ON INSULIN SECRETION IN MAN

218. Arne Åsberg: EPIDEMIOLOGICAL STUDIES IN HEREDITARY HEMOCHROMATOSIS: PREVALENCE, MORBIDITY AND BENEFIT OF SCREENING.
219. Johan Fredrik Skomsvoll: REPRODUCTIVE OUTCOME IN WOMEN WITH RHEUMATIC DISEASE. A population registry based study of the effects of inflammatory rheumatic disease and connective tissue disease on reproductive outcome in Norwegian women in 1967-1995.
220. Siv Mørkved: URINARY INCONTINENCE DURING PREGNANCY AND AFTER DELIVERY: EFFECT OF PELVIC FLOOR MUSCLE TRAINING IN PREVENTION AND TREATMENT
221. Marit S. Jordhøy: THE IMPACT OF COMPREHENSIVE PALLIATIVE CARE
222. Tom Christian Martinsen: HYPERGASTRINEMIA AND HYPOACIDITY IN RODENTS – CAUSES AND CONSEQUENCES
223. Solveig Tingulstad: CENTRALIZATION OF PRIMARY SURGERY FOR OVARAIN CANCER. FEASIBILITY AND IMPACT ON SURVIVAL
224. Haytham Eloqayli: METABOLIC CHANGES IN THE BRAIN CAUSED BY EPILEPTIC SEIZURES
225. Torunn Bruland: STUDIES OF EARLY RETROVIRUS-HOST INTERACTIONS – VIRAL DETERMINANTS FOR PATHOGENESIS AND THE INFLUENCE OF SEX ON THE SUSCEPTIBILITY TO FRIEND MURINE LEUKAEMIA VIRUS INFECTION
226. Torstein Hole: DOPPLER ECHOCARDIOGRAPHIC EVALUATION OF LEFT VENTRICULAR FUNCTION IN PATIENTS WITH ACUTE MYOCARDIAL INFARCTION
227. Vibeke Nossum: THE EFFECT OF VASCULAR BUBBLES ON ENDOTHELIAL FUNCTION
228. Sigurd Fasting: ROUTINE BASED RECORDING OF ADVERSE EVENTS DURING ANAESTHESIA – APPLICATION IN QUALITY IMPROVEMENT AND SAFETY
229. Solfrid Romundstad: EPIDEMIOLOGICAL STUDIES OF MICROALBUMINURIA. THE NORD-TRØNDELAG HEALTH STUDY 1995-97 (HUNT 2)
230. Geir Torheim: PROCESSING OF DYNAMIC DATA SETS IN MAGNETIC RESONANCE IMAGING
231. Catrine Ahlén: SKIN INFECTIONS IN OCCUPATIONAL SATURATION DIVERS IN THE NORTH SEA AND THE IMPACT OF THE ENVIRONMENT
232. Arnulf Langhammer: RESPIRATORY SYMPTOMS, LUNG FUNCTION AND BONE MINERAL DENSITY IN A COMPREHENSIVE POPULATION SURVEY. THE NORD-TRØNDELAG HEALTH STUDY 1995-97. THE BRONCHIAL OBSTRUCTION IN NORD-TRØNDELAG STUDY
233. Einar Kjelsås: EATING DISORDERS AND PHYSICAL ACTIVITY IN NON-CLINICAL SAMPLES
234. Arne Wibe: RECTAL CANCER TREATMENT IN NORWAY – STANDARDISATION OF SURGERY AND QUALITY ASSURANCE

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235. Eivind Witsø: BONE GRAFT AS AN ANTIBIOTIC CARRIER
236. Anne Mari Sund: DEVELOPMENT OF DEPRESSIVE SYMPTOMS IN EARLY ADOLESCENCE
237. Hallvard Lærum: EVALUATION OF ELECTRONIC MEDICAL RECORDS – A CLINICAL TASK PERSPECTIVE
238. Gustav Mikkelsen: ACCESSIBILITY OF INFORMATION IN ELECTRONIC PATIENT RECORDS; AN EVALUATION OF THE ROLE OF DATA QUALITY
239. Steinar Krokstad: SOCIOECONOMIC INEQUALITIES IN HEALTH AND DISABILITY. SOCIAL EPIDEMIOLOGY IN THE NORD-TRØNDELAG HEALTH STUDY (HUNT), NORWAY
240. Arne Kristian Myhre: NORMAL VARIATION IN ANOGENITAL ANATOMY AND MICROBIOLOGY IN NON-ABUSED PRESCHOOL CHILDREN
241. Ingunn Dybedal: NEGATIVE REGULATORS OF HEMATOPOIETEC STEM AND PROGENITOR CELLS
242. Beate Sitter: TISSUE CHARACTERIZATION BY HIGH RESOLUTION MAGIC ANGLE SPINNING MR SPECTROSCOPY
243. Per Arne Aas: MACROMOLECULAR MAINTENANCE IN HUMAN CELLS – REPAIR OF URACIL IN DNA AND METHYLATIONS IN DNA AND RNA
244. Anna Bofin: FINE NEEDLE ASPIRATION CYTOLOGY IN THE PRIMARY INVESTIGATION OF BREAST TUMOURS AND IN THE DETERMINATION OF TREATMENT STRATEGIES

