Investigation of Clinical Effects of High- and Low-Resistance Training for Patients With Knee Osteoarthritis: A Randomized Controlled Trial

Mei-Hwa Jan, Jiu-Jeng Lin, Jiann-Jong Liau, Yeong-Fwu Lin, Da-Hon Lin

Background and Purpose

Muscle strength training is important for people with knee osteoarthritis (OA). High-resistance exercise has been demonstrated to be more beneficial than low-resistance exercise for young subjects. The purpose of this study was to compare the effects of high- and low-resistance strength training in elderly subjects with knee OA.

Subjects and Methods

One hundred two subjects were randomly assigned to groups that received 8 weeks of high-resistance exercise (HR group), 8 weeks of low-resistance exercise (LR group), or no exercise (control group). Pain, function, walking time, and muscle torque were examined before and after intervention.

Results

Significant improvement for all measures was observed in both exercise groups. There was no significant difference in any measures between HR and LR groups. However, based on effect size between exercise and control groups, the HR group improved more than the LR group.

Discussion and Conclusion

Both high- and low-resistance strength training significantly improved clinical effects in this study. The effects of high-resistance strength training appear to be larger than those of low-resistance strength training for people with mild to moderate knee OA, although the differences between the HR and LR groups were not statistically significant.

MH Jan, PT, MS, is Associate Professor, Medical College, School and Graduate Institute of Physical Therapy, National Taiwan University, and Department of Physical Medicine and Rehabilitation, National Taiwan University Hospital.

JJ Lin, PT, PhD, is Associate Professor, Medical College, School and Graduate Institute of Physical Therapy, National Taiwan University.

JJ Liau, PhD, is Associate Professor, Medical College, School and Graduate Institute of Physical Therapy, National Taiwan University.

YF Lin, MD, PhD, is Chairman, Department of Orthopaedics, West Garden Hospital.

DH Lin, MD, is Attending Doctor, Department of Orthopaedic Surgery, En Chu Kong Hospital, Taipei Hsien, Taiwan, Republic of China. Address all correspondence to Dr Lin at: david1120698@yahoo.com.tw.

[Jan MH, Lin JJ, Liau JJ, et al. Investigation of clinical effects of high- and low-resistance training for patients with knee osteoarthritis: a randomized controlled trial. *Phys Ther*. 2008;88:427–436.]

Knee osteoarthritis (OA) is a common musculoskeletal disorder, the prevalence of which increases with age.[1,2] Individuals with knee OA typically have knee pain, joint stiffness, deficits in proprioception, and decreased muscle strength (force-generating capacity).[3,4] Quadriceps femoris muscle weakness has been demonstrated to correlate with knee pain and functional disability.[5-7] For instance, Steultjens and colleagues[7] reported that decreased quadriceps femoris muscle strength accounted for 15% to 20% of lower-extremity functional disability and for 5% of the knee pain associated with OA. Therefore, one aim of physical therapy intervention for patients with OA is to increase the strength of the musculature surrounding the knee joint.

Although numerous researchers[2,8-10] have reported that muscle strength training leads to increased range of motion, muscle strength, and functional ability for patients with knee OA, many unanswered questions still exist regarding the optimal exercise regimen. Issues relating to optimal intensity (training weight) and volume (relates to the number of sets as well as the number of repetitions) need to be further explored to find the ideal form of therapeutic exercise to elicit the greatest functional improvement for patients with knee OA.[11,12] Kryger and Andersen[12] demonstrated that, after 12 weeks of heavy resistance training (80% of 1 repetition maximum [RM]), elderly subjects increased their isometric knee extensor strength by 37%, their isokinetic knee extensor strength by 41% to 47%, and their lean quadriceps femoris muscle cross-sectional area by 9.8%. Folland and Williams,[13] after reviewing various articles, concluded that the gains in strength with high-resistance strength training are undoubtedly due to a combination of neurological and morphological factors. Although the neurological factors may make their greatest contribution during the early stages of a training program, so do hypertrophic processes. Furthermore, there is accumulating evidence that low-intensity training programs can be effective in increasing neuromuscular performance in elderly subjects.[14-16] Many researchers have reported that various forms of low-resistance exercise (eg, walking, stepping)[17-20] could increase muscle strength through neuromuscular mechanisms.[18,20]

Some authors[9,21] have reported the clinical effectiveness of muscle strengthening exercises in patients with knee OA and have suggested that the exercise should not include high joint load. If the knee joint is overloaded, patients with knee OA may aggravate symptoms such as pain, swelling, and inflammation.[22,23] However, other authors[24-26] have declared that strength training of a vigorous intensity (50%–80% of 1 RM) does not appear to induce or exacerbate joint symptoms in older adults. Thus, at the present time, it is not clear what level of strength training weight or resistance is optimal to facilitate symptomatic improvement or functional gains in individuals with knee OA.

The purpose of this study was to investigate differences in knee pain and functional scores, walking time, and knee muscle torque following high- and low-resistance strength training and no exercise. We hypothesized that subjects who received either high- or low-resistance strength training would exhibit greater functional improvement compared with subjects who received no exercise.

