

ORIGINAL ARTICLE

Effects of Resistance Training on Lower-Extremity Impairments in Older People With Hip Fracture

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ABSTRACT. Portegijs E, Kallinen M, Rantanen T, Heinonen A, Sihvonen S, Alen M, Kiviranta I, Sipilä S. Effects of resistance training on lower-extremity impairments in older people with hip fracture. *Arch Phys Med Rehabil* 2008;89:1667-74.

Objective: To study the effects of resistance training on muscle strength parameters, mobility, and balance.

Design: Randomized controlled trial.

Setting: Research laboratory and senior gym.

Participants: Population-based sample of eligible 60- to 85-year-old community-dwelling men and women 0.5 to 7.0 years after hip fracture. Forty-six people had no contraindications and were willing to participate in the exercise trial.

Intervention: Twelve-week intensive progressive strength-power training (n=24), aiming to reduce asymmetric deficit in leg muscle strength and power, or no intervention (n=22).

Main Outcome Measures: Isometric knee extension torque (KET) and leg extension power (LEP) measured in the weaker and stronger leg and the asymmetric deficit ($[\text{weak/sum both legs}] \times 100\%$), 10-m walking speed, dynamic balance test, and self-reported outdoor mobility.

Results: KET increased in both legs ($P < .021$), LEP tended to increase in the weaker leg ($P = .071$), and asymmetric LEP deficit decreased ($P = .010$) after training compared with the control group. LEP of the stronger leg, asymmetric KET deficit, walking speed, and balance performance were not significantly affected by training. Self-reported ability to walk outdoors improved after training. The compliance to the training was over 90%, and few adverse events (n=4; mainly musculoskeletal) were likely to be caused by the training.

Conclusions: Intensive resistance training is feasible for people with a hip fracture and improved muscle strength and power. More intensive training especially for the weaker leg may be needed to obtain more marked effects on asymmetric deficit, mobility, and balance. Also, the timing and duration of training program should be considered. (ISRCTN identifier ISRCTN34271567.)

Key Words: Aged; Femoral fracture; Muscle; Rehabilitation.

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IN OLDER PEOPLE, HIP fracture is a common trauma associated with a high risk for death and disability.¹ Of those surviving 6 months past the fracture, less than half regain prefracture physical function.^{2,3} Among them, the muscle strength and power deficit on the fractured side typically impaired mobility more than the level of strength and power on the healthy side.^{4,5} A large asymmetric deficit in LEP (ie, a large difference between the stronger and weaker leg) may impair mobility and balance, even in people with no fracture history.⁶⁻⁸

In healthy older people, progressive resistance training is known to improve muscle strength and power.⁹⁻¹² These studies, however, did not include mobility function^{11,12} or failed to show significant changes in mobility.^{9,10} Studies including frail older people^{13,14} or persons with mobility limitations^{15,16} have shown reductions in mobility limitation by resistance training. Therefore, resistance training may be an efficient and cost-effective strategy to prevent and potentially reduce mobility limitation and loss of independence in older people at risk. Nevertheless, intensive progressive resistance training has not been studied extensively in clinical populations, such as hip fracture patients. Although muscle strength and physical function may improve when using bilateral exercises,¹⁷ training programs taking into account the persistent asymmetric strength deficit after hip fracture may be more effective.

We explored the feasibility and effects of intensive progressive strength-power training on muscle strength and power, mobility, and balance function in 60- to 85-year-old men and women 6 months to 7 years after hip fracture. The training program was designed to reduce asymmetric deficit and to increase the muscle strength and power of both legs.

METHODS

Study Design

This RCT is part of a larger study investigating health, functional ability, and rehabilitation of people with a hip frac-

List of Abbreviations

| | |
|-------|-----------------------------|
| ANOVA | analysis of variance |
| CI | confidence interval |
| COP | center of pressure |
| KET | knee extension torque |
| LEP | leg extension power |
| 1-RM | one repetition maximum |
| RCT | randomized controlled trial |
| ROM | range of motion |

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ture history. In this RCT, 1 group received strength-power training twice a week and was compared with a nontraining control group. Measurements were performed before (baseline) and after the 12-week intervention.

