ORIGINAL ARTICLE

Effects of Aquatic Resistance Training on Mobility Limitation and Lower-Limb Impairments After Knee Replacement

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ABSTRACT. Valtonen A, Pöyhönen T, Sipilä S, Heinonen A. Effects of aquatic resistance training on mobility limitation and lower-limb impairments after knee replacement. Arch Phys Med Rehabil 2010;91:833-9.

Objective: To study the effects of aquatic resistance training on mobility, muscle power, and cross-sectional area.

Design: Randomized controlled trial.

Setting: Research laboratory and hospital rehabilitation pool.

Participants: Population-based sample (N=50) of eligible women and men 55 to 75 years old 4 to 18 months after unilateral knee replacement with no contraindications who were willing to participate in the trial.

Interventions: Twelve-week progressive aquatic resistance training (n=26) or no intervention (n=24).

Main Outcome Measures: Mobility limitation assessed by walking speed and stair ascending time, and self-reported physical functional difficulty, pain, and stiffness assessed by Western Ontario and McMaster University Osteoarthritis Index (WOMAC) questionnaire. Knee extensor power and knee flexor power assessed isokinetically, and thigh muscle cross-sectional area (CSA) by computed tomography.

Results: Compared with the change in the control group, habitual walking speed increased by 9% (P=.005) and stair ascending time decreased by 15% (P=.006) in the aquatic training group. There was no significant difference between the groups in the WOMAC scores. The training increased knee extensor power by 32% (P<.001) in the operated and 10% (P=.001) in the nonoperated leg, and knee flexor power by 48% (P=.003) in the operated and 8% (P=.002) in the nonoperated leg compared with controls. The mean increase in thigh muscle CSA of the operated leg was 3% (P=.018) and that of the nonoperated leg 2% (P=.019) after training compared with controls.

Conclusions: Progressive aquatic resistance training had favorable effects on mobility limitation by increasing walking speed and decreasing stair ascending time. In addition, training increased lower limb muscle power and muscle CSA. Resistance training in water is a feasible mode of rehabilitation that has wide-ranging positive effects on patients after knee replacement surgery.

Key Words: Osteoarthritis; Rehabilitation; Water.

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KNEE REPLACEMENT effectively reduces pain[1-3] and decreases perceived disability.[4,5] Nevertheless, persons with knee replacement report more disabilities than do healthy controls matched for age and sex.[6,7] One reason for the greater prevalence of disability of persons with knee replacement is difficulty in mobility-related tasks requiring muscle power such as walking, negotiating stairs, and other physical abilities.[8-14] Mobility limitations are associated with decreased lower limb muscle strength and power.[10,11,14] Earlier studies have shown that knee extensor and flexor muscle weakness continues to persist for several months, even years, postoperatively compared with the nonoperated side[8,12,14-19] or with healthy controls.[8,17,18,20,21] Our previous study showed that in persons with knee replacement, the mean asymmetric power deficit was 19% to 23% in the knee flexor and extensor muscles and 14% in knee extensor muscle mass on average 10 months postsurgery.[19] Factors leading to muscle weakness include the loss of muscle tissue because of long-term disuse of the affected leg prior to the operation,[22] procedures related to the operation,[18] and lack of postoperative strength–increasing rehabilitation.[23]

Aquatic training has been well studied in healthy people and people with knee or hip osteoarthritis with mostly positive results on mobility,[24-26] muscle strength,[24-28] or muscle mass.[27] The effects of aquatic training after knee replacement surgery have been less investigated. Two recent studies found no aquatic rehabilitation effect on mobility when the rehabilitation programs started less than 2 weeks[29,30] after knee replacement surgery. However, it has been reported[29] that 2 weeks of aquatic rehabilitation commencing 4 days after knee replacement increased hip abduction and knee extension strength compared with the ward physiotherapy. However, the training programs lasted only 2 weeks[29] or comprised traditional aquatic exercise without additional resistance.[30]

Persons with knee replacement have long-term muscle weakness and mobility limitation. It is unclear, however, whether these potential risk factors for disability can be affected by progressive aquatic resistance training. Therefore, the purpose of this randomized

List of Abbreviations

CI	confidence interval
CSA	cross-sectional area
CT	computed tomography
ICC	intraclass correlation coefficient
RPE	Rating of Perceived Exertion
WOMAC	Western Ontario and McMaster University Osteoarthritis Index

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controlled study was to investigate the effects of progressive aquatic resistance training on mobility, muscle power, and muscle CSA in women and men 55 to 75 years old after knee replacement surgery. Our hypothesis was that aquatic resistance training increases muscle power of the operated and nonoperated side and reduces mobility limitation among older persons with knee replacement.