Method

Subjects

Subjects were recruited from the Department of Orthopedics, National Taiwan University Hospital, from January 2004 to June 2005. Osteoarthritis was diagnosed on the basis of clinical history, radiographic changes, and physical examination of the patient by an orthopedic surgeon (YL). By the time patients enrolled in the study, they had bilateral knee pain that fulfilled the American College of Rheumatology criteria for knee OA.[27] The American College of Rheumatology classification system is 91% sensitive and 86% specific for a diagnosis of knee OA if a person has knee pain and osteophytes confirmed by radiography with the following 3 conditions: experiencing stiffness for less than 30 minutes in the morning, having crepitus, and being older than 50 years of age.[27] Additional inclusion criteria were: (1) an OA grade of 3 or lower on the Kellgren/Lawrence classification based on plain radiographs,[28] as assessed by the same orthopedic surgeon (YL), who had more than 30 years of clinical experience, and (2) a history of knee pain longer than 6 months (chronic knee OA). To account for the effects of medication, subjects did not take nonsteroidal anti-inflammatory drugs during their participation in the study. Patients were excluded if they had received knee physical therapy during the preceding 3 months or had other musculoskeletal problems associated with the knee joint (such as tendon or ligament tears), central or peripheral neuropathy, or other unstable medical conditions.

A sample size of 28 subjects per group provided 80% power to detect a clinically meaningful difference in muscle strength of 10 N·m (SD=15) with a pair-wise comparison among 3 groups at an alpha level of .05 (2-tailed test). The cutoff of 10 N·m for clinically significant effect was determined in a previous study.[20] In addition, in anticipation of a dropout rate of 10%, we enrolled at least 31 participants in each group.

One hundred two subjects participated in this study. After giving in-

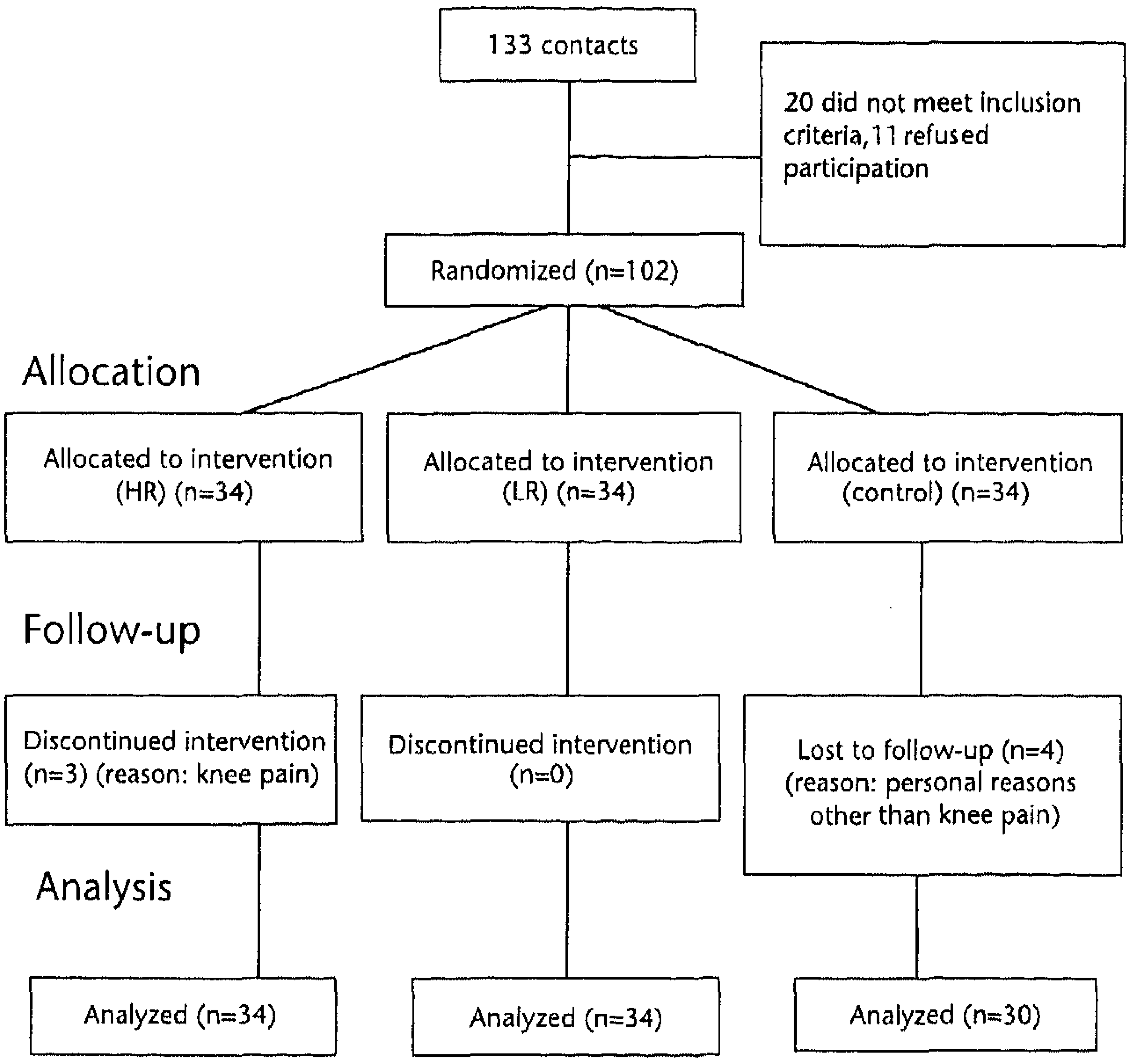

Figure.
CONSORT flow diagram showing the flow of participants through each stage of the randomized controlled trial. HR=high-resistance exercise group, LR=low-resistance exercise group.

formed consent, the subjects were randomly assigned to 1 of 3 groups using a randomization number table from a random integer generator: a group that received high-resistance exercise (HR group), a group that received low-resistance exercise (LR group), and a group that received no exercise (control group). During follow-up, 3 subjects in the HR group discontinued the training program due to knee pain with the exercise. Four subjects in the control group did not complete the follow-up assessment for personal reasons other than knee pain. Thirty subjects in the control group, 34 subjects in the HR group, and 34 subjects in LR group completed the study (Figure).