Participants

To avoid confounding the acute recovery effects, community-living 60- to 85-year-old men and women with a femoral neck or trochanteric fracture within 6 months to 7 years before baseline were invited to participate in the study. In 2004 and 2005, all 452 surviving patients with a hip fracture in the years 1998 to 2004 were identified by using the patient records of the Central Finland Central Hospital. Those willing to participate were interviewed by telephone ($n=132$). We excluded patients not living independently in the Central Finland Health Care District, those with neurologic and progressive severe illnesses, and those not able to walk outdoors without another person's assistance. Contraindications for participation in the exercise trial¹⁸ were evaluated in the clinical examination before the baseline laboratory assessments. The trial profile of the study is displayed in figure 1. Of the 25 men and 54 women participating in the baseline assessments, those without contraindications for participation in the trial were randomized into the training (8 men, 16 women) and control group (6 men, 16 women). The groups were randomized manually by drawing lots in blocks of sex and stratified by average age. In the control group, 1 participant dropped out for personal reasons and 1 participant because of dissatisfaction with the randomization outcome. In the training group, 1 participant dropped out for personal reasons, and another participant refused to participate in the training immediately after randomization because of changes in his personal life. However, he did participate in the posttrial measurements.

The trial was performed in 2 phases. To enlarge the initial sample size obtained in the year 2004, the study was repeated in the same season (August–December) of 2005 by using the exact same protocol, infrastructure, and staff. Only the recruitment area was enlarged in 2005. The study was approved by the Ethics Committee of Central Finland Health Care District,

and an informed consent form was signed before the baseline examinations.

Health Ascertainment

A physician and a research nurse performed a thorough clinical examination to assess general health status and to evaluate potential contraindications for safe participation in the measurements and strength training, according to the criteria of the American College of Sports Medicine.¹⁸ Additionally, the presence of chronic conditions and use of medication were established according to a questionnaire, current prescriptions, and medical records. The number of chronic diseases present for at least 3 months was calculated as an indicator of comorbidity.

Hip Fracture Status

Characteristics of the hip fracture and its operation were collected from medical records from the orthopedic department of the hospital. The causes of the hip fracture were falls on ground level (70%) or from a higher level (17%) or other causes, such as bike or car crashes (13%). The hip fracture was surgically fixed with osteosynthesis (54%) or arthroplasty (46%). In the training group, significantly more fractures were fixed by using arthroplasty (67%) than in the control group (23%) ($P=.007$).

The number of days between the date of hip fracture and August 1 of the year of measurements (2004 or 2005) was calculated and used as the variable for time elapsed since hip fracture. For 1 participant, the date of fracture was unknown; therefore, the date of surgery was used to calculate the time elapsed since fracture.

Participants were asked by means of a questionnaire to indicate the level of pain in the hip on the left and right side during the last week by using a visual analog scale (range, 0–100mm).

Muscle Strength and Power

Maximal voluntary isometric knee extension of both legs and handgrip strength of the dominant hand were assessed by using an adjustable dynamometer chair.^a In the knee extension strength assessment, the ankle was attached to a strain-gauge system with the knee angle fixed at 60° from full extension. Participants were encouraged to extend the leg as hard as possible. After 2 to 3 practice trials, measurements were performed at least 3 times until no further improvement occurred. Each contraction was maintained for 2 to 3 seconds. The intertrial rest period was 30 seconds. The performance of the highest maximal force was used for analysis. Three participants in the training group were unable to perform the knee extension strength measurements according to protocol because of pain ($n=1$) and poor cooperation ($n=2$). Handgrip strength was measured as an indicator for general strength.¹⁹ In the handgrip-strength assessment, the dynamometer was fixed to the arm of the chair with the elbow flexed in an angle of 90°. Participants were encouraged to squeeze the handle as hard as possible. The same protocol was used as for knee extension strength. The test-retest precision with a 2-week interval is $6\% \pm 7\%$ for handgrip strength and $6\% \pm 6\%$ for knee extension strength in our laboratory.¹⁹ In addition to the maximal force (in newtons), the maximal rate of force development over an interval of 10ms (in N/s) was recorded. Maximal KET (in Nm) was calculated by using the following formula: force (in newton) \times (chair lever arm [in meters] $\times \cos 30^\circ$) and used for analysis.¹⁰

LEP (in watts) was measured in both legs by using the Nottingham power rig.^{20,b} The seat position was adjusted for

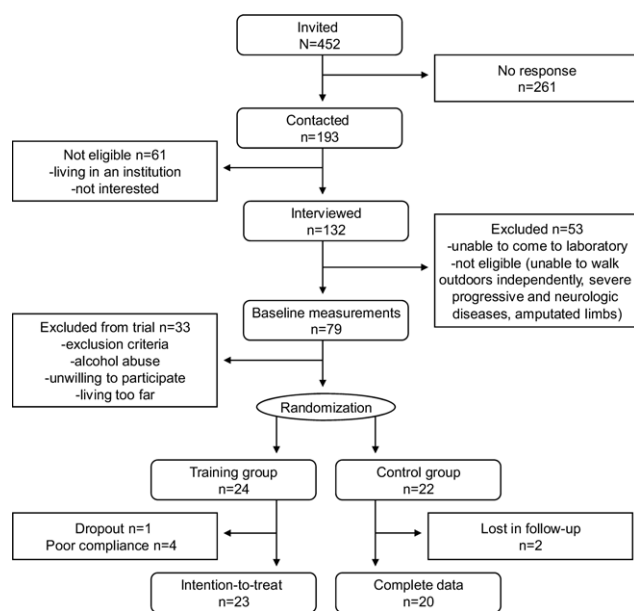


Fig 1. Flowchart of the study.

