Clinical Rehabilitation 2010; **24:** 911–918

Active, passive and proprioceptive neuromuscular facilitation stretching are comparable in improving the knee flexion range in people with total knee replacement: a randomized controlled trial

Tiffany PY Chow Department of Physiotherapy, Tai Po Hospital and Department of Rehabilitation Sciences, Hong Kong Polytechnic University and **Gabriel YF Ng** Department of Rehabilitation Sciences, Hong Kong Polytechnic University, Hong Kong, China

Received 20th May 2009; returned for revisions 8th February 2010; revised manuscript accepted 11th February 2010.

Objective: To compare the immediate and medium-term effects of three stretching methods on the knee flexion range in people with a total knee replacement.
Design: Randomized clinical trial.
Setting: Rehabilitation hospital.
Subjects: 117 patients were recruited and 100 (mean age: 68.43 ± 7.95 years) of them completed the study.
Interventions: Patients receiving total knee replacement due to knee osteoarthritis were randomly assigned into 3 groups of: active stretching (group 1, $n = 32$), passive stretching (group 2, $n = 35$) and proprioceptive neuromuscular facilitation stretching (group 3, $n = 33$).
Main measures: The immediate change in both active and passive knee flexion range after the first treatment session and the pattern of change in these ranges throughout the 2-week study period were compared among the three groups.
Results: All groups demonstrated significant improvement in knee ranges with time. The active range of group 1 improved by 19.9°, group 2 by 25.3° and group 3 by 22.5° throughout the 2-week period, whereas the improvements in the passive range were 18.8°, 24.5° and 22.7°, respectively. For between-group comparisons, no significant difference was found in both active ($P = 0.647$) and passive ($P = 0.501$) knee range immediately after stretching. For the changes at 2 weeks, there was also no significant difference among the groups in both active ($P = 0.716$) and passive ($P = 0.959$) knee ranges.
Conclusion: This study revealed that all three modes of stretching were associated with an increase in the knee flexion range of patients after total knee replacement, with no statistically significant differences between the changes seen.

Address for correspondence: Gabriel Ng, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong, China.
e-mail: rsgng@inet.polyu.edu.hk

10.1177/0269215510367992

Introduction

Total knee replacement is a common surgical procedure for patients with knee osteoarthritis.[1,2] Apart from the general mobility level, post-operative knee range is a vital outcome indicator for the operation.[1,3–9] Good knee range is important for daily functioning[3] whereas decreased knee range can lead to prolonged hospital stay and the need for manipulation under anesthesia. Therefore, it is important to identify how the joint range could be improved. Among the various rehabilitation protocols, stretching exercise has been shown to effectively increase the post-operative knee range.[3,10]

There are three common stretching methods, namely, active stretching, passive stretching and proprioceptive neuromuscular facilitation (PNF). Active stretching refers to stretching the shortened muscle by contracting the antagonistic muscles.[11] Passive stretching is a slow, controlled lengthening of a relaxed muscle by external means. PNF involves a series of contractions and relaxations of both the agonist and antagonist muscles,[12] the most usual maneuvers are the hold-relax and contract-relax techniques.[13]

Studies have been conducted to examine the stretching duration,[14,15] frequency,[10] poundage[16] and stretching type,[17–21] but no consensus could be reached. Furthermore, most of the studies tested the hamstrings[10,22,23] or hip flexors,[11] and the results of these studies may not be readily applied to knee flexion range in patients after total knee replacement.

For this reason, we aimed to compare the immediate and medium-term effects of active, passive and PNF stretching on knee flexion range in people after total knee replacement.