METHODS

Setting and Participants

In 2005, all 201 patients who according to the physical therapy records of Kymenlaakso Central Hospital had undergone unilateral knee replacement 4 to 18 months prior to the study were informed about the study. Eighty-six patients responded and were contacted by the research personnel and interviewed over the telephone. Patients with bilateral knee arthroplasty, revision arthroplasty, severe cardiovascular diseases, dementia, rheumatoid arthritis, or any major surgery in either of the knees were excluded from the study. Thus, 50 eligible volunteers (age range, 55–75y), 30 women and 20 men, were randomly assigned after the baseline measurements into an aquatic resistance training group (16 women, 10 men) and a control group (14 women, 10 men). The random allocation was concealed in sealed envelopes in blocks of sex, age, and type of knee replacement. The intervention profile is displayed in figure 1.

The reason for the knee replacement surgery for all the participants was knee joint osteoarthritis. Details of the knee replacement operation were collected from the hospital medical records. In all cases, the knee replacement surgery had been performed with cement fixation (48 with tricompartmental total knee arthroplasty, 2 with unicompartmental hemiarthroplasty). The participants with hemiarthroplasty did not differ from those with total knee replacement in any of the variables.

Before the laboratory examinations, the participants were informed about the study, and they gave their written informed consent. The study was conducted according to the Declaration of Helsinki and approved by the ethical committee of Kymenlaakso Central Hospital.

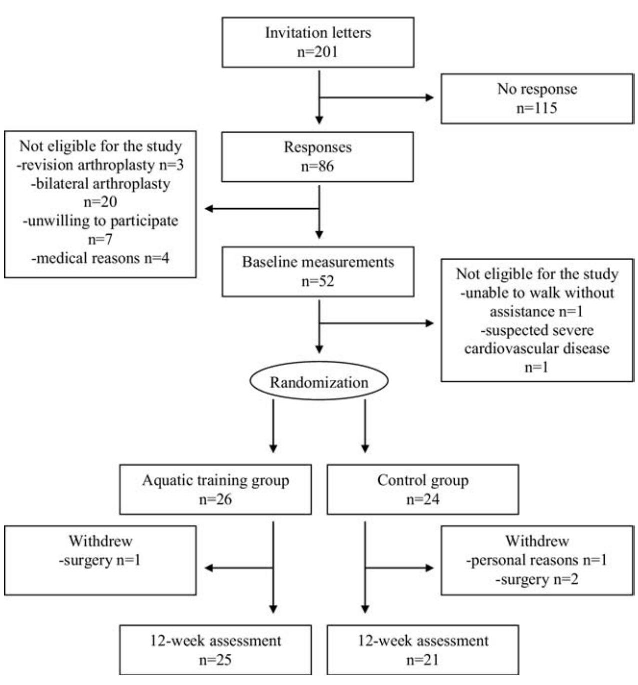

Fig 1. Intervention profile.

Measurements

Quantitative CT measurements and analyses were conducted blind to the study group. The other measurements were conducted unblind.

Health Status

The general health, clinical history, medication, and diseases of the participants were assessed by a physician before the laboratory examinations to evaluate potential contraindications for safe participation in the measurements and training. Body height and weight were measured in the laboratory using standard procedures. The presence of self-reported chronic conditions was recorded by a questionnaire. Habitual physical activity was recorded during the intervention using a training diary.

Mobility Limitation as a Primary Outcome

Mobility limitation was assessed by maximal and habitual walking speed and stair ascending time.

Maximal and habitual walking speed. Maximal[31] and habitual[32] walking speed over 10m were measured in the hospital corridor, and the time taken was recorded using photocells.[a] First, the participants were instructed to walk at their habitual walking speed. Second, they were instructed to walk as fast as possible without compromising their safety. All the participants wore thin aquatic shoes and were allowed 3m for acceleration. Each participant performed 2 trials at maximal and 2 at habitual walking speed separated by a 1-minute rest, and the faster performances were accepted as the results. In our laboratory, the ICC for persons with knee replacement has been .86 for maximal and .44 for habitual walking speed.[19]

Ascending stairs. Maximal time taken to ascend 10 stairs was measured in the hospital corridor,[33] and the time taken was recorded using photocells.[a] The stair height was 17cm and depth 29.5cm. The participants were instructed to step alternately on each stair and ascend as fast as possible without compromising their safety. Using a handrail or taking a step with both feet on the same step (bipedal ascent) was allowed only if necessary. Each participant performed 2 ascents separated by a 1-minute rest. The time of the faster performance was accepted as the result. The ICC for ascending stairs for persons with knee replacement has been .73.[19]

Self-Reports

The WOMAC questionnaire,[34] a self-rated measure of pain and stiffness and the physical functional difficulty of the participants, is widely used after joint replacement surgery research.[29,35] The version based on the visual analog scale (range, 0–100mm, with 100 indicating the worst possible situation) was used. In the physical functional difficulty score, 80% of the participants did not answer the subscale "getting in and out of the bath" because they did not have a bath. Therefore, this subscale was not included in the analysis.