leg length. The participant was seated with the arms folded, and 1 foot was placed on the pedal attached to a flywheel while the other foot rested on the floor. After 2 to 3 practice trials, participants were asked to push the pedal as hard and fast as possible 5 to 10 times until no further improvement occurred. The intertrial rest period was at least 30 seconds. The best performance was used for analysis. Because of pain or limitations in joint ROM of the knee and hip joint in the sitting position suggested by the manufacturer,²⁰ 5 participants were allowed to sit with the back leaning backward on the backrest and 1 participant was seated on a cushion of 7cm in height. The same position was used for both legs in the baseline and posttrial measurements. Although LEP was slightly higher among those leaning backward, the sitting position did not affect the results of the asymmetric deficit or training effect. Despite this adjustment, 1 participant in the training and 1 in the control group were unable to perform the LEP measurements for 1 leg. Two participants in the training and 1 in the control group were unable to perform the LEP measurements adequately for both legs because of poor cooperation. The test-retest precision with a 1- to 2-week interval in our laboratory is $8\% \pm 7\%$.²¹

To avoid confounding by the order of measurements, every other participant was tested first on the fractured side in all bilateral measurements of strength and power at baseline and posttrial.

Weaker Leg for Training

By training the weaker leg more intensively, we aimed to reduce the muscle strength and power difference between the legs. For each participant, the weaker leg was defined based on maximal knee extension strength, maximal rate of force production, and maximal LEP. The weaker leg was defined as the leg that had lower values in at least 2 of the measures. A difference between the legs ($[\text{difference between legs}/\text{best result}] \times 100\%$) of less than 5% was not considered as meaningful because the variation between the best and second-best performance in the different muscle strength measures for each leg was about 4%. In participants (1 in the training group, 1 in the control group) measured in 1 leg only because of pain, the leg not measured was considered to be the weaker leg. In 3 participants of the training group, the results for the weaker leg were conflicting or unclear. For these participants, the 1-RM of the unilateral leg press exercise, estimated during the first training sessions, was used to ascertain the choice. The 1-RM was estimated from a 3- to 6-RM test by using a conversion table²² for the leg press, knee flexion, and hip abduction and adduction exercises trained by using pneumatic resistance equipment.^c To minimize the effects of fear for pain in the 1-RM assessments that could potentially result in lower training resistance, the stronger leg was always tested first. One participant in the training group had no asymmetric deficit at baseline.

Mobility Function

Time to walk 10m with habitual speed was assessed by using photocells.^d Participants were allowed to use their walking aid commonly used for walking indoors; 42 participants did not use any walking aid, 3 used a walking stick, and 1 participant used 1 crutch. Three meters was allowed for acceleration, and the test was stopped well past the finish line. The test-retest precision with a 1- to 2-week interval in our laboratory is 5%.¹⁰

Self-reported mobility was assessed by using a questionnaire. Participants were asked to rate their ability to walk a distance of 2km as follows: (1) no difficulty, (2) some

difficulty, (3) considerable difficulty, (4) impossible without the assistance of another person, or (5) impossible even with the assistance of another person. For the analyses, a dichotomous variable was created to differentiate those with (category 2–5) and without (category 1) difficulty performing the task. At posttrial, participants were additionally asked to rate the change in walking outdoors since baseline. The response categories were (1) improved, (2) no change, or (3) decreased.

Balance

Dynamic balance was tested by using the Good Balance computerized force platform system.^a Participants were asked to move their COP along a track shown on a computer screen.²³ The test was started from a well-balanced standing position with the COP in the middle. Weight was shifted 10 times between 2 marks on the left and right with a 9-m distance in between. The performance time (time used to complete the test) and the distance (the extent of the path traveled by the COP during the test) were measured. After 2 practice trials, the best of 3 repetitions (shortest performance time) was chosen for analysis. The test was performed with the participant in stocking feet, and the participant was allowed to sit for a rest between the trials. In our laboratory, the 1-week test-retest intraclass correlation coefficient of a similar but more difficult task was .72 (95% CI, .38–.87) for time and .81 (95% CI, .58–.91) for distance.²³

Anthropometry and Physical Activity

Body weight was measured in kilograms by using a beam scale with the participant wearing light indoor clothing. Height was measured with a scale stadiometer while the participant was standing in stocking feet. Height was measured to the nearest centimeter.