Methods

One hundred and sixty-one patients who had received primary total knee replacement in our cluster hospitals and were transferred to our hospital for rehabilitation were screened. After screening, 117 subjects (100 females and 17 males) were recruited (Figure 1). The inclusion criteria were patients receiving total knee replacement due to osteoarthritis of the knee with body mass index of less than 30, pre-operative passive knee flexion range $>80^\circ$, intra-operative knee flexion $>90^\circ$, and post-operative passive knee flexion $<110^\circ$. Subjects were excluded if they had had previous surgery to the affected lower limb or if they had limited range and muscle weakness of the unaffected limb, medical conditions such as Parkinson's disease, post-operative medical complications or dementia. All subjects had received total knee replacement with the mid-line incision, fixed-bearing posteriorly stabilized and cemented prosthetic design, with posterior cruciate ligament substituted, patellar resurfaced, and well-balanced flexion and extension gaps.

The study was reviewed and approved by the Department of Rehabilitation Sciences at the Hong Kong Polytechnic University. Written informed consent was obtained from subjects before they participated in the study.

Experimental procedures

Upon admission to the hospital, the subjects were randomly assigned into the three groups: active stretching (group 1), passive stretching (group 2) and proprioceptive neuromuscular facilitation (PNF) stretching (group 3). The random assignment of the subjects into one of the three groups was carried out by a member of the administrative staff in our department, who was not involved in this study, drawing lots. The time of commencement of the exercises was decided by the case physiotherapist. All subjects received a rehabilitation program according to the protocols of the hospital which included pain relief treatment, knee mobilization and strengthening exercise, balance, transfer and mobility training. For the treatment of pain, in order to achieve standardization among the three groups, all patients received only an ice pack on the affected knee for 15 minutes immediately after the stretching exercise. The whole training session would last for about an hour each day. Besides the above, the subjects also received the treatment according to their respective group assignment as below.

