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The effect of eight weeks of exercise on knee adduction moment in early knee osteoarthritis – a pilot study

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Summary

Objective: Reduced muscle function, causing greater knee joint load, is a potentially modifiable risk factor of knee osteoarthritis (OA). Exercise is an important treatment of knee OA, but the effect on joint load has not been determined. The aim of this study was to investigate the effect of exercise on knee adduction moment during one-leg rise and gait.

Design: Patients below age 65 with early signs of radiographic knee OA, from a population-based cohort on OA development, were invited to participate in the study. They defined their most symptomatic knee as the index knee. Knee adduction moment during one-leg rise from a stool (48 cm), and during gait was assessed using a three-dimensional motion analysis system, before and after eight weeks of supervised exercise.

Results: Thirteen patients, seven women, mean age 54.5, 12/13 with Kellgren and Lawrence grade I or II, took part in the study. Peak knee adduction moment during one-leg rise was reduced by 0.08 (95% CI 0.01;0.16) Nm/kg, or 14%, for the index knee, and 0.05 (95% CI −0.04;0.14), or 8% for the opposite knee after eight weeks. The reductions in peak adduction moment during gait were smaller and not significant.

Conclusions: This study indicates that peak knee adduction moment could be reduced by supervised, individualized exercise in middle-aged patients presenting early signs of knee osteoarthritis, suggesting further investigation of this area. Peak adduction moment during one-leg rise seems to be more sensitive to deviations and change than peak adduction moment during gait in this population.
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Key words: Adduction moment, Exercise, Gait, Knee osteoarthritis, Quadriceps, Muscle function.

Introduction

Knee osteoarthritis development is influenced through several pathways, including biomechanical factors[1]. Muscle weakness contributes to an alteration in joint biomechanics, and may cause a shift in the mechanical axis of the knee, moving joint load toward areas not capable of supporting the increased compression, causing a local overload.[1] Reduced quadriceps strength has been shown to increase the rate of loading during gait[2]. Reduced muscle function is a modifiable risk factor of knee osteoarthritis development[3,4]. Longitudinal studies on the effect of exercise on joint load are lacking.

The load acting on the medial knee joint compartment could be estimated by the external knee adduction moment, assessed by three-dimensional movement analysis[5]. The knee adduction moment corresponds to the product of the ground reaction force, acting through the foot and medial to the knee joint, and the perpendicular distance from the ground reaction force to the axis of knee joint ab- and adduction movement.

The aim of this study was to explore the effect of a moderate exercise program on knee adduction moment during a demanding task, i.e., one-leg rise, and during gait in subjects with early signs of knee osteoarthritis.

Methods

Patients were recruited from a previously described population based cohort ($n = 183$), with chronic knee pain at inclusion[6]. Inclusion criteria were age below 65, and radiographic signs of knee osteoarthritis corresponding to Kellgren and Lawrence grade I (minute osteophytes). Out of 156 patients examined in 1995, 46 fulfilled the inclusion criteria and were contacted by telephone. Six could not be reached, and 20 were excluded due to comorbidities affecting lower extremity functioning: dysfunction in back, hip or foot ($n = 10$), inflammatory joint disease ($n = 3$), previous

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knee injury ($n = 2$), chronic widespread pain ($n = 4$) and depressive symptoms ($n = 1$). Seven patients declined to participate due to lack of time, leaving 13 patients available, mean age 54.5 (5.5) years. They were included after oral and written informed consent. The study was approved by the Research Ethics Committee at Lund University, Sweden (LU 600-02), and is in compliance with the Helsinki Declaration.