The level of physical activity was assessed by interview performed by using the Yale Physical Activity Questionnaire.²⁴ The questionnaire includes a physical activity dimension sum index, which is the summation of 5 weighted subindexes. Participants were asked how many times they performed vigorous physical activity (weight 5) and leisure walking (weight 4) during the past month and the duration of each physical activity session. The frequency, duration score, and the weight of the respective activity were multiplied. Additionally, participants were asked to estimate the duration of the time spent moving around (weight 3), standing (weight 2), and sitting (weight 1) on an average day in the past month. The duration scores were multiplied with the weight.

Intervention

The training group participated in a 12-week individually tailored training program that was organized twice a week (1–1.5h) in a senior gym and supervised by an experienced physiotherapist. The aim was to reduce asymmetric deficit and to increase strength and power of the lower-limb muscles. The weaker leg was trained first in every exercise, and more sets and repetitions and/or a higher resistance were used. The exact training protocol for both legs is displayed in table 1.

Each training session included both strength and power exercises and started with a 10-minute warm-up sitting on a chair. Pneumatic resistance equipment^c was used for the leg press, knee flexion, and hip abduction and adduction exercises. Exercises were performed with as large an ROM as possible with pain-free performance. The training equipment allowed for limiting the ROM individually for each leg. The ankle plantarflexion exercises, rising to the toes and returning the heel onto the ground, were performed with a weighted vest in

Table 1: Training Protocol for the Weaker Leg and Stronger Leg for the Strength and Power Exercises Performed With Resistance Equipment (Leg Press, Knee Flexion, and Hip Abduction and Adduction) or a Weighted Vest (Ankle Plantarflexion)

| Training Mode | Strength | | | | Power | | | |
|-----------------------------|-------------------------|--------------------|-------------------------|--------------------|-------------------------|--------------------|-------------------------|-----------------|
| | Weaker Leg | | Stronger Leg | | Weaker Leg | | Stronger Leg | |
| | Volume (set/repetition) | Resistance (%) | Volume (set/repetition) | Resistance (%) | Volume (set/repetition) | Resistance (%) | Volume (set/repetition) | Resistance (%) |
| Resistance equipment | | | | | | | | |
| First period* | 2/8 | 60–70 [‡] | 1/10 | 50–60 [‡] | 3/12 | 40 [‡] | 2/12 | 40 [‡] |
| Second period [†] | 2–3/8 | 70–80 [‡] | 1–2/10 | 60–70 [‡] | 3–4/12 | 40–50 [‡] | 2–3/12 | 40 [‡] |
| Weighted vest | | | | | | | | |
| First period* | 2/8 | 0 [§] | 1/10 | 0 [§] | 2/12 | 0 [§] | | |
| Second period [†] | 2–3/8 | 10–15 [§] | 1–2/10 | 10–15 [§] | 2–3/12 | 10 [§] | | |

*The period between the first and second 1-RM estimation.

[†]The period after second 1-RM estimation.

[‡]The percentage of 1-RM.

[§]The percentage of baseline body weight.

^{||}Both legs trained simultaneously.

front of a mirror while holding a handrail. In the strength exercise, the participant was standing on 1 leg. If necessary, the other foot was allowed to touch the floor for balance. In the power exercise, participants were standing on both legs for safety reasons.

The first 2 training sessions were used to familiarize the participants with the facility, equipment, and staff. The exercises were performed with very low loads, and correct movement technique was ensured. In the following sessions, the 1-RM was estimated (see Weaker Leg for Training section). The 1-RM assessments were repeated in weeks 6 to 8. The training intensity was increased progressively throughout the training period when tolerated. The intensity was adjusted individually, and the resistance was based on the latest 1-RM estimation.

In week 7, isometric strength and LEP measurements were repeated for the training group to check whether the asymmetric deficit still existed. Reversion of the LEP deficit had occurred in 6 participants, reversion of the strength deficit in 2 participants, and both deficits had been reverted in 1 participant. From week 9 onward, these participants trained the strength and/or power exercises similarly for both legs according to the protocol of the weaker leg (more intensive protocol). One participant had no deficit at baseline and, therefore, trained both legs similarly, according to the protocol of the weaker leg for the whole period.

A physician was consulted for all pain and other medical symptoms emerging during the training period. This was done to ascertain which of the symptoms were likely to be related to the training and whether they affected the training.

