ORIGINAL ARTICLE

Maintenance of Aquatic Training-Induced Benefits on Mobility and Lower-Extremity Muscles Among Persons With Unilateral Knee Replacement

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ABSTRACT. Valtonen A, Pöyhönen T, Sipilä S, Heinonen A. Maintenance of aquatic training-induced benefits on mobility and lower-extremity muscles among persons with unilateral knee replacement. Arch Phys Med Rehabil 2011;92:1944-50.

Objective: To evaluate the maintenance of observed aquatic training-induced benefits at 12-month follow-up.

Design: Twelve-month follow-up of a randomized controlled study.

Setting: Research laboratory and hospital rehabilitation pool.

Participants: Population-based sample of 55 to 75-year-old women and men 4 to 18 months (on average 10mo) after unilateral knee replacement. Fifty people were willing to participate in the exercise trial and 42 people in the follow-up study.

Intervention: Twelve-month follow-up of 12-week progressive aquatic resistance training, or no intervention.

Main Outcome Measures: Isokinetic knee extensor and flexor power, thigh muscle cross-sectional area (CSA), habitual walking speed, stair ascending time, and sit-to-stand test.

Results: After a 12-month follow-up, a 32% (95% confidence interval [CI], 10–53) training effect in knee extensor power (P=.008) and 50% (95% CI, 9–90) in knee flexor power (P=.005) of the operated knee remained. In muscle CSA, the training-induced benefit had disappeared at the follow-up. All the significant 12-week improvements in habitual walking speed, stair ascending time, and sit-to-stand in the training group compared with controls were lost at follow-up.

Conclusions: After the 12-month follow-up, the 12-week aquatic training-induced benefits in knee extensor and flexor power were maintained, whereas the mobility benefits had disappeared. Aquatic resistance training should be continued at least on some level to maintain the training-induced benefits in mobility.

Key Words: Follow-up studies; Rehabilitation; Walking; Water.

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KNEE JOINT OSTEOARTHRITIS and related knee replacement surgery cause muscle strength and functional decline,[1-3] which have been reported to remain lower than in age-matched people beyond 1 year and even at 13 years after surgery.[1,4-8] In our previous 12-week randomized controlled trial,[9] we showed that progressive aquatic resistance training initiated on average 10 months after knee replacement had positive effects on muscle power, muscle mass, and mobility in the lower limbs, that is, decreased functional decline in persons with knee replacement.

To date, very little is known about the maintenance of training/therapeutic exercise-induced benefits in persons with knee replacement. As far as we know, only 1 earlier study has reported maintenance of dry-land strength training in persons with knee replacement. These results showed that improvements in muscle strength and mobility observed after 6-week progressive strengthening intervention were maintained after 12-months follow-up.[10] After progressive aquatic resistance training in persons with knee replacement, the long-term effects of training are unclear. So far, the maintenance of aquatic exercise effects after knee replacement surgery has been investigated only with 2- to 6-week-long rehabilitation programs.[11,12] However, it remains somewhat unclear whether the training-induced benefits of the progressive and intensive training program with additional resistance in persons with knee replacement can be maintained after cessation of training.

The purpose of this study was to evaluate whether the observed aquatic training-induced benefits in lower-leg muscle power, cross-sectional area (CSA), and mobility,[9] assessed by habitual walking speed, stair ascending time, and the sit-to-stand test, were maintained after follow-up for 12-months in persons with knee replacement. Our hypothesis was that aquatic training-induced benefits would be maintained during the follow-up.

METHODS

Design

This study was a 12-month follow-up of a 12-week randomized, controlled aquatic resistance training intervention (register no. ISRCTN50731915). The intervention refers to a 12-week randomized controlled trial[9] and the follow-up to the 12-month period after the end of the intervention. The measurements were conducted at baseline, after the 12-week inter-