EXERCISE INTERVENTION

Patients participated in supervised exercise classes twice weekly for eight weeks. The exercise program aimed at improving lower extremity strength and neuromuscular control. The rationale for choosing dynamic, weight-bearing exercises was to optimize the equilibrium of cartilage repair and degeneration[7]. Exercises in closed-chain movements activate agonists as well as antagonists at hip, knee and ankle simultaneously, and are similar to activities in daily living. Performance of exercises using knee over toes alignment involves muscles around hip, knee and ankle, and is believed to correspond to a neutral loading pattern at all three joint sites, i.e., neither varus nor valgus. Intensity of exercises during baseline was individually determined by patient's ability of sustaining the quality and control of exercise, i.e., without sudden changes in speed or direction of movement. An increase in intensity was suggested by the physical therapist when exercises could be easily performed without losing quality. The exercise program is briefly outlined below, for complete exercise program see Appendix.

After a 10 min warming up session on ergometer cycle or treadmill, exercises were performed at four stations, 3 × 15 times or 3 × 60 s (rebounder).

- Station 1: situps, hiplift and lunging forward;
- Station 2: proprioceptive task, knee bendings, and rebounder exercise;
- Station 3: knee control on slippery surface, during step up and down, and during straddle-legged body weight transfer; and
- Station 4: pulley exercises in four directions: hip extension, abduction, flexion and adduction.

Finally, stretching exercises for muscles triceps surae, quadriceps, hamstrings, and iliopsoas were performed.

Pain coping strategies, like information, goal setting and distraction, were encouraged, and pain was not considered an obstacle as long as it did not exceed what patient judged as acceptable pain, and no increased symptoms were persistent after 24 h[8]. If so, intensity was lowered until the level of pain was acceptable.

Patients were encouraged to maintain alignment during physical activities in daily life, and to perform weight bearing submaximal activity, such as walking, aerobics or skiing, for at least 30 min or two times 15 min every day.

RADIOGRAPHIC EXAMINATION

Posteroanterior radiographs of both tibiofemoral joints were obtained in semi-flexed weight-bearing position in a fluoroscopy unit[9]. Knee radiographs were classified according to Kellgren and Lawrence system[10].

The hip–knee–ankle (HKA) angle was assessed in a standing anteroposterior radiograph of the lower limb[11]. The HKA angle was defined as the lateral angle between the lines from the centre of the tibial spines to the centre of the femoral head and the talus, respectively. An angle of more than 180° denotes a varus alignment[11]. All radiographs were read by the same experienced radiologist using a thoroughly validated scientific method.[12]

Assessment of knee symptoms

The Knee injury and Osteoarthritis Outcome Score (KOOS) was used to assess patients' knee symptoms.[13,14] The KOOS is scored from 0 to 100, separately for each subscale, 0 indicating extreme problems and 100 indicating no problems. A change of 10 points or more is considered a clinically significant change[15]. The questionnaire and scoring manual can be found at www.koos.nu.

OUTCOME MEASUREMENTS

Knee adduction moment

In a previous study of the cohort from which the current patients were recruited, worse functional performance at baseline, assessed by maximum number of one-leg rise, was found to predict incident knee osteoarthritis five years later[4]. In the same report, gait speed had no predictive value. We thus hypothesized that one-leg rise would be a more appropriate task, allowing for greater deviations in peak adduction moment, and more sensitive to change over time than peak adduction moment during gait. Primary outcome was thus decided *a priori* to be peak external knee adduction moment during one-leg rise.

External knee adduction moment was assessed before and after eight weeks of exercise using a three-dimensional movement analysis system: Vicon 612 system with six 100 Hz cameras, (OMG, Oxford, UK) and AMTI force-plate (OR6-7, Advanced Mechanical Technologies) embedded in floor-level. Force data were sampled at 200 Hz. Peak external knee adduction moment was assessed during one-leg rise and during gait, and calculated by Plug-In Gait software.

Special markers, reflecting the infrared light from the cameras, were attached by a physical therapist with specific knowledge and experience within the area of motion analysis, over standardised landmarks according to the biomechanical model of Kadaba *et al.* (1990)[16] and Davis *et al.* (1991)[17].