Power Training

The aim of this part of the training was to increase muscle power and movement velocity by a high-velocity regimen. Considering that this was a clinical population, relatively low resistance was used for safety reasons. Studies performed by using similar protocols with low resistance have shown improvements in muscle power,²⁵ mobility,²⁶ and balance function²⁷ in older people. The leg press and ankle plantarflexion power exercises were performed early in the training session in sets of 12 repetitions (see table 1), and the concentric phase of the contraction was performed as fast as possible. The leg press exercise for the weaker leg consisted of 3 to 4 sets and for the stronger leg of 2 to 3 sets with a resistance of 40% to 50% of 1-RM. The ankle plantarflexion exercise was performed standing on both legs in 2 to 3 sets by using a weighted vest with 0% to 10% of baseline body weight.

Strength Training

The aim of this part of the training was to increase muscle strength by using conventional strength-training protocols.^{10,12} Strength exercises were performed at a slower pace with fewer repetitions (weaker leg: 2–3 sets of 8 repetitions; stronger leg: 1–2 sets of 10 repetitions) and higher resistance (see table 1). Leg press, knee extension, and hip abduction and adduction exercises were performed with a resistance of 60% to 80% of 1-RM for the weaker leg and 50% to 70% of 1-RM for the stronger leg. From week 8 onward, the leg press–strength exercise was performed only once a week. The ankle plantarflexion strength exercise was performed standing on 1 leg with 0% to 15% of body weight; if necessary, the other foot was allowed to touch the floor for balance.

Control Group

The control group did not receive any intervention. Participants were encouraged to continue their lives as usual and maintain their prestudy level of physical activity during the 12-week trial.

Statistical Analysis

The data collected in the years 2004 and 2005 were pooled for analysis. Power calculations performed in advance indicated that a minimum of 30 subjects should be included in both study groups to detect significant changes in the main outcome measures (muscle strength, power, balance) at α equal to .05 and β equal to .20 (power, 80%). Despite the intensive recruitment, our design was slightly underpowered with 22 to 24 persons per group.

Based on the definition of the weaker leg, the asymmetric deficit for KET and LEP was calculated as follows: (weaker leg/sum both legs) \times 100%. The value 50% represents equal strength or power in both legs, indicating no asymmetric deficit. Lower values indicate poorer strength or power in the weaker leg. The relative change in KET, LEP, mobility, and balance measures between the pre- and posttrial measurements was calculated as ((post – pre)/pre) \times 100%. For the asymmetric KET and LEP deficit, the change during the intervention was calculated as post minus pre. The difference between the mean relative change in the training and control group (effect) was calculated as well as the 95% CI. The training compliance was calculated according to (number of sessions attended/number of session offered) \times 100%.

Statistical tests were first performed separately for men and women. Because the results were similar, the data were pooled

Table 2: Baseline Physical Characteristics of the Men and Women in the Training and Control Groups

| Characteristics | Training Group (n=24) | Control Group (n=22) | P (t test) |
|--------------------------------|--------------------------|-------------------------|---------------|
| Age (y) | 73.8±6.6 | 74.1±7.2 | .882 |
| Time since hip fracture (d) | 1587.7±736.2 | 1551.0±857.2 | .877 |
| Body weight (kg) | 71.1±11.0 | 72.5±12.0 | .671 |
| Body height (m) | 1.72±0.1 | 1.77±0.1 | .223 |
| No. of chronic diseases (n) | 2.8±1.4 | 2.3±1.4 | .180 |
| YPAQ sum index (p) | 41.1±20.1 | 44.0±20.2 | .632 |
| Handgrip strength (N) | 245.5±81.3 | 251.0±96.0 | .835 |
| Pain hip weaker leg (mm)* | 34.8±6.9 | 39.6±7.1 | .632 |
| Pain hip stronger leg (mm)* | 5.0±3.7 | 15.2±5.7 | .131 |

NOTE. Values are mean ± SD.

Abbreviation: YPAQ, Yale Physical Activity Questionnaire.

*Pain assessed with a visual analog scale.

to obtain a larger sample size. All reported results were derived from intention-to-treat analysis. The exclusion of those with poor compliance did not change the results significantly. Participants with missing variables in the muscle-strength and power tests were dropped from the respective analysis only.

Group differences in baseline characteristics were tested by using independent *t* tests or cross-tabulation with chi-square tests. To test differences in KET, LEP, and hip pain between the legs, paired-sample *t* tests were used. Means and 95% CIs of the main outcome variables between the training and control group were tested by using general linear univariate ANOVA adjusted for the year of participation. The adjustment was performed as a precaution to account for potential effects of factors such as group dynamics. Training effects were analyzed as group by time interaction derived from repeated-measures ANOVA adjusted for the year of participation. The self-reported change in mobility from pre- to posttrial was tested by using cross-tables with McNemar tests (within-group change) and chi-square tests (group difference).