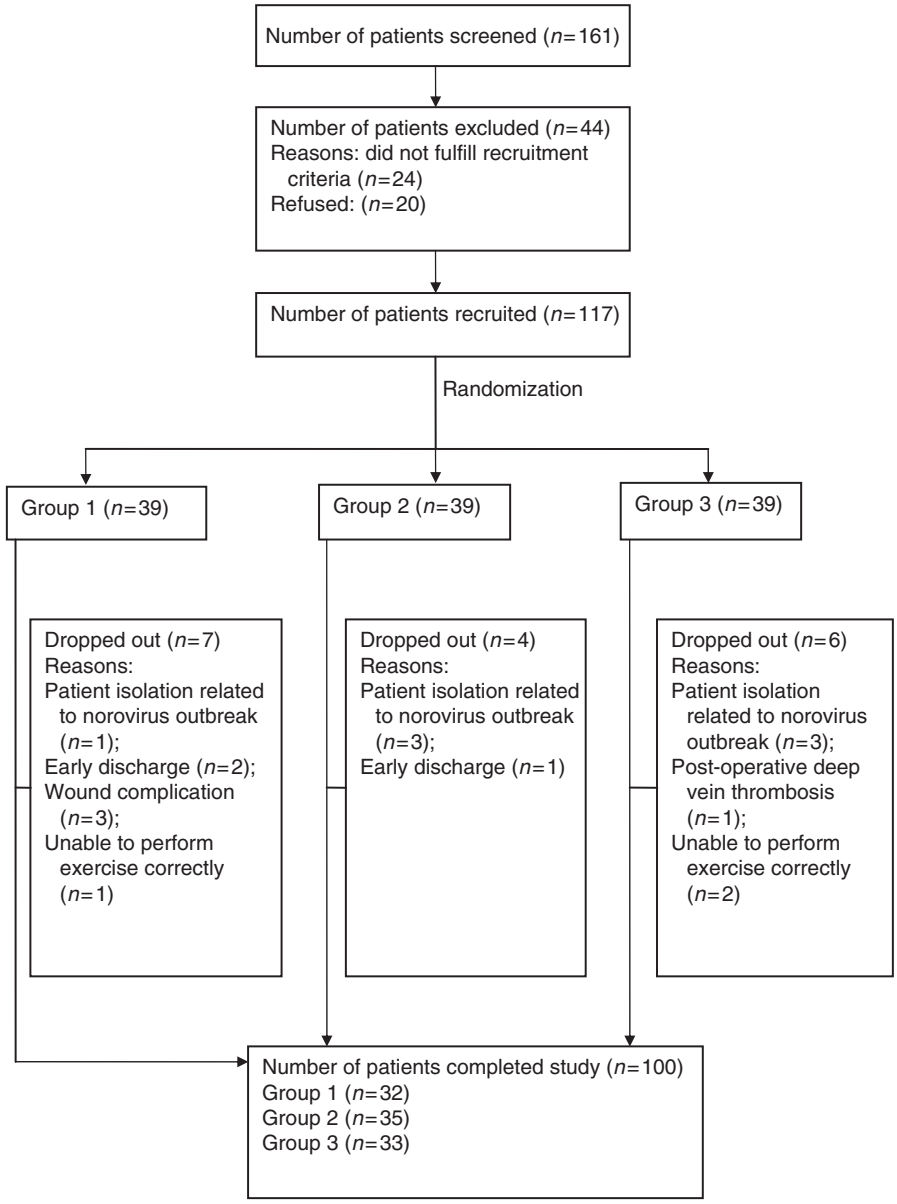

Figure 1 Flow diagram of the study.

Group 1 (Active stretching)

Subject was in a prone position, lying with head against the wall. A three-ring sling was applied to each ankle and connected via a reciprocal pulley from a wall mount. The range of stretching was actively controlled by the subject by flexing the affected knee and extending the other knee simultaneously. Flexion of the affected knee was sustained for 20 seconds after the patient had perceived the stretch followed by 10 seconds of rest.

Group 2 (Passive stretching)

Subject was in a supine position, lying with head against the wall. For the knee being stretched, the thigh was supported by a wall-mount sling so that the hip was flexed to 90° and the subject was asked to relax the quadriceps so that the knee would go into flexion due to the effect of gravity on the lower leg. In order to increase the gravitational stretching effect, a cuff weight was applied to the same ankle according to the subject's tolerance so that the subject would perceive a rating of no more than 3 in the Myers pain rating scale.[24] The stretching was maintained for 20 seconds followed by 10 seconds of rest.

Group 3 (PNF: sub-maximal hold-relax technique)

Subject was in a prone position and stretching was done by the physiotherapist. The affected knee was flexed passively to the end of range with the therapist's hand on the subject's lower leg, and the subject would then perform 5 seconds of quadriceps contraction against the resistance of the therapist. At the end of the 5th second, the subject would be asked to totally relax and the therapist would push the knee into more flexion and hold at that newly acquired range for 10 seconds. The amount of stretching force was dependent on the subject's tolerance so that the subject would perceive a rating of no more than 3 in the Myers pain rating scale.

For all the groups, the total treatment time per day was comparable and stretching was done 5 days a week for 2 weeks.

Data collection

Demographic data of each subject were collected (Table 1). Pre-stretch numerical pain rating scale was recorded on alternate days starting from the first day of treatment to 12 days afterwards to check there was no sudden increase in pain level throughout the treatment period. Knee circumference measured at the center of patella was also recorded so that any swelling of the knee which could affect the knee range could be taken into account. As pain level may have an interaction with exercise performance, it could not be treated as the covariate in the data analysis, therefore the total number of days with administration of analgesics during the study period was recorded for later analysis.

Measurement of the knee range was based on the method of Clarkson and Gilewich using a universal goniometer.[25] The subject was in the supine position with hips in the anatomical position and both knees extended. The axis of the goniometer was placed at the lateral femoral epicondyle, the stationary arm was parallel with the femur, pointing at the greater trochanter while the movable arm was parallel with the fibula, pointing toward the lateral malleolus. For the active knee range measurement, the subject was asked to actively flex the knee to the maximal extent, whereas for the passive knee range measurement, the physiotherapist would push the knee into the maximum flexion tolerated by the subject. Knee range was measured three times in each session and the average was used for analysis. Pre- and post-stretch active and passive knee flexion ranges were measured on alternate days starting from the first day of treatment.