Intervention

Training weight. According to the criteria defined by Beneka et al[29] for elderly people, 50% and 90% of 1 RM should be attained for low- and high-resistance strength training, respectively. However, in an unpublished pilot study (N=10), we found that 7 subjects with Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)[30] pain scores of ≥5 were not able to tolerate a training weight of 80% of 1 RM. After several trials, 60% of 1 RM was designated as the initial intensity for high-resistance strength training (about 45–50 kg). In order to observe a greater clinically meaningful difference between high- and low-resistance exercises, the initial low-resistance training intensity was set at 10% of 1 RM (about 7–10 kg). For the purpose of accomplishing a similar total volume of training (resistance × repetitions × sets), the high-resistance exercise (60% of 1 RM) consisted of 8 repetitions × 3 sets (training volume per session=1 RM × 0.6 × 24=14.4 × 1 RM), and the low-resistance exercise (10% of 1 RM) consisted of 15 repetitions × 10 sets (training volume per session=1 RM × 0.1 × 150=15 × 1 RM).

Exercise procedure. Before resistance training, the EN-Dynamic Track leg press machine* (Enraf-Nonius BV, Netherlands) was used to measure 1-RM unilateral strength in the lower extremity. The testing resistance was set at 0.5 to 0.6 times body weight. A single set of repetition-to-fatigue test was performed. All subjects were encouraged to perform as many unilateral leg press repetitions as possible until they could not press or failed to complete a full range of motion again. Finally, the resistance load and the number of repetitions of each subject were recorded to estimate the unilateral 1-RM value using Odvar Holten Pyramid diagram[31] provided by the software of the EN-Dynamic Track machine. Subjects performed knee resistance training in a sitting position, with one foot placed on the center of the pedal of the EN-Dynamic Track machine. Subjects were asked to fully extend and flex their knee joint from 90 degrees of knee flexion. Each action was completed rhythmically, with the first second spent extending the knee and the following second spent flexing the knee.

The subjects in both exercise groups underwent 3 training sessions per week for 8 weeks in our kinesiology laboratory. The program was delivered individually to the subjects and supervised by an experienced

* Enraf-Nonius, Röntgenweg 1/PO Box 810, 2600 AV Delft, the Netherlands.

therapist. Every 2 weeks, 1 RM was retested, and the training weight for both groups was progressively increased by 5% of the new 1 RM, as tolerated. Subjects rested for 1 minute between sets. Both legs were trained, with a 5-minute interval between left and right knee sessions. Subjects in the control group did not receive any intervention. All subjects assigned to an exercise group used an exercise bicycle for 10 minutes as a warm-up before undertaking resistance training. Cold packs were applied to subjects' knees for 10 minutes after exercise completion. An exercise session took approximately 30 minutes in the HR group and 50 minutes in the LR group. All subjects were asked to cease any exercise activity outside of the exercise training.

Measurements

Pain and physical function scores. Pain was assessed for 5 activities (walking on level ground, walking up and down stairs, sleeping, sitting, and standing) using the WOMAC pain scale,[30] with a maximum score of 20 points. For each of these actions, pain was scored between 0 and 4, with 4 indicating great pain and 0 indicating no pain. The function of bilaterally affected knees was assessed by the physical function subscale of the WOMAC. The capacity of individuals to perform a variety of tasks was scored between 0 and 4, with 4 indicating great difficulty and 0 indicating no difficulty. A total of 17 tasks were included, such as walking up and down stairs, standing up, bathing, and general housework. Thus, the maximum overall score, which indicates severe disability, was 68 points.

Walking time over 4 different terrains. Subjects were required to complete 3 tasks as rapidly as possible: (1) walking on a 60-m-long, level-ground hard surface (a corridor); (2) walking along a figure-eight pattern consisting of 2 circles (each with a 50-cm radius); and (3) walking up and down 13 steps on a staircase (each step was 16 cm high, 30 cm long, and 80 cm wide). In addition, subjects were asked to walk at a comfortable pace along a 12-m-long spongy surface measuring 10 cm in thickness and 21 Shore 000 in hardness (medium hard). All walking trials were recorded using a Casio HS-20 stopwatch,[†] which is accurate to 0.01 of a second. Intersession intrarater walking time reliability was examined in an unpublished preliminary study of 10 young subjects who were healthy, taking 2 trials for each terrain. The intraclass correlation coefficients (3,2) were .80, .81, .76, and .82 for the ground-level, stair-climbing, figure-eight, and spongy-surface tasks, respectively. Additionally, the standard error of measurement (SEM) for these tasks was 2.2, 2.1, 1.0, and 1.1 seconds, respectively.

Measurement of knee extensor and flexor torque. Muscle torque of the bilateral knee extensors and flexors was tested at 60°, 120°, and 180°/s using a Cybex 6000 isokinetic dynamometer.[‡] Subjects were placed in a sitting position against a backrest inclined 15 degrees backward from vertical and were secured to the machine at the upper chest, pelvis, and distal femur on the tested side. The subjects were instructed to extend their knee as far as possible and then to flex as far as the device allowed. The between-sessions (1-week interval) intrarater reliability of muscle torque measurement was examined by using the intraclass correlation coefficient, and the values were found to range from .83 to .88 for the 3 muscle velocity contractions in both the extensor and flexor muscles. The SEMs ranged from 4.7 to 8.4 N·m.

[†] Casio Computer Company Ltd, 6-2, Hon-machi 1-chrome, Shibuya-ku, Tokyo, Japan.
[‡] Cybex International Inc, 10 Trotter Dr, Medway, MA 02053.