SPSS software^e was used for statistical analysis, and statistical significance was set at *P* less than .050.

RESULTS

Baseline Characteristics

Table 2 displays physical characteristics of the training and control groups. Age, weight, time since fracture, number of chronic diseases, level of physical activity, handgrip strength, and pain in the hip of both legs did not differ between the groups.

Participants were on average 73.8 years old, and, on average, over 4 years had elapsed since the hip fracture. In both groups, the level of pain in the hip of the weaker leg was significantly (*P* < .009) higher than in the stronger leg at baseline.

Compliance and Feasibility

During the training period, short-term adjustments for load or training frequency were made in 6 participants after consultation with the physician; in 2 cases, musculoskeletal problems and in 1 case chest pain were likely to be related to the training. Additionally, 1 participant developed prolonged radicular pain in the lower limb after the training period. In 2 participants, poor compliance to the training (based on the number of sessions attended) was caused by health-related problems that were present before the start of the trial and in 1 participant because of an unrelated wrist fracture. The training compliance was excellent, being on average 91%±15%. Without the 3 participants with rather poor compliance (48%–72%), the training compliance was on average 97%±3%.

Muscle Strength and Power

In 83% of participants, the fractured leg was the weaker leg. Sixty-one percent of participants had a clear and consistent deficit in all laboratory strength and power tests. At baseline, the weaker leg had on average significantly (*P* < .004) poorer KET and LEP than the stronger leg in both groups (table 3).

At baseline, there were no significant differences between the training and control group in mean KET and LEP (see table 3) or the asymmetric KET (*P* = .959) and LEP (*P* = .672) deficit. Figure 2 shows that in the training group, the weaker leg provided on average 46% (95% CI, 43%–48%) of the summed KET of both legs. In the control group, the asymmetric KET deficit was on average 44% (95% CI, 41%–47%). The LEP deficit was on average 45% (95% CI, 43%–47%) and 45% (95% CI, 42%–47%) in the training and control group, respectively.

After the trial, the mean gain of KET in the weaker leg (effect, 17%; 95% CI, –2% to 38%) and in the stronger leg (effect, 15%; 95% CI, 5%–25%) was significantly greater in the training group compared with the control group (group by time interaction, *P* = .021, *P* = .004, respectively) (see table 3). However, the training did not affect the asymmetric KET deficit (effect, 0%; 95% CI, –2% to 3%) (see fig 2A). The mean gain in LEP in the weaker leg (effect, 11%; 95% CI, 0%–23%) tended to be greater in the training group compared with the control group (group by time interaction, *P* = .071) (see table 3). The training did not affect LEP in the stronger leg (effect, –3%; 95% CI, –18% to 11%). The mean reduction in asymmetric LEP deficit (effect, 4%; 95% CI, 1%–7%) was

Table 3: Baseline Group Differences in the Main Outcome Variables and the Effects of Training, for the Continuous Variables

| Continuous Variables | Baseline | | | | Posttrial | | Baseline* | Interaction† |
|-----------------------|----------|---------------------|----|---------------------|-----------|---------------------|-----------|--------------|
| | n | Mean (95% CI) | n | Mean (95% CI) | n | Mean (95% CI) | P | P |
| Walking speed (m/s) | 24 | 1.1 (1.0–1.2) | 22 | 1.1 (0.9–1.2) | 23 | 1.2 (1.1–1.3) | | |
| Time balance (s) | 24 | 12.0 (10.4–13.6) | 21 | 10.7 (9.0–12.4) | 21 | 10.7 (9.2–12.2) | .270 | .516 |
| Distance balance (cm) | 24 | 182.0 (168.0–196.0) | 21 | 177.0 (162.0–192.0) | 21 | 173.4 (158.0–189.0) | .622 | .996 |
| KET weaker (Nm) | 21 | 38.3 (30.0–46.6) | 22 | 37.6 (29.5–45.7) | 20 | 42.7 (35.4–50.0) | .902 | .021 |
| KET stronger (Nm) | 21 | 47.4 (38.4–56.3) | 22 | 45.4 (36.7–54.1) | 20 | 50.0 (41.1–58.8) | .757 | .004 |
| LEP weaker (W) | 21 | 91.6 (74.2–109.0) | 20 | 82.0 (64.2–99.9) | 20 | 106.6 (85.9–127.4) | .442 | .071 |
| LEP stronger (W) | 22 | 113.4 (89.6–137.1) | 21 | 99.7 (75.4–124.0) | 21 | 123.9 (99.0–148.9) | .420 | .987 |

NOTE. Values are n or mean and 95% CI.

*Baseline comparison; general linear univariate ANOVA, adjusted for the year of participation.