Maximum number of one-leg rises from a stool (48 cm) is a test of maximal performance.[4] Patients were asked to perform as many one-leg rises as possible, with full muscle control, i.e., the sitting down phase should be performed with constant speed and the up rise phase without adding extensive arm or trunk movement. Knee adduction moment was assessed during the first 30 s of the maximum number of one-leg rise test. It was decided a priori that the first rise should allow the patient to adjust body position on stool without moving the foot. To avoid influence of fatigue on one-leg rise, and to have comparable data independently of how many rises a person could perform, the peak adduction moment during second rise was used as data source instead of a mean of several rises or trials.

Patients were allowed to try out the best foot-stool-position before the trial, by rising and sitting down a couple of times. Before the start of the assessment they were asked to sit with feet above the force-plate, and on a given command put down one foot and start to raise and sit-down. The order of legs tested was decided by the patient. The foot position was not to be changed during the test, and some body-weight had to be kept on the supporting leg and foot during the entire sitting-down phase. Patients decided on the length of pause before the test of the second leg. Prior to the baseline examination of functional performance, patients were asked to identify their most symptomatic knee as their index knee.

Gait was performed on a 10-m walkway in the gait laboratory, and patients were told to walk in a rapid but comfortable speed. Gait-speed and step length were assessed. Knee adduction moment was assessed in the shock absorption phase during gait[18], which occurs at approximately 10% of the gait cycle. A gait cycle starts at heel-strike and stops at the next heel-strike by the same foot. The force plate was placed in the middle of the walkway. Three trials with satisfying force plate data were collected on each leg. The mean peak adduction moment from the three trials was calculated.

DATA HANDLING AND STATISTICS

The data on knee adduction moment were obtained by manual readings from Vicon-graphs, cleared of identity information and time of evaluation. Each knee had a separate graph. To avoid bias, each graph was given a number from a random number list by the last author (ER). The code was not available to the graph reader until all graphs were read and the data were entered into a PC.

It was decided a priori that the index knee and opposite knee should be analysed separately. Results are given as mean (SD) if nothing else is stated. Wilcoxon's signed rank test was performed to study changes of KOOS subscales from baseline to eight weeks. *p*-Values of less than or equal to 0.05 were considered to be significant, and all tests were two-tailed. Using the parametric paired *t*-test did not change the results, and was therefore used to determine 95% CI for change. Changes in peak adduction moment from baseline to eight weeks were determined by paired *t*-test (supported by PP-plots and Shapiro–Wilk statistics > 0.95). Correlations were calculated using Spearman's rank correlation test. Analyses were performed using SPSS 13.0 for Windows[19].

Results

Baseline characteristics of the 11 patients who completed the study and the two drop-outs are shown in Table I. For the index knee, peak adduction moment *during one-leg rise* was reduced after eight weeks of exercise (mean change −0.08 Nm/kg (95% CI −0.01;−0.16)). For the opposite knee, the change in peak adduction moment during one-leg rise from baseline to follow-up was not statistically significant (mean change −0.05 (95% CI 0.04;−0.14)). *During gait*, no significant changes were seen for the index knee or the opposite knee in peak adduction moment (mean change 0.02 (95% CI 0.06;−0.03) and −0.03 (95% CI 0.04;−0.09) for the index knee and opposite knee, respectively, Fig. 1.) Generally, the exercise-induced changes in knee adduction moment were larger during one-leg rise than during gait.

The average number of attended exercise classes was 13 (range 10–16) out of 16 possible. Gait speed at baseline was on average 1.35 (0.16) m/s, and mean step length was 0.69 (0.07) m. These parameters did not change after the intervention ($p = 0.24$ and 0.11, respectively).

Discussion

This study indicates that a supervised and individualized exercise program of moderate intensity could reduce peak knee adduction moment in patients with mild to moderate knee osteoarthritis. In addition, in this group of patients, knee adduction moment during one-leg rise might be more sensitive to change than knee adduction moment during gait. These results suggest a need for further investigation of this area.