Procedure

Prior to randomization, all subjects were given health education on knee OA, including weight reduction, joint protection, and appropriate behavior changes to enhance functional outcome, and an explanation of methods that may relieve pain, preserve mobility, adjust to the environment to accommodate functional deficits, and manage their discomfort at home. All subjects underwent an initial baseline assessment of WOMAC pain and physical function subscale scores, walking time on 4 different terrains, and muscle torque of the knee joint in sequence. Two trials were undertaken for each walking task, and muscle torque trials were repeated 3 times. The mean of the 2 walking trials was used for final assessment of each walking task. The highest values for each muscle torque trial at each speed were recorded as peak torque. Routine calibration of the Cybex machine was performed prior to the testing of each subject. Data were corrected for gravity. All participants were subjected to identical follow-up assessment within 3 days after completing the intervention. Either leg of each subject received the strength training alternately. The measurements of muscle torque included both legs in the analysis of between-groups differences because walking speed was the concomitant effort of both legs and the sampling of one limb for one person might not simulate the independent variable appropriately. This study had a single-blind randomized controlled trial design, and all evaluations were performed by the same examiner, who was unaware of the subjects' group assignments.

Data Analysis

The distribution of subjects by sex and the OA grades based on radio-

Table 1.
Subject Demographic Data[a]

Variable	HR Group (n=34)	LR Group (n=34)	Control Group (n=30)
Age (y)	63.3±6.6	61.8±7.1	62.8±6.3
Sex (female:male)	27:7	27:7	25:5
Height (cm)	161.8±7.8	161.9±7.2	160.4±7.6
Weight (kg)	63.1±10.5	62.8±10.2	61.9±10.8
Onset of knee OA duration (y)	3.3±2.8	2.8±2.2	3.5±3.3
X-ray grade, no. of knees			
I	8	9	7
II	43	43	40
III	17	16	13

[a] Data for height, weight, and onset of disease duration are presented as mean±SD. HR=high-resistance strength training, LR=low-resistance strength training, control=no exercise, OA=osteoarthritis.

graphs among the 3 groups were compared using the chi-square test. Baseline values for pain, function, walking time on 4 different terrains, and muscle torque of the knee were compared among groups using a one-way analysis of variance (ANOVA). A 3 × 2 two-way ANOVA was used to compare the effects of group (HR, LR, control) and timing (preintervention and postintervention). When interactions were detected, a *post hoc* analysis with Bonferroni adjustment was performed. Data were subjected to an intention-to-treat analysis and included all dropouts. Differences were considered to be significant when $P<.05$ (ANOVA) or $P<.008$ (multiple comparisons).

Results

The demographics for the 3 study groups are presented in Table 1. There was no significant difference among the 3 groups on any variables at baseline. In the HR group, 3 subjects could not continue the study due to knee pain during the exercise. In addition, 3 subjects could not tolerate resistance training beyond 70% of 1 RM.

The WOMAC pain and physical function subscale scores and walking times on 4 different terrains for the 3 groups before and after the 8-week period are presented in Table 2. The large effect sizes for those variables ranged from 0.82 to 2.42, except for walking time for level ground and on stairs in the HR and LR groups. Walking time on a spongy surface demonstrated the strongest effect sizes (2.42 and 2.08 in the HR and LR groups, respectively). The walking times on level ground and on stairs had medium effect sizes, ranging from 0.43 to 0.72. No changes were found in the control group. The minimal detectable changes with a 90% confidence interval (MDC_{90}) for pain and physical function scores were 2.73 and 6.48, respectively, in the HR group and 2.21 and 6.37, respectively, in the LR group. The MDC_{90} for walking time on level ground, on stairs, in a figure-eight pattern, and

Table 2.
Preintervention and Postintervention Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Pain and Physical Function Subscale Scores and Walking Time Over 4 Different Terrains by Treatment Group[a]

Variable	HR Group		LR Group		Control Group	
	Preintervention	Postintervention	Preintervention	Postintervention	Preintervention	Postintervention
WOMAC pain subscale	8.5±3.8	4.8±3.5*,†	7.8±3.3	4.8±2.7*,‡	8.3±4.6	7.1±3.4
WOMAC physical function subscale	26.4±9.0	14.7±8.5*,†	26.1±8.1	14.8±9.2*,‡	25.4±11.3	22.5±10.9
Walking time (s)						
Level ground	38.6±6.2	35.5±5.3*	37.5±4.9	33.9±5.1*	38.4±7.5	38.0±6.8
Stairs	15.9±5.4	13.5±4.4*	16.2±5.1	14.2±4.1*	15.9±5.5	14.5±4.2
Figure-eight pattern	11.0±2.3	6.1±2.0*,†	10.9±2.7	6.8±1.4*,‡	10.8±1.8	12.1±1.8
Spongy surface	12.6±2.7	6.3±2.5*,†	12.5±3.6	7.3±1.4*,‡	11.8±3.0	12.5±3.2

[a] Data are presented as mean±SD. Asterisk (*) denotes within-group difference was significant ($P<.05$), dagger (†) denotes significant postintervention difference between HR and control groups ($P<.008$), double dagger (‡) denotes significant postintervention difference between LR and control groups ($P<.008$).

