# MUSCLE TRAINING IN CHRONIC ANTERIOR CRUCIATE LIGAMENT INSUFFICIENCY—A COMPARATIVE STUDY

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**ABSTRACT. The aim of the investigation was to study and compare the effect of two basically different training methods on muscle strength and knee function on a consecutive and prospective series of 26 conservatively treated patients with chronic anterior cruciate ligament injury. The two training models were: model Q directed towards specific training of knee extensor muscle strength and model F aiming at training of the lower extremity and trunk muscles in functional weightbearing patterns. The parameters evaluated were: isometric and isokinetic muscle strength, a performance test (one-leg hop test), and a functional score. The results after a three-month training period showed in both groups a significant increase of muscle strength in both knee extensors and knee flexors. No significant difference of isokinetic strength values between the two groups was observed. The isometric gain of knee extension was significantly higher in the Q group. The one-leg hop test value and the functional score were also significantly increased in both groups. However, the hop test indicated a more favourable result in the group who were trained functionally.**

*Key words:* anterior cruciate ligament lesion, conservative treatment, chornic insufficiency, functional training, strength training, functional score, performance test.

Weakness of the knee extensor muscles is frequently found in chronic cases of anterior cruciate ligament (ACL) lesion (5, 6, 10, 14). Therefore, rehabilitation programs are usually directed mostly towards restoration of knee extensor strength (4, 8, 10). Computed tomography has revealed a decrease in the muscle square area of the affected thigh. Less atrophy was observed in the hamstrings and calf muscles (6). On the other hand, absence of any reduction in the muscle volume does not necessarily imply that the muscles have a normal function during situations which require postural supporting reactions. It has been claimed that an adequate reflex control of the hamstrings muscles may counteract giving-way episodes caused by a tibio-femoral subluxation (pivot shift phenomenon) (15). Therefore, training of the hamstring muscles has been advocated (7, 13) and the need of a more functional rehabilitation program has been stressed (2, 16). It is reasonable to assume that lower extremity function depends not only on knee muscle strength. In addition, an efficient function of the hip and trunk muscles is needed in order to stabilize the body segments and provide an adequate positioning of the centre of gravity in relation to the supporting area of the foot. Comparative studies have until now been confined to different knee extensor training programs only (8, 17) and the effect of so-called functional training programs has not yet been studied.

The following study was performed to compare and evaluate the effect of two basically different training models on muscle function in patients with a long-standing instability of the knee due to a late diagnosed rupture of the anterior cruciate ligament. One of the models (model Q) represents a version of progressive resistance quadriceps exercise (3) while the other one (model F) has a more functional approach aiming at an improvement of the total extremity and trunk muscle function.

The aim of the study was to compare the effect of the two training models on muscle strength and knee function.

## PATIENTS AND METHODS

In this prospective study 26 consecutive patients with chronic ACL injuries caused by different sports activities were assigned to two different training models for rehabilitation, due to serious symptoms of instability of the knee joint. Before entering the training programs at the Department of Physical Medicine all patients underwent a clinical examination by one of the orthopedic surgeons of the team. The following clinical criteria were required for being selected to the training programs:

- signs of anterior cruciate ligament insufficiency, with at least Lachman 2+ and a positive pivot-shift test

- no other clinical signs of major ligament injuries of the affected limb
- no disabling clinical signs of meniscus lesion
- an uninjured contralateral lower extremity
- normal weight-bearing radiographs.

The group consisted of 14 men and 12 women. Mean age was 24.8 years (range 15–43). The left leg was injured in 18 cases while 8 patients had an injury of the right leg. Mean time since injury was 22 months (range 1–96). All patients had been physically active before the time of the injury practising different athletic sports on a low to moderate activity level. The most frequent cause of injury was contact sports like soccer (10 cases). None of the patients was able to perform any kind of athletic sport by the time the training period started. None of the patients was an athlete on a professional level and none was eager to go back to any contact sport after finishing the treatment program. All patients experienced giving-way episodes of varying degree of severity and frequency in situations connected with activities of daily living like running for the bus or, in serious cases doing a relaxed rotating movement of the body when the injured leg was weightbearing. In no case was pain a major problem. The pivot-shift tests were graded 2 ("obvious jerk") in 16 and 3 ("impingement") in 6 cases. The remaining four patients had a slight instability ("subtle slip"). During the training period three patients (two men and one woman) interrupted the training for personal reasons. Due to this, only 23 of the 26 patients were re-examined after three months.