Lower-Extremity Impairments of the Operated and Nonoperated Side

Muscle power. Maximal muscle power of the knee extensors and flexors was measured with an isokinetic dynamometer[b] with a sampling frequency of 100Hz and measurement error of 1% throughout the entire range of motion.[27] The dynamometer was calibrated before each measurement session according to the procedure recommended by the manufacturer. Before the measurement session, the participants were carefully familiarized with the testing procedure. For each leg, the axis of rotation of the dynamometer was aligned with the condylus femoris lateralis. The lever arm of the dynamometer was attached around the ankle 2.5cm above the midpoint of the malleolus lateralis. Hip and thigh were stabilized with straps. The measurement was performed on as large a range of motion of the knee as possible. The nonoperated leg was measured first. After 2 to 3 submaximal flexion-extension movements, 5 maximal continuous flexion-extension trials were performed at an angular velocity of 180°/s. The participants were verbally encouraged to make a maximal effort throughout the whole range of motion. Peak knee extensor and flexor power (W) values were analyzed from the best extension and flexion efforts. The ICC of the isokinetic parameters for persons with knee replacement was between .90 and .96 for the operated knee.[19]

Muscle CSA. Quantitative CT scans were obtained from both midthighs using a Siemens Somatom DR Scanner[c] with the patient in a supine position.[36] Midthigh was defined as the midpoint between the level of the greatest lateral protuberance of the greater trochanter and lower edge of the patella. The scans were analyzed to measure thigh muscle CSA (cm^2)[36] using software developed for the purpose at the University of Jyväskylä.[d] The software separates fat and lean tissue on the basis of radiologic tissue density (measured as attenuation in Hounsfield units) limits. In our previous study, the coefficient of variation was calculated between 2 consecutive repeated measurements and was 1% to 2% for muscle CSA.[36]

Intervention

Exercise sessions were conducted twice a week in small classes containing 4 to 5 persons. All the classes were supervised by an experienced physiotherapist. Table 1 summarizes the training program, including the weekly sets, duration of work, rest, and the training load produced by the resistance boots as well as the mean RPE value for each week.

Each session started with an 8-minute warm-up including walking (forward, backward, and sideways), aqua jogging, and lower-leg muscle stretching. This was followed by 30 to 40 minutes of resistance training and a 5-minute cooling down period. The exercises were selected on the basis of our previous study.[27] Each training session consisted of 5 exercises for both legs: (1) knee extension-flexion movement in a sitting position, (2) hip abduction-adduction with extended knee in a standing position, (3) hip extension-flexion with extended knee in a standing position, (4) knee extension-flexion in a standing position, and (5) step-squat backward from the aqua aerobic step board. The subjects were verbally encouraged to perform each repetition with maximal effort in order to achieve the highest possible movement velocity and resistance. In each exercise, the operated leg was trained first and then the nonoperated leg. The operated leg was trained to 30% more sets compared with the nonoperated one. The participants were asked to describe their perceived exertion after each exercise with the RPE scale (range, 6–20).[37] The participants were asked to report whether they had any pain or discomfort during the training sessions.

The progression of the exercise program was ensured by using resistance boots of different sizes and by varying the amount and duration of sets. The first 2 weeks of training were conducted without resistance boots in order to adapt to the exercises. The actual training was conducted using small Aqua Runner Zero Impact Footwear[e] (2 weeks) and with medium (4 weeks) and large resistance boots[f] (4 weeks). In weeks 7 and 12, one training session was conducted without resistance boots in order to avoid overtraining. The frontal area of the medium size resistance boots was $0.045m^2$ and that of the large resistance boots, $0.075m^2$. The small footwear was attached around the foot and the medium and large boots around the lower leg and foot during the exercises. In our previous study,[27] the drag during the exercises in healthy women was double with the medium boots and triple with the large boots compared with the barefoot condition.

Intensity of training was estimated for 3 women and 3 men in the training group (mean age ± SD, 62.2±4.3y; mean height ± SD, 169.8±8.2cm; mean weight ± SD, 86.3±9.2kg) by the RPE scale and with heart rate monitoring. The average heart rates were recorded with the Polar RS400 heart rate monitor[g] during the 5 exercises, excluding the warm-up and cool-down. Age-related maximal heart rates were calculated according to the following equation: 220–age (y). Among the 6 persons tested for training intensity, the mean RPE value ± SD during the exercises was 17±1 (range, 14–18). The mean heart rate ± SD was 116±18 beats/s (range, 93–148), which was 73% of

Table 1: Summary of the Aquatic Training Protocol

Week	Sets: Operated	Sets: Nonoperated	Repetitions/Set	Work/Set (s)	Rest/Set (s)	Resistance	Mean RPE
1	2	2	25–30	45	30	No boots	14
2	2	2	25–30	45	30	No boots	15
3	2	2	20–25	35	30	Small	16
4	3	2	20–25	35	30	Small	16
5	2	2	14–20	30	30	Medium	16
6	2	2	14–20	30	30	Medium	17
7	3	2	25–30	40	30	No boots	16
	3	2	14–20	30	30	Medium	16
8	3	2	14–20	30	30	Medium	17
9	2	2	12–15	30	30	Large	17
10	3	2	12–15	30	40	Large	16
11	4	2	12–15	30	40	Large	17
12	3	2	12–15	30	40	Large	17
	3	2	25–30	30	40	No boots	16