Table 3.
Preintervention and Postintervention Isokinetic Peak Knee Extension and Flexion Torque (in Newton-meters) by Treatment Group[a]

Variable	HR Group		LR Group		Control Group	
	Preintervention	Postintervention	Preintervention	Postintervention	Preintervention	Postintervention
Extensor						
60°/s	71.4±17.6	88.1±21.6*,†	75.2±18.6	86.7±24.2*,‡	73.2±21.3	72.7±22.3
120°/s	58.7±15.6	70.9±21.0*,†	60.4±17.7	70.5±20.6*,‡	60.3±20.6	61.2±21.9
180°/s	45.6±8.8	56.7±19.9*,†	48.8±11.3	58.8±21.0*,‡	46.1±19.9	46.9±19.3
Flexor						
60°/s	43.0±18.4	57.4±18.9*,†	47.5±10.1	61.7±20.1*,‡	41.3±20.5	42.5±20.8
120°/s	38.1±15.4	50.8±18.7*,†	36.2±10.3	47.2±18.2*,‡	37.9±15.6	39.2±17.8
180°/s	29.8±8.6	40.1±16.2*,†	31.6±9.5	41.8±16.5*,‡	31.8±13.8	32.4±15.3

[a] Data for average torque of each leg are presented as mean±SD. Asterisk (*) denotes within-group difference was significant ($P<.05$), dagger (†) denotes significant postintervention difference between HR and control groups ($P<.008$), double dagger (‡) denotes significant postintervention difference between LR and control groups ($P<.008$).

on a spongy surface was 5.99, 4.99, 2.45, and 2.56 seconds, respectively, in the HR group, and 5.21, 4.67, 2.34, and 2.47 seconds, respectively, in the LR group.

The 2-way ANOVA for repeated measures on the time factor revealed a significant interaction effect for the WOMAC pain and physical function subscale scores and for walking time on 4 different terrains ($P<.001$). *Post hoc* analyses indicated that, when compared with the preintervention values, the WOMAC pain and physical function subscale scores and walking times on 4 different terrains had significant improvements in the HR and LR groups ($P<.008$) but were not changed in the control group. The *post hoc* analyses also indicated that, after the intervention, both exercise groups demonstrated significant improvements in WOMAC pain and physical function subscale scores and in walking times on the figure-eight pattern and on the spongy surface compared with the control group ($P<.008$). However, there were no significant differences in improvement between HR and LR groups for any of the variables examined ($P>.008$).

The effect sizes between HR and control groups for the aforementioned variables were from 0.64 to 3.13. The effect sizes for the LR and control groups were from 0.51 to 2.70. Examination of the effect sizes between the exercise and control groups suggests that high-resistance exercise training had a larger effect than low-resistance exercise training.

The results for average isokinetic peak torque for each leg for the 3 groups before and after the 8-week intervention period are shown in Table 3. The 2-way ANOVA for repeated measures on the time factor revealed significant interaction effects for muscle torque. *Post hoc* analyses indicated that, when compared with the preintervention values, the peak torque of the knee extensors and flexors at the 3 velocities of muscle contraction was significantly greater in both exercise groups ($P<.008$) but was not changed in the control group. After the intervention, both exercise groups had significantly greater improvements in knee extensor and flexor torque at the 3 velocities of muscle contraction compared with the control group ($P<.008$). However, there was no significant difference in improvement in muscle torque between the HR and LR groups ($P>.008$).

At the 3 velocities of muscle contraction, the effect sizes of the knee extensors and flexors ranged from 0.67 to 0.85 and from 0.74 to 0.83, respectively, in the HR group. In the LR group, the effect sizes of the knee extensors and flexors ranged from 0.53 to 0.62 and from 0.86 to 1.40, respectively. For muscle torque, the effect sizes ranged from 0.57 to 0.75 in the HR group and from 0.42 to 0.68 in the control group. The differences in the effect size among groups suggest a larger training effect for the HR group than for the LR group.

Discussion

Individuals with knee OA who undertook a program involving a similar volume of mechanical work strength training for 8 weeks displayed significant improvements in knee pain, function of the lower extremity, walking speed on 4 different terrains, and knee muscle torque following either high-resistance or low-resistance exercise. Compared with the control group, however, high-resistance exercise training appears to have a larger effect than low-resistance exercise training on all variables measured.

Improvement in WOMAC Pain and Physical Function Subscale Scores

Increases in both flexor and extensor muscle strength have been shown to increase general knee stability.[32] Enhanced knee stability results in better functional performance of the lower extremity. Therefore, an essential aim of exercise therapy in patients with knee OA should be to increase both extensor and flexor muscle strength. Deyle et al[33] examined the frequency of knee arthroplasty in patients with knee OA who undertook an 8-week strength training program. They found that 20% of the subjects in the placebo group had undergone arthroplasty at the 1-year follow-up, whereas only 5% of the subjects who underwent the exercise intervention required surgery. This is further evidence supporting the notion that strength training is beneficial for patients with knee OA.

In both the HR and LR groups, the improvements in WOMAC pain subscale scores (range=3.0–3.7) and physical function subscale scores (range=11.3–11.7) were greater than the MDC_{90} (2.7 and 6.5, respectively). We concluded that both high-resistance and low-resistance exercise training in the current study led to clinically meaningful reductions in pain and improvements in functional performance in patients with knee OA.

Our results support the findings of previous studies[2,4,8–11] indicating that strength training reduces pain and improves physical function in people with knee OA. Fransen et al[11] reviewed various articles and found that the statistically significant beneficial effect sizes for individual therapeutic exercises in people with knee OA were 0.52 for pain and 0.32 for physical function, which are lower than those of the current study (range=0.82–1.34). Fransen et al declared that their review underestimated the overall beneficial effect of exercise among people with knee OA because of the reportable difficulties in accurately assessing improvement in people with early or mild symptoms due to small absolute improvement. Furthermore, we have hypothesized that a possible reason for overestimating the effect size in the current study may have been due to the 10 minutes of biking for warm-up preexercise training, as well as the 10-minute application of cold therapy following exercise intervention. Cooling the tissues can increase the pain threshold and decrease muscle spasm.[34,35] Cold is recommended for clinical use in myofascial pain syndromes to decrease muscle spasm and pain.[34,35] There have been no controlled studies indicating its usefulness in OA, although it may reduce soft tissue swelling over painful joints. Additional studies are necessary to delineate the effects of warm-up, other modalities (eg, cold), and exercise interventions and their interactive effects in patients with knee OA.