†Group by time interaction derived from repeated-measures ANOVA, adjusted for the year of participation.

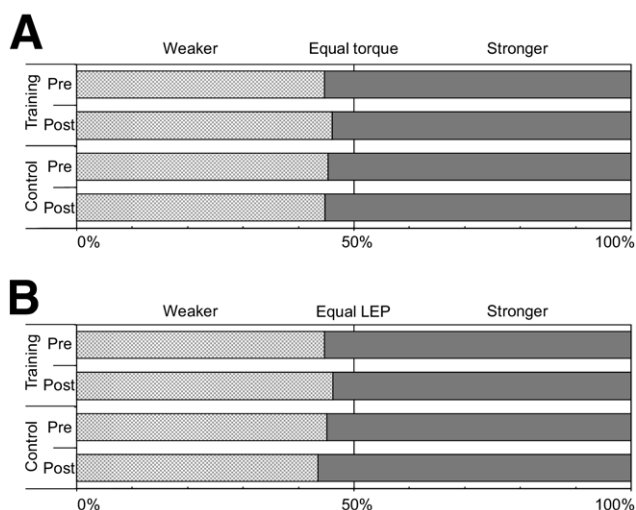


Fig 2. Baseline and post-trial asymmetric deficit in (A) KET (interaction $P=.763$) and (B) LEP (group by time interaction, $P=.010$) in the training and control group.

significantly greater in the training group compared with the control group (group by time interaction, $P=.010$) (see fig 2B).

Mobility and Balance

Baseline walking speed and the time and distance in the dynamic balance test did not differ between the groups (see table 3). When comparing the changes in the training and control group over time, habitual walking speed (effect, -2% ; 95% CI, -12% to 8%) and the distance (effect, 3% ; 95% CI, -10% to 17%) in the dynamic balance test were not affected by training. The time (effect, -9% ; 95% CI, 27% – 8.5%) in the dynamic balance test improved more in the training group compared with the control group, although not significantly (group by time interaction, $P=.516$).

At baseline, difficulties in walking 2km were reported equally in the training and control group (65%) (table 4). In the training group, of the 15 participants reporting difficulties in walking 2km at baseline, 5 reported no difficulties at post-trial (McNemar, $P=.063$). In the control group, only 1 participant reported a corresponding change. When asked directly about the experienced change, an improvement in outdoor mobility was reported by 10 participants of the training group compared

with 1 participant in the control group; a decrease was reported by 2 and 3 participants, respectively (χ^2 , $P=.016$).

DISCUSSION

This study shows that intensive progressive resistance training is feasible for hip fracture patients because they were able to perform the training protocol with high compliance. Muscle strength and power increased by the training, especially in the weaker leg. The effects on the asymmetric deficit and performance-based mobility and balance were less clear. Self-reported difficulties in outdoor mobility tended to decrease by training.

In many studies, resistance training increased muscle strength and power in older adults.⁹⁻¹⁶ Some strength-training studies in clinical populations failed to show improvements because of rather low training resistance^{28,29} or they did not take into account the asymmetric strength and power deficit.¹⁷ In patients rehabilitating from hip replacement surgery for hip osteoarthritis, it was shown that asymmetric deficit in strength can be reverted only with the addition of unilateral strength training to the standard rehabilitation protocol.³⁰ However, training 1 leg only is impossible in the long-term. Increasing muscle strength in both legs, while reducing the asymmetric deficit, may be more effective. In 2 studies in patients with severe injurious falls³¹ or hip fracture,³² muscle strength and functional performance improved and the asymmetric deficit also seemed to decrease after unilateral training of both legs. However, the authors did not report significance of the reduction in asymmetric deficit. In our study, only the asymmetric LEP deficit decreased significantly. A larger distinction in training loads for the stronger and weaker leg may be needed. It should also be considered that in the weaker and more painful leg, maximal strength is likely to be underestimated,^{33,34} resulting in close to equal training loads for the weaker and stronger leg. Thus, the training resistance may have been relatively low for the weaker leg especially. Nevertheless, muscle strength and power of the weaker leg increased significantly. In this context, a potential cross-training effect commonly seen after unilateral training of the lower limbs should also be considered.