NOTE. Training was conducted 2 times a week. Weeks 7 and 12 were conducted with 2 different training sessions: one with resistance boots and one without extra resistance. During weeks 1 to 6 and weeks 8 to 11, the 2 training sessions were similar.

the age-related maximal heart rate. In the hydroboot conditions, the movement velocities were slower and the number of repetitions a set lower but the resistance higher compared with the barefoot condition.[27,38]

Control Group

The control group did not receive any intervention. Participants were encouraged to continue their lives as usual and maintain their habitual level of physical activity during the trial.

Statistical Analysis

Means and SDs were calculated. The data obtained from men and women were pooled to obtain a larger sample size because there were no differences between the sexes in age, postoperation time, or training response. All the analyses were based on an intention-to-treat analysis. Participants with missing variables in the muscle power tests (1 because of pain in the knee, 2 because of technical problems) or in the CT measurement (3 because of technical problems) were omitted only from the analysis in question.

All the variables were normally distributed; therefore, the analysis of covariance was used to assess the training effects between the training and control groups. Age, sex, postoperative time, and training compliance were tested separately and together as covariates. Because they did not have an influence on the results, only the baseline measurement was used as covariate.

Training compliance in the training sessions was calculated for each participant according to the following equation:

$$(\text{attended/offered}) \times 100\%$$

The relative change in mobility, WOMAC scores, muscle power, and muscle CSA measures between the pretrial and posttrial measurements was calculated as

$$(\text{post–pre})/\text{pre} \times 100\%$$

The differences (effects) between the mean relative changes in the study groups and the 95% CIs of the difference were also calculated. Ninety percent CI of the minimal detectable change for the absolute differences between the groups was calculated as

$$\text{SEM} \times z \times \sqrt{2}$$

to assess clinically significant differences.

All the eligible patients with knee replacement were included in the study and thus, with the present dropout rate, the sample size of the study provided 80% statistical power to detect a difference of about 10% between the groups in habitual walking speed at a significance level of P less than .05.

RESULTS

Baseline Characteristics

Table 2 shows the baseline physical characteristics of the training and control groups. No between-group differences were observed at baseline.

Program Feasibility

The dropout rate was 6%. In the training group, 1 participant (knee replacement operation on the other knee), and in the control group, 3 participants (1 for personal reasons and 2 for a knee replacement operation on the other knee) were lost to follow-up (see fig 1). Training compliance in the aquatic training sessions was excellent, averaging 98% (590 sessions attended/600 offered). In the training group, the participants did not report any pain during the training program. However, 1 participant visited the study physician because of elevated blood pressure without taking further actions or a pause in the training regimen. The mean RPE value for training was 16 (range, 14–17).

Table 2: Baseline Physical Characteristics of the Participants in the Aquatic Training and Control Group

Characteristics	Aquatic Training Group n=26	Control Group n=24
Age (y)	66.2±6.3	65.7±6.0
Weight (kg)	83.2±15.2	83.9±15.0
Height (cm)	167.3±9.3	169.7±8.2
Time since operation (mo)	9.9±4.7	9.2±4.2
Comorbidities,* n (%)		
Cardiovascular	15 (58)	9 (38)
Endocrine	2 (8)	2 (8)
Musculoskeletal	13 (50)	8 (33)
Respiratory	2 (8)	1 (4)
Diagnosed knee osteoarthritis of the nonoperated knee, n (%)	4 (15)	4 (17)

NOTE. Values are mean ± SD unless indicated otherwise.
*Self-reported number of comorbidities.

Mobility Limitation

At baseline, there were no differences between the aquatic training and the control group in maximal walking speed (P=.214), habitual walking speed (P=.684), or stair ascending time (P=.884). In the baseline measurements, 3 participants in the training and 1 in the control group were unable to perform alternate stepping and thus used bipedal ascent.

Compared with controls, the training group showed a mean increase in their habitual walking speed of 9% (95% CI, 3%–15%) at the end of the intervention. Maximal walking speed was not affected by training (1%; 95% CI, −6% to 8%). Stair ascending time decreased significantly among the trainees compared with controls (−15%; 95% CI, −24% to −6%). After the intervention, 1 participant in each group used bipedal ascent.

Self-Reports

At baseline, there were no differences between the aquatic training and control group in the WOMAC physical functional difficulty (P=.109), pain (P=.866), or stiffness (P=.254) scores. The scores for physical functional difficulty (analysis of covariance, P=.197), pain (P=.352), and stiffness (P=.097) in the operated knee were not affected by training.