Walking Speed and Ability to Walk on Uneven Terrains

Walking is a common functional activity of daily living. Spatial and temporal gait parameters have clinical relevance in the assessment of motor pathologies.[36,37] Currently, the most widely used informal measures are walking speed on level ground and stair-climbing ability as an estimate of gait capacity.[38,39] In addition, training to walk in a figure-eight pattern and on uneven terrain usually is added in the later stages of rehabilitation of patients following anterior cruciate ligament reconstruction.[40,41] Patients tend to walk more slowly on those terrains due to increased demands on balance and proprioception. Our results demonstrate that walking speed increased for all measures on 4 different terrains in both the HR and LR groups. Perhaps more importantly, walking speed on level ground after training was greater than 100 m/min, similar to that in adults of similar ages who are healthy.[42] Walking speed in the control group remained unchanged for any of the measures. Therefore, we hypothesized that the strength training program used in the present study can effectively improve the walking speed of patients with knee OA.

In both exercise groups, the improvements in walking time (range=2.0–6.3 seconds) were greater than the SEMs (1.0–2.2 seconds) for all measures on 4 different terrains. However, the improvements in walking time were greater than the measurements of MDC_{90} for the figure-eight and spongy surface tasks, but not for walking on level ground and climbing stairs. We speculated that both high-resistance and low-resistance training with weight bearing could meaningfully improve walking speed on a curved path or uneven floor, which demands higher neuromuscular control of the lower extremity.[43,44]

Improvement in Muscle Torque

Evans[45] recommended that an intensity of approximately 80% of 1 RM should be used to maximize strength and functional gains for resistance training in the aged population. Other authors[12,46,47] also declared that high-resistance training was beneficial in increasing muscle strength, size, and range of motion in older men. Folland and Williams[13] reported that repetitive exposure to high-resistance strength training is one of the most popular ways to increase muscle strength. The effects of high-resistance strength training are attributed to a range of neurological and morphological adaptations and involve an increase in cross-sectional area of the whole muscle and individual muscle fibers as well as improvement of motor learning and coordination. Andersen et al[48] suggested that heavy resistance exercises should be included in rehabilitation programs to induce sufficient levels of neuromuscular activation to stimulate muscle growth and strength. With respect to knee OA, many researchers[9,21-23] have declared that strengthening exercises should not involve the use of excessive weight.

Patients with knee OA often exhibit a gradual decline in knee muscle strength.[4,5] Strength of the quadriceps femoris muscles has been shown to be an important predictor of walking speed and functional performance in patients with knee OA.[6] Research has indicated that weakness of the knee muscles is one of the major risks associated with joint instability.[49] Some authors[29,50] have reported that therapeutic exercise, including open and closed kinetic chain exercise, and progressive resistance training can increase muscle strength in patients with knee OA. In the present study, we found that subjects who performed resistance training using closed kinetic chain exercise displayed significant improvement in the strength of both knee extensors and flexors after an 8-week exercise intervention, regardless of the resistance used.

Previous studies[46,47,51] demonstrated that, in untrained elderly men, maximal strength improved significantly more in a low-repetition/high-resistance group compared with a high-repetition/low-resistance group. The current study showed similar results. High-resistance exercise training (high load and low repetitions) appears to translate into greater reduction in pain and improved functional performance compared with low-resistance exercise training (low load and high repetitions) for patients with knee OA, though there was no significant difference in improvement between the HR and LR groups. A review of the literature suggests that low-resistance exercise could increase muscle strength through neuromuscular mechanisms.[18,20,52,53] Therefore, we hypothesized that the gains in muscle strength in the LR group were the result of neuromuscular learning and neural adaptation. There was no significant difference in peak muscle torque between the HR and LR groups following the exercise intervention in the current study. We hypothesized that the resistance training was done in a closed kinetic chain using the EN-Dynamic Track leg-press machine, whereas the muscle torque was tested in an open kinetic chain using the Cybex 6000 isokinetic dynamometer. It is possible that the different modes of exercise training versus testing was one of the reasons for a lack of differences in strength between the 2 exercise groups.

For the purpose of controlling for confounding factors, the current study was limited to high-resistance exercise or low-resistance exercise as the essential part of the strength training programs for patients with knee OA. Training programs for patients with knee OA usually use multiple exercises to train the lower extremity. Physical therapists should add agility tasks, perturbation training, or aerobic exercise to the exercise training program for a more comprehensive program for patients with knee OA. Additionally, it is worth noting that the high-resistance exercise took 20 minutes less per session to perform than the low-resistance exercise. The advantage in time is very meaningful in clinical practice.

Study Limitations

There were several limitations in this study. Our study sample included subjects with no prior knee injuries, a large proportion of female subjects, and only subjects with bilateral knee OA (a large majority with mild-to-moderate knee OA), and subjects took no pain medication during the intervention. Thus, generalization of the findings of our study to other populations should be limited. Although there was 100% adherence to the exercise intervention in the LR group, 3 subjects in HR group discontinued the exercise intervention due to severe knee pain. We speculate that the intensity and repetitions of the resistance training might be 2 primary factors influencing the training effect in patients with knee OA. This study highlights the need to further explore the combination of intensity and repetition in resistance training for patients with knee OA.