## METHODS OF ASSESSMENT

The following assessments were used for the evaluation of the training methods:

1. *Strength measurement of knee and hip muscles.* Isometric and isokinetic strength measurements were made using a Cybex II device (Lumex Inc., New York, USA) connected to an ink jet-writer (mingograph Elema Schönander, Sweden).

Isometric muscle strength: The strength of the knee extensors and flexors was measured with the patient fixed in a back supported sitting position, arms folded in front of the body, with hips in 90 degrees and the knee in 60 degrees of flexion. The strength of the hip abductors and adductors was measured in a side lying position, the pelvis fixed firmly, the measured hip in 25 degrees of abduction. Three maximum contractions with rest periods of at least 5 sec were performed and the mean peak value calculated. The hold-duration was 3 sec.

Isokinetic muscle strength: The strength of the knee extensors and flexors was measured in the sitting position described above. The mean peak torque of ten consecutive isokinetic contractions was calculated. The angular velocity was 30 and 90 degrees per second respectively. All measurements started with the right leg. Both legs were measured. The relative strength of the injured leg compared to the uninjured one was expressed as a quotient.

2. *A performance test* (one-leg hop test) according to Tegner et al. (14). The hop was done three times with each leg and the longest distance was recorded.

3. *The modified functional score of Lysholm* (14). The items included were pain, limp, support, locking, instability, swelling, stair-climbing, and squatting. The score was based on the clinical experience of the patient. The maximum normal score is 100 points.

The time since knee injury, mean age, muscle strength, Lysholm score and performance test for both groups before training are given in Table I. There was no significant difference between the groups with regard to any variable before training. When the injured side was compared to the uninjured one, significant reductions were noted with regard to isometric and isokinetic (30°/s) knee extension strengths and the one-leg hop test.

## STATISTICAL METHODS

The analysis was performed using independent and paired $t$-tests. The Wilcoxon signed-ranks test was used in the case of ordinal-scale data. A level of $p<0.05$ was chosen for statistical significance.

## METHODS OF TRAINING

The two training programs were: Training program Q = exercise of the quadriceps muscle specifically. Training program F = exercise of the whole leg and the trunk in loaded functional patterns. Both training programs comprised exercises starting with the uninjured leg followed by the same program for the injured side.

Both patient groups were given an individual introduction comprising a simplified lecture in functional anatomy concerning the knee joint and its ligamentary construction. The purpose of this lecture was to give information which is important for understanding the mechanisms of the giving-way episodes. Emphasis was placed on teaching each patient how to avoid these painful incidents and preparing an optimal motivation for training.

Both patient groups underwent a twice-a-week training period of three months individually instructed by physical therapists at the Department of Physical Medicine. All the therapists followed the same training procedures in detail. Each training session lasted for 45–60 min. The patients were instructed to train at home every day and were gradually allowed to increase their activity level. (For detailed descriptions of training programs, see appendix).

### *Training program Q*

The training consisted of static contractions and dynamic movements in order to train the quadriceps muscle selectively. In total the patient performed four different exercises, individually adapted to the patients' activity level as regards the numbers of repetitions. The first exercise was the activation of the knee extensors in repeated contractions with the foot dorsally flexed and the knee straight. The contraction of the muscles lasted 20 sec and was repeated five times. The second exercise consisted of quadriceps contractions with the patient sitting on a quadriceps table making static and dynamic contractions with weights. The static contractions were performed according to the principles of de Lorme (3) with maximal load at 60 degrees. The dyanamic contractions were made from 90, 45 and 15 degrees of flexion. Repetitions were made from each position 10 times in a modified de Lorme model. The third exercise was straight leg raising with the foot dorsally flexed. The movements took 20 sec each and were performed ten times. The last exercise consisted of static contractions standing with the knees and hips in 90 degrees of flexion with the back pressed against a wall. This isometric exercise lasted 20 sec and was repeated 10 times.