Lower-Extremity Impairments

At baseline, there were no differences between the aquatic training and the control group in knee extension power (P=.440) or knee flexion power (P=.430) on the operated side, or in knee extension power (P=.974) or knee flexion power (P=.734) on the nonoperated side. In addition, thigh muscle CSA did not differ between the groups at baseline in the operated (P=.657) or nonoperated leg (P=.693).

The mean gain in knee extension power was significantly greater in both the operated (effect 32%; 95% CI, 18%–47%) and nonoperated leg (10%; 95% CI, 5%–16%) in the training group compared with controls. Compared with controls, a significant increase was also observed in knee flexion power in the operated (48%; 95% CI, 8%–89%) and in the nonoperated leg (8%; 95% CI, 2%–14%) in the training group. A small but

Table 3: Effects of Aquatic Training (Mean ± SD, Mean Difference, and 95% CI)

	Aquatic Training Group				Control Group					
	Baseline		Posttrial		Baseline		Posttrial			
Variable	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD	Mean Difference† (95% CI)	ANCOVA P‡
KEP operated (W)	23	112.6±51.4	23	145.6±64.0	20	129.7±47.3	20	129.3±44.8	33.5* (17.7 to 49.3)	<.001
KEP nonoperated (W)	23	153.6±50.9	23	172.3±60.0	20	158.4±57.2	20	160.4±56.9	16.9* (7.2 to 26.6)	.001
KFP operated (W)	23	99.8±49.4	23	135.9±60.0	20	116.0±42.9	20	117.8±41.3	32.3* (11.6 to 53.0)	.003
KFP nonoperated (W)	24	130.2±44.1	24	144.2±53.6	20	141.0±50.9	20	143.4±51.8	12.6* (5.0 to 20.2)	.002
CSA operated (cm^2)	24	105.2±30.0	24	110.1±30.7	19	101.5±21.1	19	103.5±20.2	3.0* (0.5 to 5.4)	.018
CSA nonoperated (cm^2)	24	114.5±29.1	24	117.6±39.3	19	111.1±25.4	19	112.0±24.6	2.2* (0.4 to 4.1)	.019
Maximal walking speed (m/s)	25	1.90±0.30	25	1.96±0.31	21	1.84±0.53	21	1.87±0.52	0.04 (−0.08 to 0.16)	.532
Habitual walking speed (m/s)	25	1.31±0.17	25	1.41±0.24	21	1.30±0.24	21	1.29±0.26	0.12* (0.04 to 0.20)	.005
Stair ascending (s)	25	4.96±2.10	25	4.27±1.67	21	4.68±1.81	21	4.71±1.74	−0.66* (−1.12 to −0.20)	.006
WOMAC total score§ (mm)	25	22.4±10.6	25	17.9±8.5	21	18.1±11.6	21	18.3±16.0	−4.1 (−9.1 to 1.0)	.110
Pain score‖ (mm)	25	16.8±10.6	25	13.0±8.7	21	17.0±14.6	21	15.5±12.4	−2.4 (−7.4 to 2.7)	.352
Stiffness score‖ (mm)	25	32.7±24.0	25	25.9±20.6	21	26.1±19.3	21	30.3±25.5	−8.9 (−19.5 to 1.7)	.097
Physical functional difficulty score‖ (mm)	25	22.6±11.7	25	18.5±9.4	21	17.0±11.5	21	17.3±17.2	−3.6 (−9.3 to 2.1)	.212

Abbreviations: ANCOVA, analysis of covariance; CSA, cross-sectional area; KEP, knee extension power; KFP, knee flexion power; VAS, visual analog scale.
*Clinically significant difference between the groups. Assessed by minimal detectable change at the 90% confidence level, calculated for the absolute mean difference (effect) between the groups as $SEM \times z \times \sqrt{2}$.
†Mean difference (effect) calculated as the absolute mean difference (95% CI) between the study groups.
‡Derived from ANCOVA, baseline as covariate.
§Total score of WOMAC questionnaire based on VAS.
‖Assessed with WOMAC questionnaire, subscales of pain, stiffness and physical functional difficulty based on VAS.

significant increase in thigh muscle CSA in the operated (3%; 95% CI, 0%–5%) and in the nonoperated leg (2%; 95% CI, 0%–3%) was observed in the training group compared with the control group (table 3).

DISCUSSION

The results of this study support our hypothesis and show that 12 weeks of progressive aquatic resistance training decreased mobility limitation in women and men 55 to 75 years old after unilateral knee replacement. In addition, knee extensor and flexor power and thigh muscle CSA increased with training, especially in the operated leg.