The peak adduction moment during gait was not significantly reduced from exercise (Fig. 1). Previous studies have shown that peak adduction moment during gait is

Table I
Baseline characteristics

ID	Age (years)	BMI (kg/m^2)	Gender	Index knee	KOOS* pain 0–100 worst–best	Stride length (m)	Gait speed (m/s)	Medial JSW† (mm)		Kellgren and Lawrence		HKA‡ (degrees)	
								Index	Opposite	Index grade: 0/1/2/3/4	Opposite grade: 0/1/2/3/4	Index	Opposite
	Md 53	Md 25.5	54% Women	54% Left knee	Md 97	Md 1.40	Md 1.36	Md 4.1	Md 4.1	$n = 2/5/5/1/0$	$n = 2/7/4/0/0$	Md 182	Md 181
1§	48	37.8	F	Left	100	1.54	1.56	4.3	4.1	1	2	182	180
2	56	23.1	F	Right	69	1.44	1.72	3.5	3.5	0	0	183	183
3	50	25.5	M	Left	78	1.36	1.35	3.7	4.4	1	1	188	185
4	61	28.9	M	Right	64	1.58	1.40	6.8	7.0	2	1	181	181
5	48	24.1	F	Left	97	1.40	1.30	5.0	4.4	1	1	178	178
6	53	24.8	M	Right	100	1.11	1.14	4.1	3.3	2	1	175	176
7§	60	27.5	F	Right	97	1.13	1.24	4.3	3.8	2	1	184	183
8	59	23.4	F	Right	89	1.39	1.42	4.1	4.7	0	2	179	180
9	49	27.6	M	Left	100	1.47	1.36	3.5	3.8	2	1	186	186
10	63	26.7	M	Right	100	1.51	1.40	3.1	4.5	3	2	186	185
11	49	24.3	F	Left	94	1.39	1.45	3.7	3.9	2	1	178	179
12	53	22.2	F	Left	100	1.24	1.13	3.8	3.9	1	0	181	181
13	60	30.3	M	Left	64	1.40	1.21	6.7	5.3	1	2	189	186

*Knee injury and Osteoarthritis Outcome Score, 0–100 worst to best scale[13,14].

†Joint space width in millimetre.

‡Hip–knee–ankle alignment. An angle of more than 180° denotes a varus alignment, and less than 180° a valgus alignment[11].

§Drop-out during intervention.