*Training program F*

This training program comprised exercises for training the trunk as well as the leg muscles in functional synergies. The guiding principle of the training model was not only to increase muscle strength but above all to acquire motor control by loading the extremities in movements challenging equilibrium of the body. To achieve this purpose the program combined low-activity stabilizing positions of the trunk with dynamic movements of the leg, using the foot or the extremity as a fulcrum for movements acting on the proximal joints of the extremities (Fig. I). The program always started with the patient in lying position with exercises for the abdominal oblique muscles of the uninjured side followed by the same movements for the side of the injured extremity. This order of training, starting with abdominal exercises was continued during the whole training period. The program consisted of different steps of advancement, gradually comprising more complex and difficult movements. The patients were not allowed to proceed before having muscular control of less demanding functional muscle synergies. As a criterion for allowing this advancement the reaction time and quality of muscular response on loading was used, comparing the performance with that of the non-injured side. When adequate functional ability was observed by the therapist the patient was allowed to advance in the training, doing movements of different speed, jumping, turning, squatting, throwing balls while running.

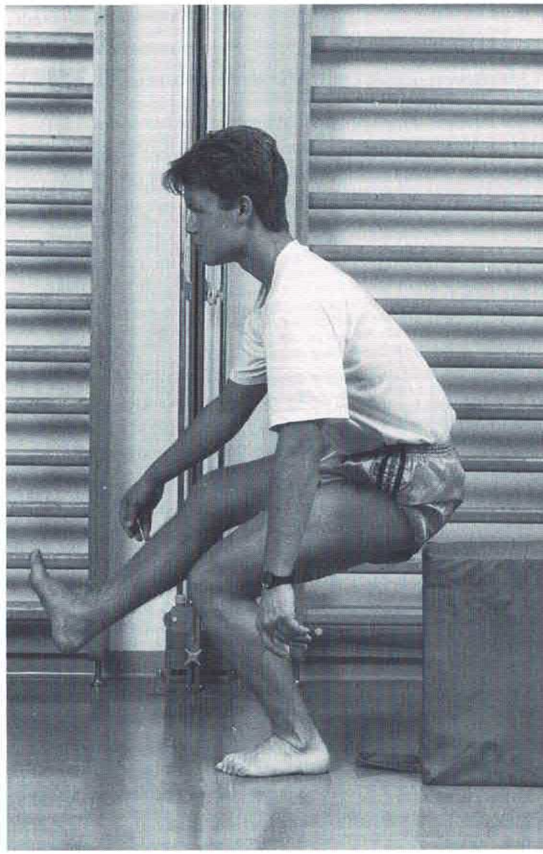

*Fig. 1.* A knee extension exercise of the functional training program. The subject rises from the sitting position.

## RESULTS

*Muscle strength.* After three months of training both groups showed a significant increase of isometric knee extension strength ($p<0.001$) of the injured leg. The training method Q, however, increased strength significantly more than the other technique ($p=0.01$). On the other hand, there was no significant difference between the two training groups with regard to the increase of knee extensor strength measured isokinetically at 30 and 90 degrees per second. The muscle strength increased also in the non-injured leg in both groups. At three months, there was no significant difference between the injured and the non-injured side, irrespective of training groups or strength tests. Before training, 11 patients of the total material had a relative knee extensor strength (ratio injured/noninjured leg) exceeding 0.9. After the training period the number increased to 17 and 18 of 23 patients concerning isokinetic and isometric strength respectively.

Before training the isokinetic and isometric knee flexor strength were only slightly reduced in the injured leg as compared to the non-injured side (Table I). The difference was not significant. Ten and 16 patients respectively of the total 26 had initially a relative knee flexor strength exceeding 0.9 for the different parameters. After the training period increased strength values were recorded on both sides. There was no significant difference in this respect between the two training groups.

The isometric strength of the hip adductors and abductors was virtually the same on both sides (Table I). In 18 and 21 cases respectively the relative muscle strength exceeded 0.9 before training. At re-examination after three months the strength values had increased bilaterally without any significant difference between the training groups.