List of Abbreviations

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

Table 1: Baseline Physical Characteristics of the Participants at Follow-Up*

Characteristics	Aquatic Training Group (n=25)	Control Group (n=17)
Age (y)	65.8±6.2	66.4±5.7
Body weight (kg)	84.1±14.8	82.3±14.8
Body height (cm)	167.9±9.0	169.5±7.3
Time since operation (mo)	10.1±4.7	8.5±3.9
Comorbidities*, n (%)		
Cardiovascular	15 (60)	7 (41)
Endocrine	1 (4)	2 (12)
Musculoskeletal	12 (48)	4 (24)
Respiratory	1 (4)	1 (6)
Diagnosed knee osteoarthritis of the nonoperated knee, n (%)	3 (12)	2 (12)

NOTE. Values are the mean ± SD unless indicated otherwise. No between-group differences at baseline.
*Self-reported number of comorbidities.

vention, and at 12-month follow-up by the same research personnel. Quantitative computed tomography (CT) measurements and analyses were conducted blinded to the study group. The other measurements were conducted unblinded. This follow-up study assesses the physical performance traits that showed a treatment effect during the intervention. In addition, using the Western Ontario and McMaster University Osteoarthritis Index (WOMAC) questionnaire self-reported physical functional difficulty, pain, and stiffness are used to describe the status of the knee on the operated side during the follow-up.

Participants

In 2005, all the 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 were contacted by the research personnel and interviewed over the telephone. Exclusion criteria were: bilateral knee arthroplasty, revision arthroplasty, severe cardiovascular diseases, dementia, rheumatoid arthritis, and any major operation in either of the knees. Thus, 50 eligible volunteers (age range, 55–75y; 30 women and 20 men) were randomized 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 (table 1). Forty-six participants (92%) completed the training intervention.[9] During the 12-month follow-up, 4 participants in the control group dropped out. Thus, 42 volunteers completed the 12-month postintervention follow-up study (fig 1).

The reason for the participants' knee replacement surgery was knee joint osteoarthritis. Characteristics of the knee replacement operation were collected from the hospital medical records. All the participants had undergone knee replacement surgery with cement fixation (41 with tricompartmental total knee arthroplasty, 1 with unicompartmental hemiarthroplasty). Independent samples *t* test was used to verify that the person with hemiarthroplasty did not differ from the participants with total knee replacement in the baseline measurements 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

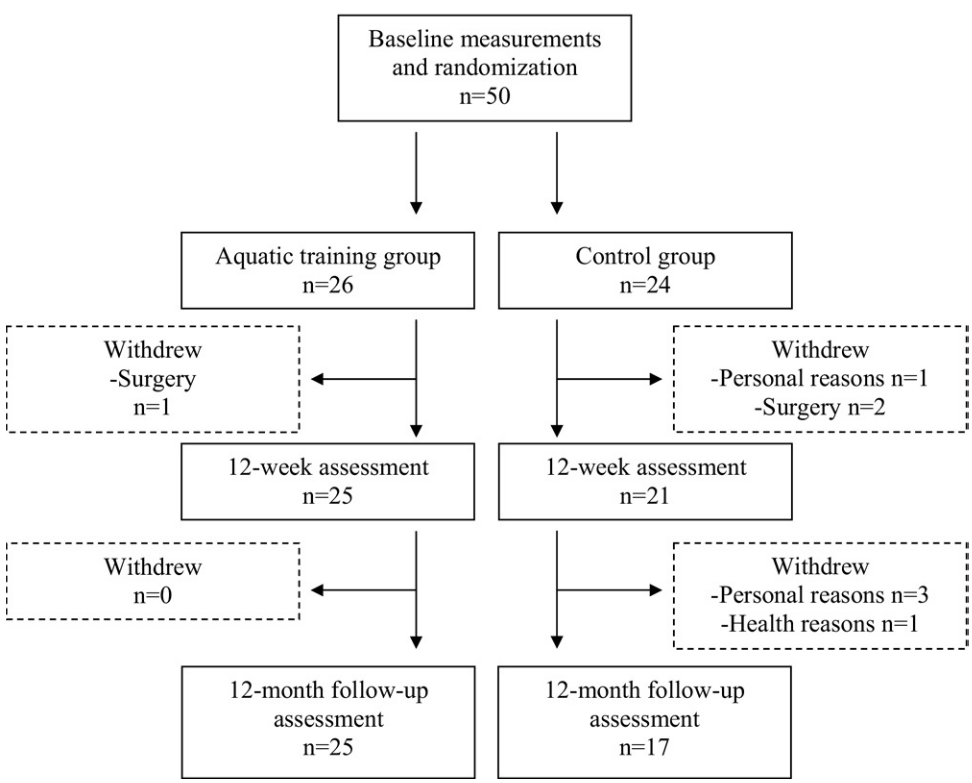

Fig 1. Trial profile.

of Helsinki and approved by the ethical committee of Kymenlaakso Central Hospital.