245. Jim Aage Nøttestad: DEINSTITUTIONALIZATION AND MENTAL HEALTH CHANGES AMONG PEOPLE WITH MENTAL RETARDATION
246. Reidar Fossmark: GASTRIC CANCER IN JAPANESE COTTON RATS
247. Wibeke Nordhøy: MANGANESE AND THE HEART, INTRACELLULAR MR RELAXATION AND WATER EXCHANGE ACROSS THE CARDIAC CELL MEMBRANE

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248. Sturla Molden: QUANTITATIVE ANALYSES OF SINGLE UNITS RECORDED FROM THE HIPPOCAMPUS AND ENTORHINAL CORTEX OF BEHAVING RATS
249. Wenche Brenne Drøyvold: EPIDEMIOLOGICAL STUDIES ON WEIGHT CHANGE AND HEALTH IN A LARGE POPULATION. THE NORD-TRØNDELAG HEALTH STUDY (HUNT)
250. Ragnhild Støen: ENDOTHELIUM-DEPENDENT VASODILATION IN THE FEMORAL ARTERY OF DEVELOPING PIGLETS
251. Aslak Steinsbekk: HOMEOPATHY IN THE PREVENTION OF UPPER RESPIRATORY TRACT INFECTIONS IN CHILDREN
252. Hill-Aina Steffenach: MEMORY IN HIPPOCAMPAL AND CORTICO-HIPPOCAMPAL CIRCUITS
253. Eystein Stordal: ASPECTS OF THE EPIDEMIOLOGY OF DEPRESSIONS BASED ON SELF-RATING IN A LARGE GENERAL HEALTH STUDY (THE HUNT-2 STUDY)
254. Viggo Pettersen: FROM MUSCLES TO SINGING: THE ACTIVITY OF ACCESSORY BREATHING MUSCLES AND THORAX MOVEMENT IN CLASSICAL SINGING
255. Marianne Fyhn: SPATIAL MAPS IN THE HIPPOCAMPUS AND ENTORHINAL CORTEX
256. Robert Valderhaug: OBSESSIVE-COMPULSIVE DISORDER AMONG CHILDREN AND ADOLESCENTS: CHARACTERISTICS AND PSYCHOLOGICAL MANAGEMENT OF PATIENTS IN OUTPATIENT PSYCHIATRIC CLINICS
257. Erik Skaaheim Haug: INFRARENAL ABDOMINAL AORTIC ANEURYSMS – COMORBIDITY AND RESULTS FOLLOWING OPEN SURGERY
258. Daniel Kondziella: GLIAL-NEURONAL INTERACTIONS IN EXPERIMENTAL BRAIN DISORDERS
259. Vegard Heimly Brun: ROUTES TO SPATIAL MEMORY IN HIPPOCAMPAL PLACE CELLS
260. Kenneth McMillan: PHYSIOLOGICAL ASSESSMENT AND TRAINING OF ENDURANCE AND STRENGTH IN PROFESSIONAL YOUTH SOCCER PLAYERS
261. Marit Sæbø Indredavik: MENTAL HEALTH AND CEREBRAL MAGNETIC RESONANCE IMAGING IN ADOLESCENTS WITH LOW BIRTH WEIGHT
262. Ole Johan Kemi: ON THE CELLULAR BASIS OF AEROBIC FITNESS, INTENSITY-DEPENDENCE AND TIME-COURSE OF CARDIOMYOCYTE AND ENDOTHELIAL ADAPTATIONS TO EXERCISE TRAINING
263. Eszter Vanky: POLYCYSTIC OVARY SYNDROME – METFORMIN TREATMENT IN PREGNANCY
264. Hild Fjærtoft: EXTENDED STROKE UNIT SERVICE AND EARLY SUPPORTED DISCHARGE. SHORT AND LONG-TERM EFFECTS
265. Grete Dyb: POSTTRAUMATIC STRESS REACTIONS IN CHILDREN AND ADOLESCENTS
266. Vidar Fykse: SOMATOSTATIN AND THE STOMACH
267. Kirsti Berg: OXIDATIVE STRESS AND THE ISCHEMIC HEART: A STUDY IN PATIENTS UNDERGOING CORONARY REVASCULARIZATION
268. Björn Inge Gustafsson: THE SEROTONIN PRODUCING ENTEROCHROMAFFIN CELL, AND EFFECTS OF HYPERSEROTONINEMIA ON HEART AND BONE