The one-leg hop distance was significantly reduced in the injured compared to the uninjured leg in both groups before training (Table I). The performance improved after the training period without significant difference between the groups. In the F-group, however, there was no longer any significant difference be-

Table I. *The duration of the ACL-lesion, mean age, muscle strength of the injured (I) and uninjured (U) leg respectively, Lysholm knee score and one-leg hop test before training*

Ext. = knee extension, Flex. = knee flexion, Abd. = hip abduction, Add. = hip adduction, isom. = isometric contraction, isok. = isokinetic contraction

| | | Q-group | F-group |
|---|---|---|---|
| *N* (M/F) | | 9 (4/5) | 17 (10/7) |
| Mean age | | 27.4 | 23.6 |
| Duration mean (range, months) | | (1–96) | (1–76) |
| Muscle strength Nm (mean ± SD) | | | |
| Ext. | I | 138 ± 66 | 147 ± 63 |
| Isom. | U | 186 ± 66 | 175 ± 63 |
| Flex. | I | 91 ± 37 | 87 ± 38 |
| Isom. | U | 93 ± 39 | 98 ± 36 |
| Abd. | I | 113 ± 22 | 106 ± 26 |
| Isom. | U | 107 ± 29 | 110 ± 33 |
| Add. | I | 91 ± 20 | 77 ± 27 |
| Isom. | U | 77 ± 24 | 74 ± 31 |
| Ext. | I | 139 ± 45 | 136 ± 56 |
| Isok. 30°/s | U | 155 ± 50 | 157 ± 47 |
| Ext. | I | 112 ± 26 | 121 ± 45 |
| Isok. 90°/s | U | 131 ± 36 | 131 ± 38 |
| Flex. | I | 96 ± 27 | 97 ± 33 |
| Isok. 30°/s | U | 106 ± 23 | 102 ± 26 |
| Flex. | I | 92 ± 26 | 95 ± 30 |
| Isok. 90°/s | U | 100 ± 25 | 98 ± 29 |
| Lysholm knee score | | 76.4 ± 12.5 | 71.8 ± 12.4 |
| One-leg hop test (cm) | I | 127 ± 39 | 142 ± 43 |
| | U | 165 ± 36 | 172 ± 33 |

tween the mean values of the injured and the non-injured side respectively. In the Q-group the difference between the sides was still significant ($p=0.003$).

The Lysholm score increased significantly in both groups without difference between the groups. Before training the knee score was good/ excellent (> 83) in 6 patients. After the training period 10 out of 15 patients in the F-group had a score higher than 83 points, and in the Q-group 8 out of 9.

Patient compliance in both groups was good. Most patients, however, reported that knee extensor strengthening alone was dull whereas the functional training was varied and stimulating.

## DISCUSSION

Most patients included in this prospective study had a long-standing impairment and disability with decreased functional level and giving-way episodes. Their functional capacity was greatly reduced, and they had instability problems in daily life activities (5), but no major pain problems except in relation to giving-way episodes. Twenty out of 26 patients had a Lysholm score below 83 points. Performance as measured by the one-leg hop test was significantly reduced. Muscle strength, however, was on an average only moderately reduced. Compared to the non-injured side, strength in the injured side was reduced significantly only in the knee extensors. Measurement of the isokinetic and isometric knee flexor strength did not reveal any significant difference between the sides. The same is valid for the strength of the isometric hip adduction and abduction. If the strength values are compared to those of healthy subjects (1) a reduction of the muscle strength of the non-injured side also, might be suspected in the cases of the present study.

The strict selection criteria of the present study were chosen in order to obtain as homogeneous a patient group as possible. More severely damaged knees with multiple ligament lesions were not included. This might explain why muscle strength on the average was only moderately reduced.

The measurement of the isometric knee extensor and flexor strength was performed according to the principles generally recommended. The calculation of the isokinetic strength values, however, was based on the average torque of ten maximum consecutive contractions. An analysis of the single torque values did not indicate any influence of fatigue. The average of ten isokinetic maximum contractions was therefore considered to be representative of dynamic muscle strength. Isometric hip adductor and abductor strength were measured in a side lying position. During the measurement not only the acting hip is loaded but also the stabilising opposite hip on which the patient is lying. Since the pelvis was fixed firmly against the bench the load on the opposite hip muscles was minimized.