Data analysis

For the immediate treatment effect, one-way ANCOVA was used to compare the pre- and post-stretching difference of active and passive knee ranges between the three groups on the first treatment session. The covariates were age and pre-stretch knee flexion range. The change in percentages of active and passive knee ranges was also analyzed. For the within group comparison, paired t-test was used to analyze the difference before and after the first treatment session.

In order to reveal the rate of change in knee flexion, regression coefficients of the active and passive knee ranges throughout the treatment period of individual subjects were calculated. The regression coefficients of the three groups were then compared by one-way ANCOVA. The covariates were age and pre-stretch knee flexion ranges, change in pre-stretch knee circumference from the first to the last stretching session and number of days with analgesic administration. For the within group comparison, paired t-test was used to analyze the difference before and after the whole studied period.

Since a total of three paired t-tests were done, Bonferroni adjustment was used to control for type I errors with the level of significance set at 0.017.

Results

Of the 117 subjects recruited, 17 of them did not complete the study for the following reasons: patient isolation related to norovirus outbreak ($n=7$), early discharge ($n=3$), wound complication ($n=3$), post-operative deep vein thrombosis ($n=1$), and other reasons ($n=3$) (Figure 1). There were no significant differences on the demographic data among the three groups (Table 2, $P>0.05$).

For the within group comparisons, significant improvements in active and passive ranges were demonstrated after the first stretching session and also at the end of the whole study period in all groups (Table 3, $P<0.017$). However, there was no significant between-group difference in both active and passive knee ranges either measured immediately after stretching or at the end of the 2-week interval (Table 3, $P>0.017$).

Table 1 Demographic data of the patients recruited for the study ($N=117$)

	Group 1 ($n=39$)	Group 2 ($n=39$)	Group 3 ($n=39$)
Female/male	32/7	32/7	36/3
Mean age (SD)	67.10 (8.02) Range: 54–82	69.95 (7.96) Range: 52–81	70.10 (6.45) Range: 57–81
Mean BMI (SD)	24.70 (3.14) Range: 19.5–29.9	25.89 (2.85) Range: 18–29.9	25.04 (2.78) Range: 19.7–30
Side of surgery left/right	22/17	24/15	17/22
Mean active pre-stretch range in degrees (SD)	72.4 (13.45) Range: 40–95	71. 7 (11.94) Range: 30–90	70.9 (17.36) Range: 10–105
Mean passive pre-stretch range in degrees (SD)	79.0 (12.94) Range: 45–100	78.4 (11.87) Range: 35–95	77.5 (14.24) Range: 45–108
Mean pre-stretch knee circumference in cm (SD)	40.6 (3.61)	42.0 (3.01)	40.3 (3.05)
Median pre-stretch pain level measured in NPRS	6	5	5
Mean number of days with analgesics (SD)	11.4 (2.83)	10.7 (3.65)	11.9 (2.69)

BMI, body mass index; NPRS, numeric pain rating scale.

Table 2 Demographic data of the patients who completed the study ($N=100$)

	Group 1 ($n=32$)	Group 2 ($n=35$)	Group 3 ($n=33$)
Female/male	26/6	28/7	31/2
Mean age (SD)	66.7 (8.29) Range: 54–82	69.8 (8.00) Range: 52–81	70.2 (6.59) Range: 57–81
Mean BMI (SD)	24.55 (3.1) Range: 19.5–29.9	25.92 (2.91) Range: 18.8–29.9	25.21 (2.81) Range: 19.7–30
Side of surgery left/right	18/14	23/12	14/19
Mean active pre-stretch range in degrees (SD)	72.1 (12.92) Range: 40–95	70.3 (11.78) Range: 30–90	71.4 (14.86) Range: 40–105
Mean passive pre-stretch range in degrees (SD)	78.7 (12.64) Range: 45–100	77.0 (11.76) Range: 35–95	76.8 (14.14) Range: 45–108
Mean pre-stretch knee circumference in cm (SD)	40.5 (3.72)	42.2 (3.06)	40.5 (3.19)
Median pre-stretch pain level measured in NPRS	6	5	5
Mean number of days with analgesics (SD)	11.6 (2.78)	10.7 (3.70)	12.5 (1.87)