Muscle strength and especially muscle power have been associated with mobility and balance function.^{21,35-37} However, mobility and balance were not clearly affected by training in this and other studies.^{9,10} This may be at least partly related to the relatively good health and well functioning of our participants, despite the hip fracture. The exercises of the training were mainly performed in a sitting position and, therefore, did not challenge balance. Using balance specific exercises^{23,38} or

Table 4: Baseline Group Differences in the Main Outcome Variables and the Effects of Training for the Categorical Variables

| Categorical Variables | Baseline | | Post-trial | | P |
|----------------------------|----------------|---------------|----------------|---------------|--------|
| | Training Group | Control Group | Training Group | Control Group | |
| Ability to walk 2km | | | | | |
| Without difficulty | 8 (35) | 7 (35) | 13 (57) | 8 (40) | 1.000* |
| Difficulties | 15 (65) | 13 (65) | 10 (43) | 12 (60) | 0.063† |
| | | | | | 1.000‡ |
| Change in walking outdoors | | | | | |
| Improved | | | 10 (43) | 1 (5) | 0.016§ |
| No change | | | 11 (48) | 16 (80) | |
| Reduced | | | 2 (9) | 3 (15) | |

NOTE. Values are n (%).

*Baseline group comparison (χ^2 test).

†Difference between baseline and post-trial within training group (McNemar test).

‡Difference between baseline and post-trial within control group (McNemar test).

§Group comparison (χ^2 test).

functional exercises^{31,39} may be more effective to improve balance and mobility. On the other hand, resistance training is safe to perform in a sitting position, especially for hip fracture patients that often have impaired balance.^{40,41} Additionally, improvements in balance have been found after high-velocity resistance training.²⁷ Our hypothesis was that an asymmetric deficit in muscle strength and power may complicate the transfer of weight from 1 leg to the other, which is important in walking. Additionally, lateral balance is a predictor for falls to the side that may cause hip fracture.⁴² Hip abductor and adductor muscles, which were trained in this study, play an important role in lateral balance control. However, potentially, adaptation of the distance between the feet (width of the base of support) may have partly masked changes in balance function because the width was not standardized. Increased confidence may prompt a position with a smaller base of support, generating more challenges for balance control. The improvement in dynamic balance assessing lateral balance in the training group, although not significant, may be functionally relevant in reducing the risk for falls. Potentially, the improvement may indirectly indicate an increase in muscle strength of the hip abductor and adductor muscles, which were not measured directly.

The relationship of muscle strength and power with mobility and balance is curvilinear.³⁵ Improvements in strength and power may lead to concurrent improvements in mobility and balance in mobility-limited or frail older adults but not necessarily in relatively well-functioning people.²¹ Our study population may have consisted of rather well-functioning people, despite the hip fracture, because of exclusion of those not living independently or unable to walk outdoors independently. However, factors other than muscle strength and power such as insecure walking (fear of falling)⁴³ and pain^{5,33,34} may play an important role in walking especially.

Self-reported difficulties in different mobility tasks have been used as a proxy for preclinical disability.^{44,45} In this study, the training reduced the proportion of people reporting difficulties in walking 2km. In addition, outdoor mobility improved more in the training group. Also, in other studies including mobility-limited or frail older people, similar improvements have been reported after training.¹⁶ These are important findings with respect to living independently in the community.

Intensive training, especially in clinical populations, requires careful supervision and individualized protocols. Participation in exercise programs should be preceded by medical screening for contraindications.¹⁸ Pain and medical conditions in the legs especially should be taken into account. Therefore, resistance used in the training needs to be adjusted individually. The ROM of the knee and hip joints may be limited, especially in people with joint replacements, knee osteoarthritis, or hip fracture. When these issues are considered, resistance training is generally well tolerated and feasible for a population with a history of hip fracture. This has also been shown in previous studies in recent hip fracture patients.^{17,32}

Study Limitations

The study was slightly underpowered, which may partly explain the nonsignificant changes in walking and dynamic balance. Importantly, the change in muscle strength and power was significant. Especially considering the large heterogeneity of clinical populations³ such as this, a larger sample size and longer duration of the training program may show more clear training effects. Measuring maximal performance in clinical populations is rather challenging because of pain and fear for pain.^{5,33} Therefore, maximal muscle strength and power may have been underestimated in this study. Also, the change in

strength and power by training may have been underestimated because of different methods used in the laboratory assessments and the training. The fractured leg was not always the weaker leg because of potential influences of other diseases and injuries affecting 1 leg since the hip fracture. The training, specifically aiming to reduce asymmetric deficit, may thus be more effective when targeted to a population with a clear and consistent deficit, such as in the rehabilitation phase after disease or injury affecting 1 leg only.

CONCLUSIONS

Intensive and progressive strength-power training is feasible in people with a history of hip fracture. The training generally improved the muscle strength and power of both legs. However, people may be more responsive in the rehabilitation phase after major injury when the asymmetric deficit is likely to be large. To effectively reduce the asymmetric deficit, a more marked distinction in protocol for the stronger and weaker leg may be needed; also, pain and pain management after hip fracture need to be considered. To improve mobility and balance function, other issues such as fear of falling and training specificity also need to be taken into account.

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