The reduction of muscle strength was only slight for knee extensors (20% reduction for isometric and 10% for isokinetic values) and insignificant for the other muscles tested. The recurrent giving-way episodes reported can thus hardly be ascribed to reduced maximum strength. Twenty-two of the 26 patients had a moderate or severe instability according to the pivot-shift tests. This mechanical instability probably induces afferent inhibition of muscle function during weight-bearing. In addition, the loss of proprioceptive sensory inflow from the ruptured ACL may contribute to the impairment of postural fixation of the knee joint (4).

Training improves muscle function as reflected by isometric and isokinetic strength, functional score and performance test. Our findings are in confirmity with previous studies (e.g. 14). However, results of training programs with a functional approach have not been published before. In the present study, progressive resistance quadriceps exercises were found to be more efficient than the functional training technique as far as isometric knee extension strength was concerned. There was, however, no significant difference between the two groups when the isokinetic muscle strength was measured.

From a biomechanical point of view the so-called functional training technique has a clear advantage. When the knee joint is loaded in a flexed position, e.g. during functional extension exercises (Fig. 1), there is a co-contraction of the knee extensors and knee flexors. The knee flexors counteract the ACL strain caused by the knee extensors (12). During conventional strength training of the knee extensors these muscles put a considerable force component on the tibia in an anterior direction between 0 and 60 degrees of flexion (11, 12) without simultaneous activation of the knee flexors. The stabilizing effect of well-trained hamstring muscles has been demonstrated (9, 13).

In spite of the basically different approach in neuromuscular re-education both groups improved in isometric as well as in isokinetic strength values and in functional capacity as measured by means of the performance test and the knee score. The conventional progressive resistance quadriceps exercises were superior concerning their specific effect on the isometric knee extension. On the other hand, the results of the one-leg hop test indicate a more favourable effect of the functional training method. The advantage of the latter method is the more physiological approach comprising other functions involved in normal movements: postural reactions in combination with voluntary movements.

## APPENDIX

### *Two training programs (Q and F) for conservatively treated patients with chronic anterior cruciate ligament injury*

Patients underwent a twice-a-week training period of three months individually instructed by physical therapists. Each training session lasted for 45–60 min. The patients were instructed to train at home every day.

#### *Training program Q (Exercise of the quadriceps muscle specifically)*

Training always starts with the non injured leg in order to enable the patient to perceive the difference in activating muscles of the injured compared with the non injured leg.

Exercise no. 1.
*Training:* Knee extensors.
*Position:* Sitting with legs extended on a couch, relaxed knees, hands behind the body.
*Performance:* 5 knee extensions lasting 20 sec, 1 sec relaxation between contractions.
Thereafter a series of 10 continuously repeated contractions.

Exercise no. 2.
*Training:* Knee extensors (following a modified routine in accordance with the principles of de Lorme). Each load to be administered is calculated by testing the maximum isometric knee extensor torque at 60 degrees of flexion.
*Position:* The patient is sitting on a quadriceps table, the leg attached to a loaded lever arm, the arms folded in front of the body.
*Performance:* 3 series of 10 dynamic extension movements of the knee joint, starting from 90, 45, and 15 degrees of flexion respectively, are performed with weights equivalent to 75% of maximum torque.

Exercise no. 3.
*Training:* Knee extensors, dorsiflexors.
*Position:* Lying supine with dorsiflexed foot.
*Performance:* The leg is slowly raised from the couch as far as possible keeping the knee joint maximally extended and then lowered to the starting position.
This exercise is repeated 10 times with 20 sec of relaxation between the movements.

Exercise no. 4.
*Training:* Knee extensors.
*Position:* Standing with the back against a wall, holding an isometric contraction of knee and hip joints in 90 degrees of flexion.
*Performance:* This position is repeated 10 times during 20 sec with 20 sec between each performance.

The training is intensified by increasing the weight and number of repetitions of movements when muscle strength is improved.