Intervention

The training program has been reported in the original intervention paper.[9] Briefly, the 12-week aquatic exercise was specifically targeted at improving lower-extremity muscle strength and power. Exercise sessions were conducted twice a week in small classes containing 4 to 5 persons. All the classes were supervised by an experienced physiotherapist.

Each training session consisted of 5 exercises for both legs: (1) 1-leg 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) 1-leg knee extension-flexion in a standing position, and (5) step-squat backwards from the aqua aerobic step board. The subjects were instructed to perform each repetition with maximal effort in order to achieve the highest possible movement velocity and resistance. The progression of the exercise program was ensured by using resistance boots of different sizes (small, medium, large) and by varying the amount and duration of sets. In the hydro-boot conditions, the movement velocities were slower and the number of repetitions per set was lower but the resistance higher compared with the barefoot condition.[13,14] 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.

Health Status

Body height and weight were measured using standard procedures. 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. The presence of self-reported chronic conditions was recorded with a questionnaire. In addition, the participants reported their general health and habitual physical activity at baseline, after the intervention, and at follow-up.

Knee Extensor and Flexor Power

Maximal muscle power (W) of the knee extensors and flexors in the operated leg was measured with an isokinetic dynamometer.[14] [a] After a few 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 maximal effort throughout the whole range of motion. Peak power (P) values were analysed from the best extension and flexion efforts. The intraclass correlation coefficient (ICC) of the isokinetic parameters for persons with knee replacement varied between .90 and .96 for the operated knee.[3]

Muscle CSA

CT scans were obtained from mid-thigh using a Siemens Somatom DR Scanner[b] with the patient in a supine position.[15] The scans were analyzed to measure thigh muscle CSA (cm^2) using software developed for that purpose at the University of Jyväskylä (Geanie 2.1[c]). In our previous study, the coefficient of variation was calculated between 2 consecutive repeated measurements, and was 1% to 2% for muscle CSA.[15]

Mobility

Mobility was assessed by habitual walking speed, stair ascending time, and the sit-to-stand test. In all the mobility variables, each participant performed 2 trials separated by a 1-minute rest, and the faster performance was accepted as the result.

Habitual walking speed. Habitual walking speed over 10m was measured in the hospital corridor and the time taken was recorded using photocells.[16] [d] All the participants were allowed 3m for acceleration.

Stair ascending. Maximal time taken to ascend 10 stairs was measured in the hospital corridor[17] and the time taken was recorded using photocells. The participants were instructed to step alternately on each stair as fast as possible without compromising their safety. A handrail or taking a step with both feet on the same step was allowed only if necessary. The ICC for ascending stairs for persons with knee replacement has been .73.[3]

Sit-to-stand. Maximal time taken to stand up and sit down 10 times on a standard chair was measured,[17] and the time taken was recorded using a stopwatch. The chair height was 43cm and the depth was 37cm. The participants were instructed to stand up and sit down as fast as possible without using their hands. The ICC for sit-to-stand was measured in our laboratory in a pilot study for 17 participants (12 women, 5 men; mean age, 77y) with unilateral knee replacement an average of 8 months after surgery. The ICC for sit-to-stand was .83 in persons with knee replacement.

Pain, Stiffness, and Physical Functional Difficulty

The WOMAC questionnaire, a self-rated measure of pain and stiffness and physical functional difficulty, is widely used after joint replacement surgery research.[12,18] 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.