BMI, body mass index; NPRS, numeric pain rating scale.

Table 3 The change in the active and passive knee flexion ranges after the first stretching session and throughout the study

Group		Pre, Mean ± SD and (95% CI)	1st post,Mean ± SD and (95% CI)	% increase	Last post, Mean ± SD and (95% CI)
Group 1 ($n=32$)	Active range	72.1 ± 12.92 (67.4 to 76.8)	78.3 ± 13.34* (73.4 to 83.2)	8.64	92.0 ± 12.15* (86.9 to 97.1)
	Passive range	78.7 ± 12.64 (74.2 to 83.3)	83.9 ± 11.86* (79.5 to 88.2)	6.54	97.5 ± 11.90* (92.5 to 102.6)
Group 2 ($n=35$)	Active range	70.3 ± 11.78 (66.3 to 74.4)	78.3 ± 12.54* (74.0 to 82.6)	11.38	95.6 ± 11.25* (91.5 to 99.7)
	Passive range	77.0 ± 11.76 (73.0 to 81.1)	83.5 ± 13.21* (79.0 to 88.1)	8.45	101.5 ± 11.83* (97.1 to 105.8)
Group 3 ($n=33$)	Active range	71.4 ± 14.86 (66.1 to 76.7)	78.9 ± 10.98* (75.0 to 82.9)	10.58	93.9 ± 11.15* (89.6 to 98.1)
	Passive range	76.8 ± 14.14 (71.8 to 81.8)	84.6 ± 11.18* (80.6 to 88.7)	10.21	99.5 ± 11.03* (95.3 to 103.7)

Pre, pre-stretching knee flexion range; 1st post, post-stretching knee flexion range after the first stretching session; % increase, percentage increase in knee flexion range after the first stretching session; last post, post-stretching knee flexion range after the whole study period. *$P<0.017$.

Discussion

The present results revealed significant improvements in both active and passive knee flexion ranges within each group over time but no significant difference was found among the three groups throughout the entire study period. These results suggested that all the three stretching protocols had an equivalent effect in improving the post-operative knee flexion in patients with total knee replacement but no particular stretching mode had more effect than others. In the absence of an untreated control group, we cannot know whether the treatments are beneficial.

Studies on the range of motion (ROM) of the knee after total knee replacement have been mainly focused on mobilization exercises rather than stretching exercises.[20,21] However, in these studies, the details of exercise were not described, making it difficult to compare with other studies. Therefore, there is a lack of consensus on a good stretching method to improve knee range after total knee replacement.

Ferber and associates[17] compared three different stretching techniques (static stretch, contract-relax and agonist contract-relax) on 24 older adults aged from 50 to 75 years. The total stretching duration was 80 seconds for each subject. The knee extension range and knee flexor muscle activity were tested. It was shown that the agonist contract-relax technique could increase range of motion more than the other two methods but the electromyography (EMG) activity of the stretched muscle was the greatest, which indicated the muscles were not relaxed. Therefore, special care should be taken to prevent muscle injury, especially in the elderly with total knee replacement.

In a more recent study,[11] the short-term effects of static stretching and PNF on knee ROM were reported. The group comprised 19 healthy and active volunteers. The PNF stretches required the subjects to maintain maximal isometric tension of quadriceps against manual resistance for five seconds, followed by a 30-second passive stretch. For static stretching, the stretching force was held for 30 seconds at a point of discomfort. There were four repetitions of each stretching exercise with a 20-second resting period between each repetition. It was found that both protocols could increase active and passive knee flexion range.