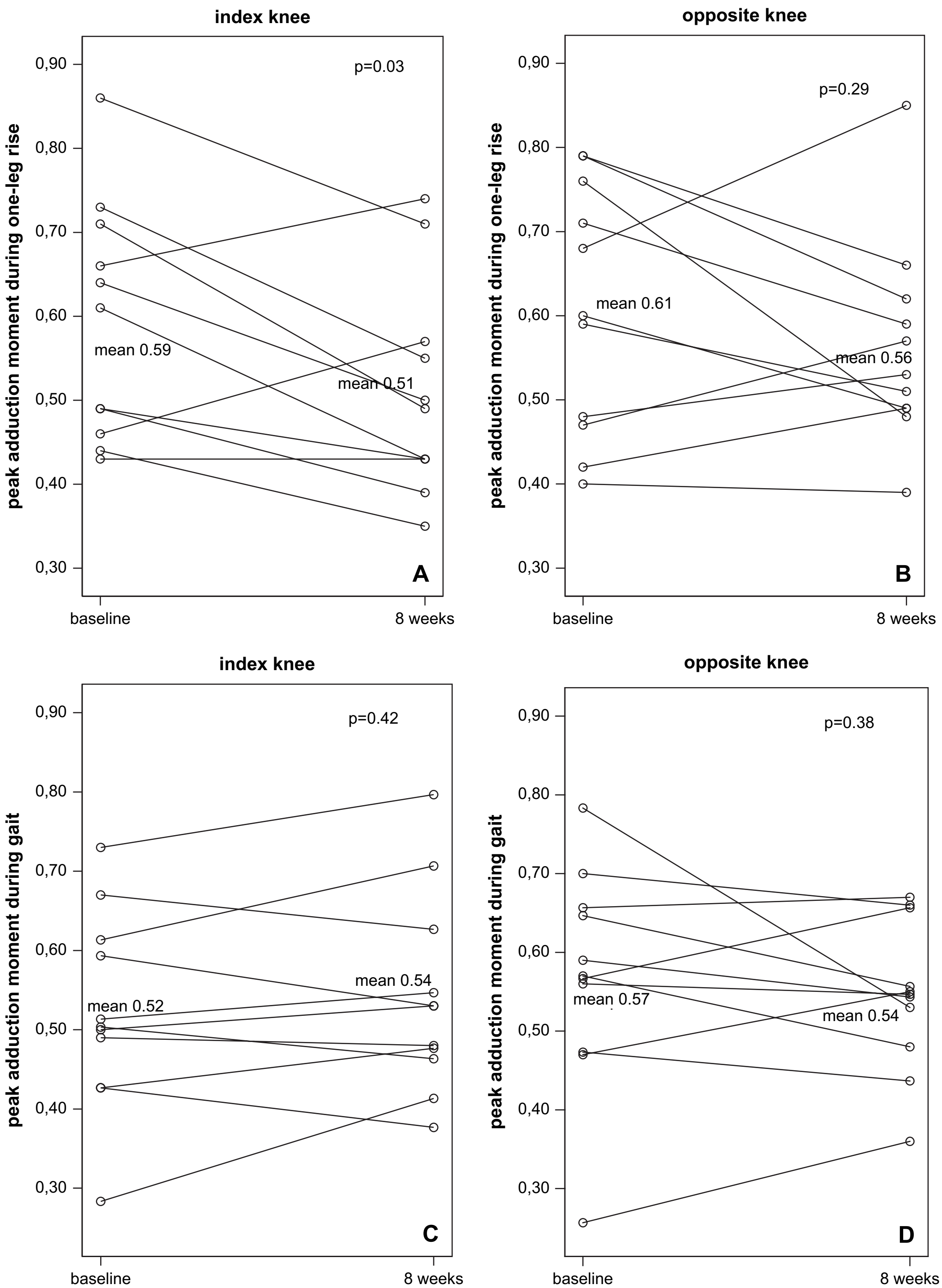

Fig. 1. Change over time in peak adduction moment during one-leg rise (A and B) and during gait (C and D) in index and opposite knees.

related to joint space width and severity of knee osteoarthritis, with higher levels of peak adduction moment in subjects with reduced joint space width and more severe disease[20,21]. The present study population had mild to moderate disease, and the minimum joint space width was 3.1 mm (Table I). This might contribute to generally low peak adduction moments during gait, similar to levels described in knee-healthy individuals[20]. An increase in muscle function may therefore not have further beneficial effects on adduction moment during gait in subjects with mild knee osteoarthritis. The mean peak adduction moment at baseline, and the mean changes after eight weeks is larger during one-leg rise, suggesting that a more demanding test might be needed to detect deviations in joint load in subjects with less severe disease. It is possible that other parameters during gait, not examined in the present pilot-study, are more sensitive to change in middle-aged patients with mild disease severity. The clinical importance of the reduction in peak adduction moment during one-leg rise of 0.08 Nm/kg, or 14%, is yet to be determined. Previous studies of valgus bracing[22,23] and wedged insoles[24] have shown a reduction of 13 and 8%, respectively. It has been suggested that every 20% increase in knee adduction moment increases the risk of radiographic progression six years later by six times,[25] and that an 8% increase in peak adduction moment increases the risk of developing chronic knee pain three to four years later.[26]

The primary concern of this study is the small number of patients and the lack of control group. This limits the possibilities of interpreting the results and controlling for possible confounders. Previous data on effects from exercise interventions on joint kinetics are rare, and this study is thus important but should be considered a pilot-study.