Statistical Analysis

Means and SDs were used as descriptive statistics. The data obtained from men and women were pooled to obtain a larger sample size as there were no differences between the sexes in age, time since operation, or training response. All the available participants were measured and analyzed as randomized regardless of training compliance. The outcomes for the participants who dropped out during the follow-up were not used because of our long follow-up time. Independent samples *t* test was used to verify that the dropouts did not differ from the other participants in any characteristics or outcome variables. Participants with missing values in the physical performance tests (2 because of acute knee surgery, 3 because of other health problem) or in the CT measurement (2 because of unwillingness to participate) were omitted only from the analysis in question.

SPSS 17.0[e] was used for statistical analysis. All the variables were normally distributed. The analysis of covariance was used to assess the training effect at posttrial and follow-up training measurements between the training and control groups. Age, sex, time since operation, and training compliance were tested separately and together as covariates. Because they had no influence on the results, only the baseline measurement was used as covariate.

The relative change in muscle power, muscle CSA, and mobility between the pre- and posttrial measurements as well as pretrial and follow-up measurements was calculated as (post – pre)/pre × 100% or (followup – pre)/pre × 100%. The

Table 2: Mean ± SD Values at Baseline, at the End of the Intervention, and at Follow-Up in the Aquatic Training and Control Groups

Variable	Aquatic Training Group				Control Group			
	n	Baseline*	Posttrial	Follow-Up	n	Baseline*	Posttrial	Follow-Up
KEP (W)	21	112.6±51.4	145.6±64.0	144.6±60.5	16	133.2±45.4	130.8±41.4	134.7±53.7
KFP (W)	21	99.8±49.4	135.9±60.0	137.1±63.2	16	118.3±43.6	119.4±40.0	122.5±52.7
Thigh muscle CSA (cm^2)	25	105.2±30.0	110.1±30.7	109.3±28.4	15	101.2±20.7	103.3±19.6	105.6±22.1
Habitual walking speed (m/s)	21	1.31±0.18	1.41±0.24	1.39±0.15	16	1.33±0.23	1.34±0.23	1.35±0.24
Stair ascending (s)	21	4.96±2.10	4.27±1.67	4.39±1.54	16	4.86±1.96	4.77±1.82	4.77±1.90
Sit-to-stand 10 repetitions (s)	21	21.4±3.42	17.8±1.94	19.0±3.18	16	21.8±4.01	20.4±3.46	19.4±4.6
WOMAC total score† (mm)	25	22.4±10.6	17.9±8.5	17.4±10.3	17	16.7±12.5	17.7±17.8	14.6±10.1
Pain score‡ (mm)	25	16.8±10.6	13.0±8.7	13.3±8.9	17	15.7±15.1	15.3±13.2	9.5±6.8
Stiffness score‡ (mm)	25	32.7±24.0	25.9±20.6	21.7±14.8	17	23.3±17.9	27.0±24.8	22.1±20.7
Physical functional difficulty score‡ (mm)	25	22.6±11.7	18.5±9.4	18.1±11.0	17	15.9±12.5	16.9±19.1	14.8±11.0

Abbreviations: KEP, knee extensor power; KFP, knee flexor power; Thigh muscle CSA, thigh lean tissue cross-sectional area.
*No between-group differences in any of the variables at baseline.
†Total score of WOMAC questionnaire based on the visual analog scale.
‡Assessed with WOMAC questionnaire, subscales of pain, stiffness, and physical functional difficulty based on the visual analog scale.

differences (effect) in the mean relative changes between the study groups and the 95% confidence intervals (CIs) of the difference were also calculated.

RESULTS

Participation in the Follow-Up

Forty-two participants (84%) were measured in the follow-up assessment. All the participants from the training group participated in the follow-up assessment session, whereas 4 subjects in the control group withdrew from the study during the follow-up period (see fig 1). During the 12-month follow-up, 2 participants in the training and 1 in the control group also had their nonoperated knee replaced. One participant in each group had revision arthroplasty during the follow-up. At the follow-up measurements, 2 participants in the training group (asthma, sprain in the ankle) and 1 in the control group (sprain in the knee) had acute health problems, and consequently they attended only to the CT measurements and completed the questionnaires. At follow-up, 3 participants in the training and 1 in the control group had increased their habitual physical activity, and 2 participants in the training and 3 in the control group had decreased their habitual physical activity. None of the participants continued aquatic resistance training after the intervention.