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269. Torstein Baade Rø: EFFECTS OF BONE MORPHOGENETIC PROTEINS, HEPATOCYTE GROWTH FACTOR AND INTERLEUKIN-21 IN MULTIPLE MYELOMA
270. May-Britt Tessem: METABOLIC EFFECTS OF ULTRAVIOLET RADIATION ON THE ANTERIOR PART OF THE EYE
271. Anne-Sofie Helvik: COPING AND EVERYDAY LIFE IN A POPULATION OF ADULTS WITH HEARING IMPAIRMENT
272. Therese Standal: MULTIPLE MYELOMA: THE INTERPLAY BETWEEN MALIGNANT PLASMA CELLS AND THE BONE MARROW MICROENVIRONMENT

273. Ingvild Saltvedt: TREATMENT OF ACUTELY SICK, FRAIL ELDERLY PATIENTS IN A GERIATRIC EVALUATION AND MANAGEMENT UNIT – RESULTS FROM A PROSPECTIVE RANDOMISED TRIAL
274. Birger Henning Endreseth: STRATEGIES IN RECTAL CANCER TREATMENT – FOCUS ON EARLY RECTAL CANCER AND THE INFLUENCE OF AGE ON PROGNOSIS
275. Anne Mari Aukan Rokstad: ALGINATE CAPSULES AS BIOREACTORS FOR CELL THERAPY
276. Mansour Akbari: HUMAN BASE EXCISION REPAIR FOR PRESERVATION OF GENOMIC STABILITY
277. Stein Sundstrøm: IMPROVING TREATMENT IN PATIENTS WITH LUNG CANCER – RESULTS FROM TWO MULITCENTRE RANDOMISED STUDIES
278. Hilde Pleym: BLEEDING AFTER CORONARY ARTERY BYPASS SURGERY - STUDIES ON HEMOSTATIC MECHANISMS, PROPHYLACTIC DRUG TREATMENT AND EFFECTS OF AUTOTRANSFUSION
279. Line Merethe Oldervoll: PHYSICAL ACTIVITY AND EXERCISE INTERVENTIONS IN CANCER PATIENTS
280. Boye Welde: THE SIGNIFICANCE OF ENDURANCE TRAINING, RESISTANCE TRAINING AND MOTIVATIONAL STYLES IN ATHLETIC PERFORMANCE AMONG ELITE JUNIOR CROSS-COUNTRY SKIERS
281. Per Olav Vandvik: IRRITABLE BOWEL SYNDROME IN NORWAY, STUDIES OF PREVALENCE, DIAGNOSIS AND CHARACTERISTICS IN GENERAL PRACTICE AND IN THE POPULATION
282. Idar Kirkeby-Garstad: CLINICAL PHYSIOLOGY OF EARLY MOBILIZATION AFTER CARDIAC SURGERY
283. Linn Getz: SUSTAINABLE AND RESPONSIBLE PREVENTIVE MEDICINE. CONCEPTUALISING ETHICAL DILEMMAS ARISING FROM CLINICAL IMPLEMENTATION OF ADVANCING MEDICAL TECHNOLOGY
284. Eva Tegnander: DETECTION OF CONGENITAL HEART DEFECTS IN A NON-SELECTED POPULATION OF 42,381 FETUSES
285. Kristin Gabestad Nørsett: GENE EXPRESSION STUDIES IN GASTROINTESTINAL PATHOPHYSIOLOGY AND NEOPLASIA
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