Although all groups showed significant improvements, the therapeutic mechanism underlying each mode of intervention is not fully known. For the active stretching group, since the subjects were asked to contract their hamstrings actively, the improvement could be due to the efficiency of this muscle and reciprocal inhibition during the antagonistic contraction.[11] For the passive stretching group, it has been reported that the

biomechanical effects of sustained stretching were due to changes in the viscoelastic characteristics[11,26] and stretch tolerance.[26] Furthermore, this group assumed a supine lying position during treatment which was the most comfortable because the surgical wound was not compressed in the early post-operative stage.

For the PNF stretching, the working mechanism involves a reciprocal muscle inhibition technique throughout the exercise and a rhythmic contraction/relaxation such as this has been reported to enhance the effectiveness of the stretch.[23,27] Since the stretching duration and force applied in this study were adjusted according to the extension strength and the pain level of the subjects, the result might be affected by wound pain during the isometric contraction in the early post-operative phase.

There are some limitations of this study that need to be acknowledged: (1) there was not a control group that did not have any treatment, therefore it was impossible to know whether any stretching exercise has a specific beneficial effect; (2) since pain can affect knee range, despite the number of days with analgesic administration being recorded and analyzed as a covariate, the exact dosage and type of analgesics could not be analyzed due to the various combinations of drugs and their interactive effects; (3) the outcome measure was limited to knee flexion range but lacked other clinically relevant outcome measures such as mobility and gait speed.

We concluded that active, passive and proprioceptive neuromuscular facilitation stretching are all associated with improvement in knee flexion range in patients receiving total knee replacement but none of these three modes of stretching had significantly more effect than the others.

Clinical messages

- Active, passive and PNF stretching exercises are all associated with an increase in post-operative knee flexion range in patients with total knee replacement.
- Considering simple logistics and comfort for the patients, passive stretching may be the most suitable mode of stretching in patients with total knee replacement.

Acknowledgements

We thank Mr. Peggo Lam (former Scientific Officer of the Department of Rehabilitation Sciences, The Hong Kong Polytechnic University) for his help in providing the statistical advice and support.

References

1 Kolisek FR, Gilmore KJ, Peterson EK. Slide and flex, tighten, extend (SAFTE): a safe, convenient, effective, and no-cost approach to rehabilitation after total knee arthroplasty. *J Arthroplasty* 2000; **15**: 1013–1016.
2 Maloney WJ. The stiff total knee arthroplasty: evaluation and management. *J Arthroplasty* 2002; **17**: 71–73.
3 Chiu KY, Ng TP, Tang WM *et al*. Review article: knee flexion after total knee arthroplasty. *J Orthop Surg (Hong Kong)* 2002; **10**: 194–202.
4 Dennis DA, Komistek RD, Stiehl JB *et al*. Range of motion after total knee arthroplasty: the effect of implant design and weight-bearing conditions. *J Arthroplasty* 1998; **13**: 748–752.
5 Gatha NM, Clarke HD, Fuchs R *et al*. Factors affecting postoperative range of motion after total knee arthroplasty. *J Knee Surg* 2004; **17**: 196–202.
6 Maloney WJ, Schurman DJ. The effects of implant design on range of motion after total knee arthroplasty: total condylar versus posterior stabilized total condylar designs. *Clin Orthop Relat Res* 1992; **278**: 147–152.
7 Menke W, Schmitz B, Salm S. Range of motion after total condylar knee arthroplasty. *Arch Orthop Trauma Surg* 1992; **111**: 280–281.
8 Ritter MA, Harty LD, Davis KE *et al*. Predicting range of motion after total knee arthroplasty: clustering, log-linear regression, and regression tree analysis. *J Bone Joint Surg Am* 2003; **85**: 1278–1285.
9 Stiehl JB, Voorhorst PE, Keblish P *et al*. Comparison of range of motion after posterior cruciate ligament retention or sacrifice with a mobile bearing total knee arthroplasty. *Am J Knee Surg* 1997; **10**: 216–220.
10 Bandy WD, Irion JM, Briggler M. The effect of time and frequency of static stretching on flexibility of the hamstring muscles. *Phys Ther* 1997; **77**: 1090–1096.
11 Winters MV, Blake CG, Trost JS *et al*. Passive versus active stretching of hip flexor muscles in