Muscle Power and CSA

The absolute values at baseline, at the end of the intervention, and at the 12-month follow-up are presented in table 2. After the 12-week intervention, significant ($P<.037$) training effects of 3% to 49% were observed in knee extensor and flexor power and in thigh muscle CSA in the training group compared with controls (tables 2 and 3). At 12-month follow-up, a 32% (95% CI, 10–53) effect in knee extensor power and 50% (95% CI, 9–90) effect in knee flexor power of the operated knee remained in the training group compared with the control group (fig 2). In thigh muscle CSA, the training-induced benefit had disappeared at follow-up.

Mobility

After the intervention, significant ($P<.025$) training effects of 7% to 12% were observed in habitual walking speed, stair ascending time, and sit-to-stand in the training group compared with controls (see tables 2 and 3). However, at follow-up, no between-group differences were seen in any of the mobility variables (fig 3).

Pain, Stiffness, and Physical Functional Difficulty

The scores for physical functional difficulty, pain, and stiffness in the operated knee were not affected by training ($P<.310$). At follow-up, no between-group differences

Table 3: 12-Week Training Effect (95% CI) and 12-Month Follow-Up Mean Difference (95% CI)

Variable	Training Effect %* (95% CI)	ANCOVA $P^\dagger$	Mean Difference % at Follow-Up* (95% CI)	ANCOVA $P^\dagger$
KEP (W)	33 (17 to 50)	<.001	32 (10 to 53)	.008
KFP (W)	49 (3 to 94)	.008	50 (9 to 90)	.005
Thigh muscle CSA (cm^2)	3 (0 to 5)	.037	−1 (−5 to 3)	.486
Habitual walking speed (m/s)	7 (1 to 14)	.025	2 (−6 to 11)	.414
Stair ascending (s)	−12 (−21 to −4)	.015	−8 (−19 to 4)	.229
Sit-to-stand 10 repetitions (s)	−10 (−16 to −4)	<.001	0 (−11 to 12)	.995

Abbreviations: ANCOVA, analysis of covariance; KEP, knee extensor power; KFP, knee flexor power; Thigh muscle CSA, thigh lean tissue cross-sectional area.
*12-week training effect percent and 12-month follow-up mean difference calculated as the relative mean difference (95% CI) between the study groups.
†Derived from the ANCOVA using the absolute values at the end of the intervention and at follow-up; baseline as the covariate.

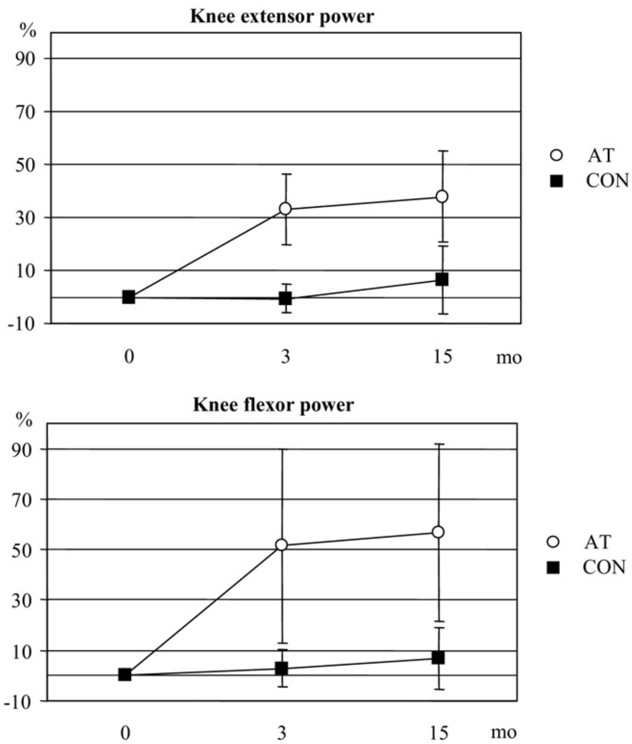

Fig 2. Muscle power variables for the aquatic training and control groups: knee extensor power, knee flexor power. Percentage change (95% CIs) for the training and control groups after the intervention (3mo) and at 12-month follow-up (15mo=12mo after cessation of training). Abbreviations: AT, aquatic training group; CON, control group.