The Vicon system uses manually defined anatomical landmarks to calculate the joint centres and axis. This might reduce the reliability of the knee adduction moment assessment. It cannot be excluded that the placement of markers has influenced the results of the present study. It is not possible to determine if this factor would have strengthened or weakened the results. To minimize the influence of the marker placement all markers on all patients were applied by the same physiotherapist, with several years of experience from this application.

Factors that have been proposed to affect knee adduction moment, besides joint space width,[21] are toe-out angle,[27] gait speed,[20,28] stride length,[5] static hip–knee–ankle alignment,[18,27,29] and pain.[18,30,31] It has been suggested that one-leg stance would diminish the influence of toe-out angle, gait speed and stride-length on peak knee adduction moment, but still allow assessment of knee adduction moment.[32] In the present study, peak adduction moment was assessed during one-leg rise, and the foot position was not changed during the test. Kinetics were analysed in the frontal plane only. It is possible that mechanical compensations in hip or ankle occurred during rising, changing the lever arm of the ground reaction force, and thereby affecting the peak knee adduction moment.[5] However, these factors could have influenced results in both directions. Patients in the present population had overall mild disease, with only minor impact of knee osteoarthritis on symptoms and radiographic as well as kinematic data compared to patients with more severe disease described in previous studies[18,20] (Table I). Exercise has a moderate effect on pain in knee osteoarthritis.[33] In the present study neither pain nor the kinetic variable did change after the exercise intervention. This could be due to lack of power, and the mild disease severity in the present population. It has previously been suggested that a reduction in pain is associated with an increase in knee adduction moment during gait,[34] but not during more demanding activities such as stair stepping.[30] A reduction in pain or an increase in gait speed or step length from the exercise intervention would most likely have increased the peak adduction moment.[20,28,30,35] The importance of a reduction in knee adduction moment at follow-up might therefore be even more pronounced than shown.

Conclusion

Eight weeks of supervised exercise, aiming at increasing lower extremity strength and neuromuscular control, can possibly reduce peak knee adduction moment in middle-aged patients with early radiographic signs of knee osteoarthritis. Peak adduction moment during one-leg rise seem to be more sensitive to deviations and change than peak adduction moment during gait in this group of patients with mild to moderate disease.

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Conflict of interest statement: The author(s) declare that they have nothing to disclose.

Appendix. Eight week exercise program for patients with knee osteoarthritis

Subjects performed lower extremity weight-bearing exercises aimed at increasing neuromuscular control and lower extremity strength.

Following a 10-min warm-up on a treadmill or bicycle at low intensity exercises were performed at four stations (Described as station 1–4 below). Station 1–3 consisted of three exercise tasks, numbered 1.1–3.3. Each exercise task comprised several levels of intensity, ranging from low to high, and described as 1.1.1–3.3.3 below. Station 4 consisted of pulley exercises in four different directions and one advancement in intensity. Intensity was determined by the supervising physiotherapist, and individually increased during the eight-week intervention. To allow for a higher level of intensity subjects had to be able to perform the exercise easily and correctly at the lower level. Three sets of each task were performed on each station before moving to the next station. Tasks were performed with sustained neuromuscular control, i.e., without sudden changes in speed or direction. Patients were told to perform each task with full muscle control, so that on demand the movement could be stopped at any time and position. This was tested by the physiotherapist now and then during the session. Patients were instructed to align the knee over the toes throughout all exercises.

Pain during exercise was not considered an obstacle as long as it did not exceed what patient judged as "acceptable" pain, and there was no increase in symptoms after 24 h. If so, intensity was temporarily lowered until the level of pain was acceptable.

After the full exercise program, stretching exercises were performed, using hold-relax technique, for hamstrings, quadriceps, iliopsoas and triceps surae.