Our results showed training effects in the operated knee of 32% and 48% for knee extensor and flexor power, respectively. The corresponding values for the nonoperated side were 8% and 10%. The greater improvement in the operated leg was expected because the operated leg received 30% more training than the nonoperated one. The operated leg was also weaker at the baseline measurements. The training effect for the nonoperated knee was in line with the values from 6% to 13% reported in earlier studies on aquatic resistance training in healthy adults and older persons.[25,27,28] Earlier studies in subjects with hip or knee osteoarthritis have reported mixed results of the effects of aquatic exercise on the muscle strength of the lower limbs.[24,26,39,40] In persons with osteoarthritis, pain in the impaired joint can affect training intensity. In addition, in earlier studies the training programs lasted for only 6 weeks[24] or did not include extra resistance.[26,39] However, after knee replacement, when the joint is pain-free, a training effect seems to be evident, as found in our study. This was also found in the earlier study,[29] which reported that 2 weeks of aquatic rehabilitation commencing 4 days after knee replacement increased hip abduction and knee extension strength compared with the ward physiotherapy.

The muscle CSA results of this study are in line with those of our previous study,[27] which showed an increase of 4% to 5% in extensor and flexor muscle CSA in healthy women after aquatic training. Muscle hypertrophy is one of the mechanisms underlying increasing muscle strength during training. However, as has been suggested by earlier studies in healthy older persons, the increase in muscle mass induced by resistance training is much less than the increase in muscle strength,[41-43] as was also seen in this study. An increase in muscle mass also has important advantages other than increased force production. Muscle tissue acts as a dynamic metabolic store, as a vital source of heat, and as protective padding for the skeleton against falls.[44]

Our 12-week aquatic resistance training program was specifically targeted at improving lower extremity muscle power and mass, and thus mobility. Aquatic resistance training increased habitual walking speed and stair ascending time compared with controls. However, maximal walking speed was not affected by the training, which may be a result of the relatively fast walking speed (1.9m/s) of the participants at the baseline. In earlier studies, aquatic training with or without additional resistance has shown favorable effects in the mobility in healthy older women[25] and in persons with osteoarthritis.[24,26] In addition, 2 earlier studies have been reported on the effects of 2 to 6 weeks of aquatic exercise intervention compared with dry-land rehabilitation[30] or with ward control[29] on mobility among people recovering from knee replacement surgery. In the recovery phase (<2wk postsurgery), mobility increased equally in all study groups with no between-group differences. However, the operated side would appear to remain weaker for years compared with the nonoperated side or with healthy controls, suggesting increased risk for mobility limitation after knee replacement. Our encouraging results in habitual walking speed and stair ascending may be a result of the progressive extra resistance produced by the resistance boots during the training. In addition, the result may partly be a result of the low base level of functional ability and muscle power of the older people with knee replacement surgery, which is impaired, at least partly, by pain and long-term disuse before the operation and for up to months afterward.

In an earlier study, an 8-week intensive functional dry-land rehabilitation program after knee replacement decreased self-reported physical functional difficulty.[35] No group differences in the WOMAC physical functional difficulty were found after a 6-week water-based and dry-land rehabilitation program commencing 2 weeks after knee replacement.[30] In the present study, the training had no effect on the self-reported physical functional difficulty compared with controls. This might be a result of the relative good health of the study population, who did not appear to have problems with the simpler tasks, such as lying in bed and sitting. Training also had no effect on pain, which was expected because of the relatively small pain scores at baseline, as also found after knee replacement in other studies.[35,45,46]

Our 12-week aquatic resistance training program induced marked improvements in lower-extremity muscle power and mass, and thus mobility, in persons with a knee replacement operation 4 to 18 months earlier. The training program was not started right after the operation, which is the usual course in rehabilitation practice. The results indicate that it would be important to offer rehabilitative exercise strategies for the patients with joint replacement in the long run and not only for the very acute phase.

All in all, the marked improvements in muscle power and mobility in our study might be a result of the use of an effective and safe training medium, water. Water minimizes the effects of gravity, which reduces compressive and shear forces on joints and thus offers a comfortable training medium for patients with musculoskeletal problems. In addition, water offers variable, easily individually adjustable resistance to movements. The resistance offered by water to movements increases with speed: the drag produced by water quadruples when velocity doubles.[27] Thus, progressive resistance-type aquatic training seems to lead to both functional and structural adaptations in the neuromuscular system. Therefore, progressive aquatic training with resistance boots can be recommended in rehabilitation for patients with knee replacement.

Study Limitations

This study has some limitations. We have made multiple comparisons in these data, and it is possible that there is a study-wide type I error. However, in randomized controlled trials with selected and preplanned main outcome, correction of multiple comparisons is unnecessary. We were not able to conduct complete blinding, which thus limits the strength of the conclusions. Unfortunately, we did not know the preoperative impairment or level of mobility limitation of the participants or the rehabilitation before the baseline measurements. However, the randomization, at least in part, reduced this potential bias. In addition, the intensity of training was challenging to define. Even though the subjects were encouraged to exercise with maximal effort, we do not know whether they exercised to fatigue. This study has several strengths. First, it was a randomized controlled trial with both training and control groups, and with only a very few dropouts. Second, the trainees performed the training protocol with a high compliance (98%) and did not report any pain during training. Third, the recruitment of the participants was population-based, and the study groups were homogeneous. In the future, the intensive training program with mixed aquatic and dry-land training program should be considered.