subjects with limited hip extension: a randomized clinical trial. *Phys Ther* 2004; **84**: 800–807.
12 Balady GJ, Berra KA, Golding LA. *ACSM's guidelines for exercise tsesting and prescription*. Philadelphia: Lippincott Williams & Wilkins, 2000.
13 McAtee RE, Charland J. Facilitated stretching. Champaign, Human Kinetics,1999.
14 Bonnar BP, Deivert RG, Gould TE. The relationship between isometric contraction durations during hold-relax stretching and improvement of hamstring flexibility. *J Sports Med Phys Fitness* 2004; **44**: 258–261.
15 Feland JB, Myrer JW, Schulthies SS *et al*. The effect of duration of stretching of the hamstring muscle group for increasing range of motion in people aged 65 years or older. *Phys Ther* 2001; **81**: 1110–1117.
16 Swank AM, Durham MP. Adding weights to stretching exercise increases passive range of motion for healthy elderly. *J Strength Cond Res* 2003; **17**: 374–378.
17 Ferber R, Osternig LR, Gravelle DC. Effect of PNF stretch techniques on knee flexor muscle EMG activity in older adults. *J Electromyogr Kinesiol* 2002; **12**: 391–397.
18 Funk DC, Swank AM, Mikla BM *et al*. Impact of prior exercise on hamstring flexibility: a comparison of proprioceptive neuromuscular facilitation and static stretching. *J Strength Cond Res* 2003; **17**: 489–492.
19 Marek SM, Cramer JT, Fincher L *et al*. Acute effects of static and proprioceptive neuromuscular facilitation stretching on muscle strength and power output. *J Athl Train* 2005; **40**: 94–103.
20 Beaupre LA, Davies DM, Allyson Jones C *et al*. Exercise combined with continuous passive motion or slider board therapy compared with exercise only: a randomized controlled trial of patients following total knee arthroplasty. *Phys Ther* 2001; **81**: 1029–1037.
21 Frost H, Lamb SE, Robertson S. A randomized controlled trial of exercise to improve mobility and function after elective knee arthroplasty. Feasibility, results and methodological difficulties. *Clin Rehabil* 2002; **16**: 200–209.
22 Feland JB, Marin HN. Effect of submaximal contraction intensity in contract-relax proprioceptive neuromuscular facilitation stretching. *Br J Sports Med* 2004; **38**: E18.
23 Davis DS, Ashby PE, McCale KL *et al*. The effectiveness of 3 stretching techniques on hamstring flexibility using consistent stretching parameters. *J Strength Cond Res* 2005; **19**: 27–32.
24 Myers J. Perception of chest pain during exercise testing in patients with coronary artery disease. *Med Sci Sports Exerc* 1994; **26**: 1082–1086.
25 Clarkson HM, Gilewich GB. *Musculoskeletal assessment. Joint range of motion and manual muscle strength*. Baltimore: Williams & Wilkins, 1989.
26 Magnusson SP. Passive properties of human skeletal muscle during stretch maneuvers. *Scand J Med Sci Sports* 1998; **8**: 65–77.
27 Spernoga SG, Uhl TL, Arnold BL *et al*. Duration of maintained hamstring flexibility after a one-time, modified hold-relax stretching protocol. *J Athl Train* 2001; **36**: 44–48.