Conclusion

Both high-resistance and low-resistance strength training reduced pain and improved function in patients with knee OA. Although high-resistance strength training demonstrated effect sizes that consistently were slightly greater than those achieved with low-resistance strength training, the differences in improvement between the HR and LR groups were not significant.

Mrs Jan and Dr DH Lin provided concept/idea/research design. Mrs Jan provided writing, fund procurement, and clerical support. Dr JJ Lin provided data collection and analysis and project management. Dr Liau provided facilities/equipment and institutional liaisons. Dr YF Lin and Dr DH Lin provided subjects and consultation (including review of manuscript before submission).

The study design was approved by the Ethics Committee of National Taiwan University Hospital.

This article was received October 3, 2006, and was accepted November 26, 2007.

DOI: 10.2522/ptj.20060300

References

1 Felson DT, Naimark A, Anderson J. The prevalence of knee osteoarthritis in the elderly: the Framingham Osteoarthritis Study. *Arthritis Rheum.* 1987;30:914–918.

2 Philadelphia Panel Evidence-Based Clinical Practice Guidelines on Selected Rehabilitation Interventions for Knee Pain. *Phys Ther.* 2001;81:1675-1700.

3 Harrison AL. The influence of pathology, pain, balance, and self-efficacy on function in women with osteoarthritis of the knee. *Phys Ther.* 2004;84:822-831.

4 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.

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

6 McAlindon TE, Cooper C, Kirwan JR, Dieppe PA. Determinants of disability in osteoarthritis of the knee. *Ann Rheum Dis.* 1993;52:258-262.

7 Steultjens MPM, Dekker J, van Baar ME, et al. Muscle strength, pain, and disability in patients with osteoarthritis. *Clin Rehabil.* 2001;15:331-341.

8 Mangione KK, McCully K, Gloviak A, et al. The effects of high-intensity and low-intensity cycle ergometry in older adults with knee osteoarthritis. *J Gerontol A Biol Sci Med Sci.* 1999;54:M184-M190.

9 van Baar ME, Dekker J, Oostendorp RAB, et al. The effectiveness of exercise therapy in patients with osteoarthritis of the hip or knee: A randomized clinical trial. *J Rheumatol.* 1998;25:2432-2439.

10 Deyle GD, Allison SC, Matekel RL, et al. Physical therapy treatment effectiveness for osteoarthritis of the knee: a randomized comparison of supervised clinical exercise and manual therapy procedures versus a home exercise program. *Phys Ther.* 2005;85:1301-1317.

11 Fransen M, McConnell S, Bell M. Exercise for osteoarthritis of the hip or knee. *Cochrane Database Syst Rev.* 2001;2:CD004376.

12 Kryger AI, Andersen JL. Resistance training in the oldest old: consequences for muscle strength, fiber types, fiber size, and MHC isoforms. *Scand J Med Sci Sports.* 2007;17:1-9.

13 Folland JP, Williams AG. The adaptations to strength training. *Sports Med.* 2007;37:145-168.

14 Chandler JM, Duncan PW, Kochersberger G, Studenski S. Is lower extremity strength gain associated with improvement in physical performance and disability in frail, community-dwelling elders? *Arch Phys Med Rehabil.* 1998;79:24-30.

15 Taaffe DR, Pruitt L, Pyka G, et al. Comparative effects of high- and low-intensity resistance training on thigh muscle strength, fiber area, and tissue composition in elderly women. *Clin Physiol.* 1996;16:381-392.

16 Hortobágyi T, Tunnel D, Moody J, et al. Low- or high-intensity strength training partially restores impaired quadriceps force accuracy and steadiness in aged adults. *J Gerontol A Biol Sci Med Sci.* 2001;56:B38-B47.

17 Mangione KK, Craik RL, Tomlinson SS, Palombaro KM. Can elderly patients who have had a hip fracture perform moderate-to high-intensity exercise at home? *Phys Ther.* 2005;85:727-739.

18 Hilberg T, Herbsleb M, Puta C, et al. Physical training increases isometric muscular strength and proprioceptive performance in haemophilic subjects. *Haemophilia.* 2003;9:86-93.

19 Lin DH, Lin YF, Chai HM, et al. Comparison of proprioceptive functions between computerized propioception facilitation exercise and closed kinetic chain exercise in patients with knee osteoarthritis. *Clin Rheumatol.* 2007;26:520-528.

20 Jan MH, Hung JY, Lin JCH, et al. Effects of a home program on strength, walking speed, and function after total hip replacement. *Arch Phys Med Rehabil.* 2004;85:1943-1951.

21 Kettunen JA. Kujala UM. Exercise therapy for people with rheumatoid arthritis and osteoarthritis. *Scand J Med Sci Sports.* 2004;14:138-142.

22 Baliunas AJ, Hurwitz DE, Ryals AB, et al. Increased knee joint loads during walking are present in subjects with knee osteoarthritis. *Osteoarthritis Cartilage.* 2002;10:573-579.

23 Lucchinetti E, Adams CS, Horton WE, Torzilli PA. Cartilage viability after repetitive loading. *Osteoarthritis Cartilage.* 2002;10:71-81.

24 Nichols JF, Omizo DK, Peterson KK, Nelson KP. Efficacy of heavy resistance training for active women over sixty: muscular strength, body composition, and program adherence. *J Am Geriatr Soc.* 1993;41:205-210.

25 Coleman EA, Buchner DM, Cress ME, et al. The relationship of joint symptoms with exercise performance in older adults. *J Am Geriatr Soc.* 1996;44:14-21.