($P<.896$) were observed in the physical functional difficulty score, pain, or stiffness (see table 2).

DISCUSSION

In this 12-month follow-up of a 12-week randomized controlled aquatic training intervention after knee replacement surgery, training-induced benefits in the knee extensor and flexor power remained q year after cessation of training. However, the training effects in mobility and muscle CSA had disappeared. The present results support our hypothesis, showing that in the training group in persons with knee replacements, knee extensor and flexor power was maintained at the posttraining level 12 months after cessation of training. Previously, from 8 to 12 weeks of aquatic training in different clinical populations have shown maintained[19] or decreased[20] lower-limb strength levels 3 months after cessation of training. In addition, Petterson et al[10] found that 2 different dry-land training groups with knee replacements were stronger than a nontraining cohort 12 months after cessation of training. However, these earlier inconsistent results cannot directly be compared with our results because of differences in the clinical populations,[19,20] training programs, environments and resistances used in the training protocols,[10,19,20] or our longer follow-up period.[10,19,20]

In contrast, the training effect on muscle CSA had disappeared at the follow-up. To our knowledge, no earlier studies in persons with knee replacement have reported on the maintenance of muscle CSA after strength training. In healthy older adults, muscle CSA was maintained[21] or decreased[22] during a 6-month detraining period. In the present study, thigh muscle CSA in the training group was maintained at the posttraining level, but the between-group difference disappeared because of the slight increase in muscle CSA in the controls. It seems that 12 months without physical training was too long a period to maintain training effects on muscle CSA. Nevertheless, the habitual physical activity of the participants was sufficient to enable them to maintain the training-induced muscle power.

In this study, the training effect on mobility in our study disappeared after the 12-month follow-up period. This is contrary to our hypothesis and to previous studies which have found further improvements in mobility from 3 to 12 months after cessation of training in persons with knee replacement,[10,11] However, previous studies and our study are not fully comparable, as the interventions in the former studies