1. Station
  1.1. Exercise Task – hiplift
    Lying supine, one leg placed with foot on a twinball, knee in comfortable flexed position. The other knee flexed and held against the belly with both hands (Fig. 1). Lift and lower pelvis 15 times per leg.
    Advancement of exercise
      1.1.1 Perform hiplift with knee of performing leg maximum flexed
      1.1.2 Perform hiplift with knee of performing leg alternately flexed and extended
      1.1.3 Keep hips lifted during completion of the task. Flex and extend knee 15 times with hips lifted

1.2. Sit-ups

Lying supine, knees flexed and feet on the floor. Raise the shoulders 15 times with hands reaching the knees/thighs.

Advancement of exercise
- 1.2.1 Performed with arms kept on the chest
- 1.2.2 Performed with hands held at the top of head
- 1.2.3 Performed with arms held over the head, along body line
- 1.2.4 Performed with arms held over the head along bodyline, holding a medicine ball of 1 kg

1.3. Lunging forward

Standing upright. Put one foot forward in a large step. Smooth landing with a knee bending, until the behind knee almost touches the floor. Push back to standing position with the front foot. Perform task 15 times per leg.

Advancement of exercise
- 1.3.1 Perform exercise with arms hanging by side and holding dumbbells (weight individually chosen)
- 1.3.2 Perform exercise with barbell on top of shoulders behind the neck
- 1.3.3 Perform exercise with bar-bell on top of shoulders, behind the neck. Twisting barbell toward front knee during the knee bending

2. Station

2.1. Proprioceptive task

Lying prone on a traverse board, placed against a set of wall bars. Top of board 136 cm above the floor. A soft-ball, diameter 34 cm, is placed under the belly, one foot lifted (Fig. 2). Starting position: the flexed knee of non-supporting leg rests on traverse board. Flexing and extending the knee of the supporting limb 15 times, with knee kept in line with the toes.

Advancement of exercise
- 2.1.1 The non-supporting leg is extended and abducted to lateral of the traverse board
- 2.2.2 The non-supporting leg extended and abducted to lateral of the traverse board, simultaneous neck rotation from side to side

2.2. Knee bendings

Standing in front of stool, bend both knees and lower the body until the buttock touches the stool. Don't sit down. Starting position: arms hanging by side. Repeat 15 times.

Advancement of exercise
- 2.2.1 Perform exercise while holding a medicine ball/bar bell in front of chest
- 2.1.2 Perform exercise while holding a medicine ball/bar bell in front of chest. Extend the knees and perform a jump. Lift medicine ball/bar bell over the head at take-off. Perform a smooth and "quiet" landing by flexing the knees, lowering the medicine ball/bar bell and absorbing the speed

2.3. Rebounder

Sixty seconds performance. Starting position: straddle-legged standing on rebounder with both knees flexed, and hips externally rotated to align knees over toes. Move of body weight from side to side by lifting feet alternately.

Advancement of exercise
- 2.3.1 Straddle-legged jumping from side to side, with high knee lifts
- 2.3.2 As 2.3.1 with medicine ball, 3 kg, in front of belly. Moving ball from side to side in opposite direction of jump
- 2.3.3 As 2.3.1 with medicine ball, 3 kg, lifted over the head. Moving ball from side to side in opposite direction of jump

3. Station

3.1. Sliding path

Standing on a slippery surface, or with pieces of cloth under each foot. Unilateral knee bending with knee over toes, with opposite leg sliding in abduction. Use hip adductors to pull back the abducted leg to return to standing up-right position. Perform task 15 times per leg.

Advancement of exercise
- 3.1.1 Unilateral knee bending, with opposite leg sliding in extension. Transfer body weight to the extended leg and pull back the front leg to return to standing up-right position. Turn around and continue
- 3.1.2 Skating from side to side, with push off against a wall or border

3.2. Step-board

Standing in front of the step-board. Step up with both feet on the step board and backwards down again with one foot first at the time. Repeat 15 times per leg. Height of step-board: 13, 18 or 23 cm. Each height allows for all levels of task.