CONCLUSIONS

The results of this randomized controlled trial showed that 12 weeks of progressive aquatic training reduced mobility limitation in persons with knee replacement. Knee extensor and flexor power and thigh muscle CSA increased with training, especially in the operated leg. The aquatic training was well tolerated, and thus water would appear to offer an effective environment for training muscle power and mobility after knee replacement.

References

1. Martin SD, Scott RD, Thornhill TS. Current concepts of total knee arthroplasty. J Orthop Sports Phys Ther 1998;28:252-61.
2. NIH Consensus Panel. NIH consensus statement on total knee replacement December 8-10, 2003. J Bone Joint Surg Am 2004; 86-A:1328-35.
3. Jones DL, Westby MD, Greidanus N, et al. Update on hip and knee arthroplasty: current state of evidence. Arthritis Rheum 2005;53:772-80.
4. Jones CA, Voaklander DC, Johnston DW, Suarez-Almazor ME. Health related quality of life outcomes after total hip and knee arthroplasties in a community based population. J Rheumatol 2000;27:1745-52.
5. Fitzgerald JD, Orav EJ, Lee TH, et al. Patient quality of life during the 12 months following joint replacement surgery. Arthritis Rheum 2004;51:100-9.
6. Finch E, Walsh M, Thomas SG, Woodhouse LJ. Functional ability perceived by individuals following total knee arthroplasty compared to age-matched individuals without knee disability. J Orthop Sports Phys Ther 1998;27:255-63.
7. Noble PC, Gordon MJ, Weiss JM, Reddix RN, Conditt MA, Mathis KB. Does total knee replacement restore normal knee function? Clin Orthop Relat Res 2005;431:157-65.
8. Walsh M, Woodhouse LJ, Thomas SG, Finch E. Physical impairments and functional limitations: a comparison of individuals 1 year after total knee arthroplasty with control subjects. Phys Ther 1998;78:248-58.
9. Lamb SE, Frost H. Recovery of mobility after knee arthroplasty: expected rates and influencing factors. J Arthroplasty 2003;18: 575-82.
10. Mizner RL, Petterson SC, Snyder-Mackler L. Quadriceps strength and the time course of functional recovery after total knee arthroplasty. J Orthop Sports Phys Ther 2005;35:424-36.
11. Mizner RL, Snyder-Mackler L. Altered loading during walking and sit-to-stand is affected by quadriceps weakness after total knee arthroplasty. J Orthop Res 2005;23:1083-90.
12. Rossi MD, Brown LE, Whitehurst M. Knee extensor and flexor torque characteristics before and after unilateral total knee arthroplasty. Am J Phys Med Rehabil 2006;85:737-46.
13. Minns Lowe CJ, Barker KL, Dewey M, Sackley CM. Effectiveness of physiotherapy exercise after knee arthroplasty for osteoarthritis: systematic review and meta-analysis of randomised controlled trials. BMJ 2007;335:812.
14. Yoshida Y, Mizner RL, Ramsey DK, Snyder-Mackler L. Examining outcomes from total knee arthroplasty and the relationship between quadriceps strength and knee function over time. Clin Biomech (Bristol, Avon) 2008;23:320-8.
15. Rodgers JA, Garvin KL, Walker CW, Morford D, Urban J, Bedard J. Preoperative physical therapy in primary total knee arthroplasty. J Arthroplasty 1998;13:414-21.
16. Lorentzen JS, Petersen MM, Brot C, Madsen OR. Early changes in muscle strength after total knee arthroplasty: a 6-month follow-up of 30 knees. Acta Orthop Scand 1999;70:176-9.
17. Rossi MD, Hasson S. Lower-limb force production in individuals after unilateral total knee arthroplasty. Arch Phys Med Rehabil 2004;85:1279-84.