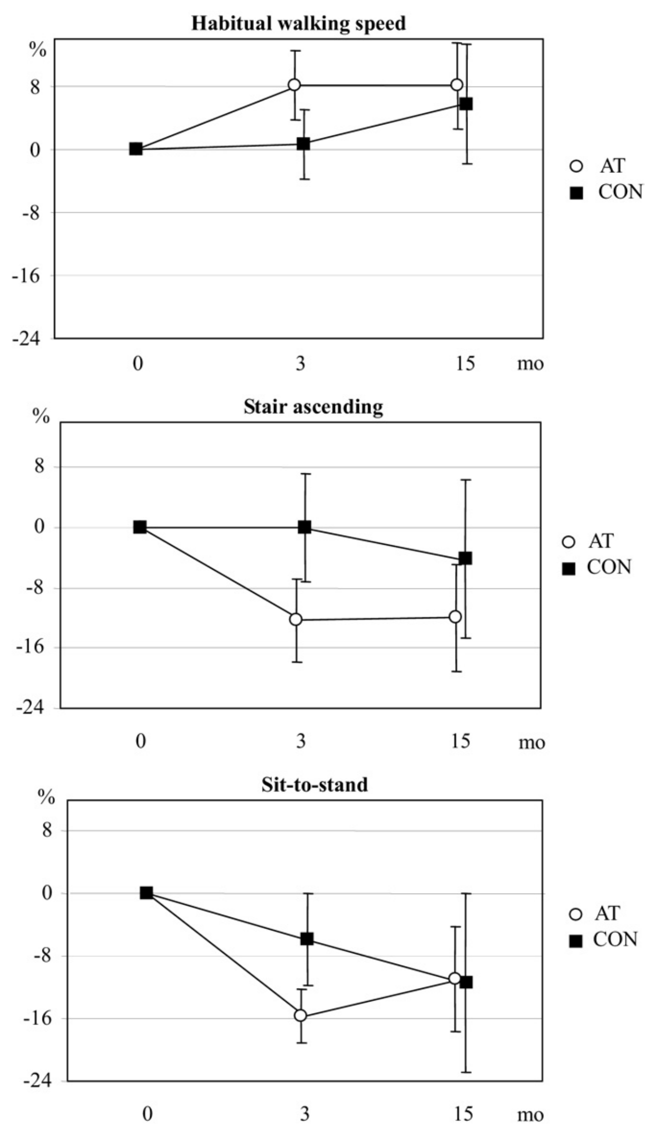

Fig 3. Mobility variables for the aquatic training and control groups: habitual walking speed, stair ascending, sit-to-stand. Percentage change (95% CIs) for the training and control groups after the intervention (3mo) and at 12-month follow-up (15mo=12mo after cessation of training). Abbreviations: AT, aquatic training group; CON, control group.

commenced in the acute recovery phase (<4wk) after surgery which was not the case in our study. In addition, a control group was not included in 1 study[11] or the training was conducted on dry land.[10] On the other hand, our findings are in line with the studies in persons with fibromyalgia, where the muscle strength was maintained after the detraining period but mobility was not.[19,23] We believe that these results may indicate that the mobility demands of daily living or the participants' habitual physical activity were not enough to maintain the training-induced changes in mobility. Indirectly, these results highlight that knee replacement patients should start rehabilitation immediately after surgery and as a regular part of the rehabilitation process to be encouraged to be physically active, because a sedentary life style increases the risk for health problems, which in turn reduces a person's functional ability. During our follow-up period, 3 persons had acute health problems and were not able to participate in the physical performance measurements. In addition, 3 participants had their nonoperated knee diagnosed and replaced during the follow-up period, which is common after knee replacement surgery.[24,25] This might also have influenced the maintenance of benefits in mobility.

Because it is challenging to persist in intensive supervised training endlessly to prevent mobility problems, periodical intensive training, as suggested by Karinkanta et al,[26] or physical activity counseling[27] would perhaps help people to maintain a good level of habitual physical activity. Aquatic training offers a suitable training environment for periods of intensive training. Water is a safe and effective environment. It reduces the compressive forces on joints while at the same time offers resistance to movements. Therefore, in water, it is possible to perform each repetition with maximal effort in a pain-free mode and achieve the highest possible movement velocity and thus resistance. In addition, a pain-free aquatic training environment may also encourage patients to move with high movement velocity in everyday life and thus maintain the training-induced benefits in muscle power.

Study Limitations

Our study had some limitations. Not all the participants attended the follow-up measurements, although compliance (84%) was nevertheless quite high. Unfortunately, we had only 1 follow-up measurement, which was conducted 12 months after cessation of training. For example, a follow-up measurement after 3 months would also have offered interesting data about maintenance of mobility. We performed multiple comparisons on this data, and it is possible that a study-wide type I error exists. We were not able to conduct complete blinding, which limits the strength of the conclusions. Finally, we were not able to do any subanalysis, whereby participants with confounding factors would be excluded, because of the small number of participants in this study.

This study has several strengths. First, this follow-up study evaluated the maintenance of the treatment effects of a randomized controlled trial after knee replacement surgery with only a few dropouts during the follow-up period. Second, the recruitment of the participants was population-based and the study group was homogeneous. Third, the maintenance of aquatic resistance training-induced benefits in persons with knee replacement was compared with that of a control group.

CONCLUSIONS

Aquatic resistance training-induced benefits in knee extensor and flexor power were maintained at 12-month follow-up in persons with knee replacement. However, 12 months seemed to be too long a period for the gains achieved in mobility to be maintained by regular physical activity alone.

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Suppliers

a. Biodex Medical Systems Inc, 20 Ramsay Rd, Shirley, NY 11967-4704.
b. Siemens Ag, Wittelsbacherplatz 2, D-80333 München, Germany.
c. Commit Ltd, PO Box 75, FI-02101 Espoo, Finland.
d. Newtest Oy, Koulukatu 31 B 11, FI-90100 Oulu, Finland.
e. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, Il 60606.