Advancement of exercise
- 3.2.1 Stand on step-board. Dip the heel and toes of one foot alternately in front of and behind the board, without putting weight on.
- 3.2.2 As 3.2.1 with barbell on top of shoulders, behind the neck. Weight individually chosen.

3.3. Straddle-legged body weight transfer with knee-bending and extension

Straddle-legged standing with flexed knees on soft surface. Hips externally rotated. Move of body weight towards one side without lifting feet from ground. Return to position with both knees flexed. Fifteen times per leg.

Advancement of exercise
- 3.3.1 Lifting the non-weight bearing foot and knee during weight transfer
- 3.3.2 As 3.3.1 with an "explosive" jump-up on one leg. Land smooth on both feet with knees flexed
- 3.3.3 As 3.3.2 with simultaneously lifting medicine ball over the head during take-off

4. Station − pulley exercises in four directions

Standing with extended knees and weight (or rubber band) attached around one foot. Self-chosen weight load (0−2 kg). Pull leg 15 times in each of the following directions: hip extension + internal rotation, hip abduction, hip and knee flexion, and hip adduction. Aim at performing 15 times in all directions on one leg, without touching the floor with the performing foot, before changing the supporting leg. Starting position: stand with both knees extended.

4.1 Standing with knee of supporting leg slightly flexed, but pulley knee extended (need hip abduction of the supporting leg)

STRETCH

Starting position for stretching exercises individually chosen for each muscle group; lying, sitting, kneeling or standing, depending on the abilities of the patient. After finding the most stretched position of each muscle group, an isometric contraction was performed for 12–15 s, followed by a relaxation of 2–3 s and a stretch for 15–20s or more. Muscle groups were iliopsoas, hamstrings, quadriceps, and triceps surae.

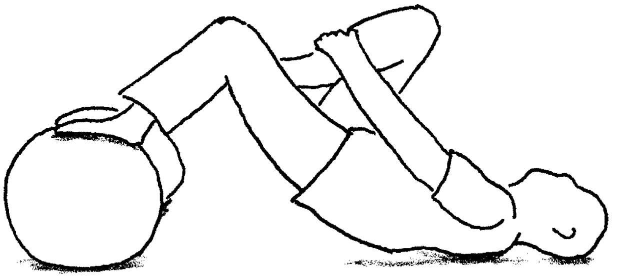

Fig. 1. Task 1.1 Hiplift, starting position.

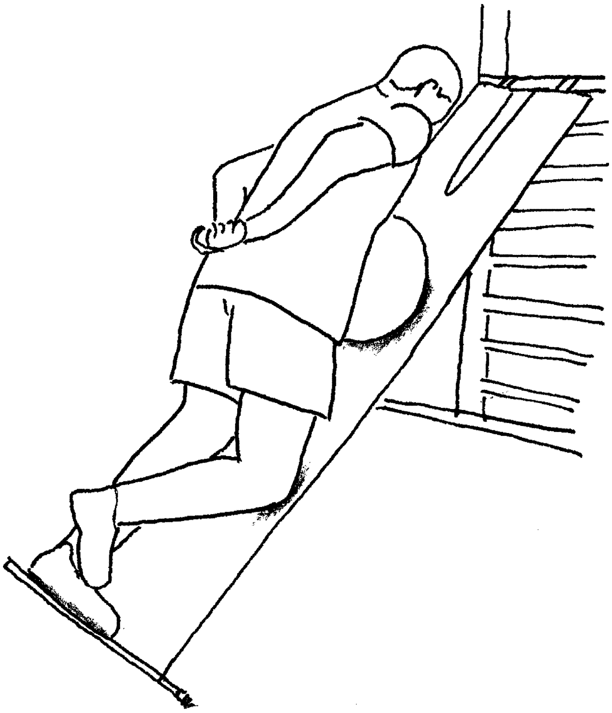

Fig. 2. Task 2.1, Proprioceptive task, starting position.

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