18. Gapeyeva H, Buht N, Peterson K, Ereline J, Haviko T, Paasuke M. Quadriceps femoris muscle voluntary isometric force production and relaxation characteristics before and 6 months after unilateral total knee arthroplasty in women. Knee Surg Sports Traumatol Arthrosc 2007;15:202-11.
19. Valtonen A, Poyhonen T, Heinonen A, Sipila S. Muscle deficits persist after unilateral knee replacement and have implications for rehabilitation. Phys Ther 2009;89:1072-9.
20. Huang CH, Cheng CK, Lee YT, Lee KS. Muscle strength after successful total knee replacement: a 6- to 13-year followup. Clin Orthop Relat Res 1996;328:147-54.
21. Silva M, Shepherd EF, Jackson WO, Pratt JA, McClung CD, Schmalzried TP. Knee strength after total knee arthroplasty. J Arthroplasty 2003;18:605-11.
22. Suetta C, Aagaard P, Magnusson SP, et al. Muscle size, neuromuscular activation, and rapid force characteristics in elderly men and women: effects of unilateral long-term disuse due to hip-osteoarthritis. J Appl Physiol 2007;102:942-8.
23. Suetta C, Andersen JL, Dalgas U, et al. Resistance training induces qualitative changes in muscle morphology, muscle architecture, and muscle function in elderly postoperative patients. J Appl Physiol 2008;105:180-6.
24. Foley A, Halbert J, Hewitt T, Crotty M. Does hydrotherapy improve strength and physical function in patients with osteoarthritis—a randomised controlled trial comparing a gym based and a hydrotherapy based strengthening programme. Ann Rheum Dis 2003;62:1162-7.
25. Tsourlou T, Benik A, Dipla K, Zafeiridis A, Kellis S. The effects of a twenty-four-week aquatic training program on muscular strength performance in healthy elderly women. J Strength Cond Res 2006;20:811-8.
26. Hinman RS, Heywood SE, Day AR. Aquatic physical therapy for hip and knee osteoarthritis: results of a single-blind randomized controlled trial. Phys Ther 2007;87:32-43.
27. Poyhonen T, Sipila S, Keskinen KL, Hautala A, Savolainen J, Malkia E. Effects of aquatic resistance training on neuromuscular performance in healthy women. Med Sci Sports Exerc 2002;34:2103-9.
28. Takeshima N, Rogers ME, Watanabe E, et al. Water-based exercise improves health-related aspects of fitness in older women. Med Sci Sports Exerc 2002;34:544-51.
29. Rahmann AE, Brauer SG, Nitz JC. A specific inpatient aquatic physiotherapy program improves strength after total hip or knee replacement surgery: a randomized controlled trial. Arch Phys Med Rehabil 2009;90:745-55.
30. Harmer AR, Naylor JM, Crosbie J, Russell T. Land-based versus water-based rehabilitation following total knee replacement: a randomized, single-blind trial. Arthritis Rheum 2009;61:184-91.
31. Rantanen T, Avela J. Leg extension power and walking speed in very old people living independently. J Gerontol A Biol Sci Med Sci 1997;52:M225-31.
32. Portegijs E, Sipila S, Rantanen T, Lamb SE. Leg extension power deficit and mobility limitation in women recovering from hip fracture. Am J Phys Med Rehabil 2008;87:363-70.
33. Gur H, Cakin N. Muscle mass, isokinetic torque, and functional capacity in women with osteoarthritis of the knee. Arch Phys Med Rehabil 2003;84:1534-41.
34. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J Rheumatol 1988;15:1833-40.
35. Moffet H, Collet JP, Shapiro SH, Paradis G, Marquis F, Roy L. Effectiveness of intensive rehabilitation on functional ability and quality of life after first total knee arthroplasty: a single-blind randomized controlled trial. Arch Phys Med Rehabil 2004;85:546-56.
36. Sipila S, Suominen H. Effects of strength and endurance training on thigh and leg muscle mass and composition in elderly women. J Appl Physiol 1995;78:334-40.
37. Borg G. Borg's perceived exertion and pain scales. Champaign: Human Kinetics; 1998. p 120.
38. Poyhonen T, Keskinen KL, Kyrolainen H, Hautala A, Savolainen J, Malkia E. Neuromuscular function during therapeutic knee exercise under water and on dry land. Arch Phys Med Rehabil 2001;82:1446-52.
39. Wang TJ, Belza B, Thompson EF, Whitney JD, Bennett K. Effects of aquatic exercise on flexibility, strength and aerobic fitness in adults with osteoarthritis of the hip or knee. J Adv Nurs 2007;57:141-52.
40. Lund H, Weile U, Christensen R, et al. A randomized controlled trial of aquatic and land-based exercise in patients with knee osteoarthritis. J Rehabil Med 2008;40:137-44.
41. Sipila S, Multanen J, Kallinen M, Era P, Suominen H. Effects of strength and endurance training on isometric muscle strength and walking speed in elderly women. Acta Physiol Scand 1996;156:457-64.
42. Sipila S, Elorinne M, Alen M, Suominen H, Kovanen V. Effects of strength and endurance training on muscle fibre characteristics in elderly women. Clin Physiol 1997;17:459-74.
43. Petrella JK, Kim JS, Tuggle SC, Bamman MM. Contributions of force and velocity to improved power with progressive resistance training in young and older adults. Eur J Appl Physiol 2007;99:343-51.
44. Parry-Billings M, Newsholme EA, Young A. The uptake, storage, and release of metabolities by muscle. In: Evans JG, Williams TF, editors. Oxford textbook of geriatric medicine. Oxford: University Press; 1992. p 604-8.
45. Escobar A, Quintana JM, Bilbao A, et al. Effect of patient characteristics on reported outcomes after total knee replacement. Rheumatology (Oxford) 2007;46:112-9.
46. Bourne RB, Chesworth BM, Davis AM, Mahomed NN, Charron KD. Patient satisfaction after total knee arthroplasty: who is satisfied and who is not? Clin Orthop Relat Res 2010;468:57-63.

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