26 Hakkinen K, Hakkinen A. Neuromuscular adaptation during intensive strength training in middle-aged and elderly males and females. *Electromyogr Clin Neurophysiol.* 1995;35:137-147.

27 Altman R, Asch E, Bloch D, et al. Development of criteria for the classification and reporting of osteoarthritis: classification of osteoarthritis of the knee. *Arthritis Rheum.* 1986;29:1039-1049.

28 Kellgren JH, Lawrence JS. Radiological assessment of osteoarthrosis. *Ann Rheum Dis.* 1957;16:494-501.

29 Beneka A, Malliou P, Fatouros I, et al. Resistance training effects on muscular strength of elderly are related to intensity and gender. *J Sci Med Sport.* 2005;8:274-283.

30 Roos EM, Klassbo M, Lohmander LS. WOMAC Osteoarthritis Index: Reliability, validity, and responsiveness in patients with arthroscopically assessed osteoarthritis. *Scand J Rheumatol.* 1999;28:210-215.

31 Gustavsen R, Streeck R. *Training Therapy, Prophylaxis and Rehabilitation.* New York, NY: Thieme Medical Publishers; 1993.

32 Bizzini M, Gorelick M, Munzinger U, Drobny T. Joint laxity and isokinetic thigh muscle strength characteristics after anterior cruciate ligament reconstruction: bone patellar tendon bone versus quadrupled hamstring autografts. *Clin J Sport Med.* 2006;16:4-9.

33 Deyle GD, Henderson NE, Matekel RL, et al. Effectiveness of manual physical therapy and exercise in osteoarthritis of the knee. *Ann Intern Med.* 2000;132:173-181.

34 Domenica FD, Sarzi-Puttini P, Cazzola M, et al. Physical and rehabilitative approaches in osteoarthritis. *Semin Arthritis Rheum.* 2007;34:62-69.

35 Brosseau L, Yonge KA, Robinson V, et al. Thermotherapy for treatment of osteoarthritis. *Cochrane Database Syst Rev.* 2003;4:CD004522.

36 Archer KR, Castillo RC, Mackenzie EJ, Bosse MJ; for the Lower Extremity Assessment Project (LEAP) Study Group. Gait symmetry and walking speed analysis following lower-extremity trauma. *Phys Ther.* 2006;86:1630-1640.

37 Bejek Z, Paróczai R, Illyés Á, Kiss RM. The influence of walking speed on gait parameters in healthy people and in patients with osteoarthritis. *Knee Surg Sports Traumatol Arthrosc.* 2006;14:612-622.

38 Deathe AB, Miller WC. The L Test of Functional Mobility: measurement properties of a modified version of the Timed "Up & Go" Test designed for people with lower-limb amputations. *Phys Ther.* 2005;85:626-635.

39 Miller WC, Speechley M, Deathe AB. Balance confidence among people with lower-limb amputations. *Phys Ther.* 2002;82:856-865.

40 Shelbourne KD, Nitz P. Accelerated rehabilitation after cruciate ligament reconstruction. *Am J Sports Med.* 1990;18:292-299.

41 Ellenbecker TS, Davies GJ. *Closed Kinetic Chain Exercise: A Comprehensive Guide to Multiple-Joint Exercise.* Champaign, Ill: Human Kinetics Inc; 2001.

42 Graf A, Judge JO, Õunpuu S, Thelen DG. The effect of walking speed on lower-extremity joint powers among elderly adults who exhibit low physical performance. *Arch Phys Med Rehabil.* 2005;86:2177-2183.

43 Beard DJ, Dodd CA, Trundle HR, Simpson AH. Proprioception enhancement for anterior cruciate ligament deficiency: a prospective randomized trial of two physiotherapy regimes. *J Bone Joint Surg Br.* 1994;76:654-659.

44 Ihara H, Nakayama A. Dynamic joint control training for knee ligament injuries. *Am J Sports Med.* 1986;14:309-315.

45 Evans WJ. Exercise training guidelines for the elderly. *Med Sci Sports Exerc.* 1999;31:12-17.

46 Trappe S, Williamson D, Godard M. Maintenance of whole muscle strength and size following resistance training in older men. *J Gerontol A Biol Sci Med Sci.* 2002;57:B138-B143.

47 Fatouros I, Taxildaris K, Tokmakidis S, et al. The effects of strength training, cardiovascular training and their combination on flexibility of inactive older adults. *Int J Sports Med.* 2002;23:112–119.

48 Andersen LL, Magnusson SP, Nielsen M, et al. Neuromuscular activation in conventional therapeutic exercises and heavy resistance exercises: implications for rehabilitation. *Phys Ther.* 2006;86:683–697.

49 Shelbourne KD. Nitz P. Accelerated rehabilitation after anterior cruciate ligament reconstruction. *Am J Sports Med.* 1990;18:292–299.

50 Fransen M, McConnell S, Bell M. Therapeutic exercise for people with osteoarthritis of the hip or knee: a systematic review. *J Rheumatol.* 2002;28:1737–1745.

51 Campos GER, Luecke TJ, Wendeln HK, et al. Muscular adaptation in response to three different resistance-training regimens: specificity of repetition maximum training zones. *Eur Appl Physiol.* 2002;88:50–60.

52 Kaufman LB, Schilling DL. Implementation of a strength training program for a 5-year-old child with poor body awareness and developmental coordination disorder. *Phys Ther.* 2007;87:455–467.

53 Reeves ND, Narici MV, Maganaris CN. Musculoskeletal adaptations to resistance training in old age. *Manual Ther.* 2006;11:192–196.