#### *Home training program Q*

The patient is instructed to perform the same training program as at the clinic twice daily during the three-month training period, starting with one exercise, then adding the others, one by one, every second week in the following order:

Exercise no. 1.
This exercise should be performed over a period of 2 weeks, then adding the following exercise:

Exercise no. 2.
Sitting on a table or a chair extending the knee fully against weights fixed to the ankle, holding isometrically for 20 sec, lowering the leg to the starting position with 20 sec between movements. 10 repetitions.

Exercise no. 3.
This is added to the two previous ones after 6 weeks of the training period.

Exercise no. 4.
This is added after 8 weeks of the training period in addition to the previous three, and performed during the remainder of the three months.

*Traning program F (Exercise of the whole leg and the trunk in loaded functional patterns)*

This program is based on training synergists generating postural reactions of the whole body. When using different joints as fulcrum of movements the result is a co-contraction of agonists/antagonists around the joint acted upon (Fig. 1). The principal goal is to obtain motor control in provoking situations where the injured leg is loaded.

Exercise no. 1.
*Training:* Oblique abdominal muscles.
*Position:* Side lying uninjured/injured side.
*Performance:* Curl up with hips and knees flexed 45 degrees and then extend. 25 repetitions or to the level of capacity of the patient.

Exercise no. 2.
*Training:* Hip extensors, knee extensors, dorsiflexors.
*Position:* Lying supine with one leg slightly flexed, the lower leg resting on a Bobath ball (diameter 45 cm). The opposite leg on the floor with the knee joint extended, the hands beside the trunk on the floor to keep in balance.
*Performance:* Extension of the hip and dorsiflexion of the foot. The leg on the ball is loaded by lifting both the pelvis and the opposite leg off the ground at the same time. This exercise is repeated 10 times, relaxing 20 sec between movements.

Exercise no. 3.
*Training:* Hip abductors.
*Position:* Side lying on the floor supported by flexed elbow, extended hip and flexed knee. The opposite extremity joints extended, the arm parallel with the trunk.
*Performance:* 10 contractions of the abductors purshing the body from the floor and at the same time abducting the upper leg, going back to the starting position between movements. No rest between movements.

Exercise no. 4.
*Training:* Hip extensors, abductors and adductors, knee extensors and flexors, dorsiflexors and plantar flexors.
*Position:* Lying supine with knee flexed, a 20 cm ball between the knees, the feet parallel and supported.
*Perfomance:* 10 contractions of the hip extensors pushing the pelvis off the ground, pressing the ball between the knees, extending one knee with dorsiflexed foot, lying down resting 20 sec between movements.
10 repetitions.

Exercise no. 5.
*Training:* Knee extensors and hip extensors.
*Position:* Sitting with one knee and hip flexed 90 degrees, the foot on the floor. The opposite leg kept with flexed hip 90 degrees and knee extended and dorsiflexed foot, finger contact with the wall or a chair to avoid compensatory movements of the body.
*Performance:* 10 movements rising on one leg to full extension, then sitting down, keeping the unsupported leg raised off the floor. 10 repetitions without resting.

Exercise no. 6.
*Training:* Hip extensors, knee extensors, plantar flexors.
*Position and performance:* Climbing tip toe of a staircase. 10 repetitions.

Exercise no. 7.
*Training:* Knee extensors, hip extensors, plantar flexors, hip abductors and adductors.
*Position:* Standing on a stair, one foot reaching down, providing excentric work for the muscles of both legs in different parts of the movement pattern.
*Performance A:* Stepping down on the floor.
*Performance B:* Reversing the movement, i.e. stepping up backwards, providing concentric work of the involved muscles.

Exercise no. 8.
*Training:* Hip flexors, adductors, knee extensors.
*Position:* Sitting on a table, hands supported behind the body, one foot on the floor. A pulley is fixed to the ankle of the other leg in opposite direction of movement. Light weights (3–3.5 Ibs).
*Performance:* Flexion/adduction of the hip, extension of the knee, dorsiflexion of the foot (moving the leg as far up as possible without compensatory movements of the body). Movement performed rhythmically working concentric/excentric. 10 repetions.

Exercise no. 9.
*Training:* Abductors, knee extensors, dorsiflexors.
*Position:* Standing with one foot on a box (5 cm high), the other leg kept adducted with dorsiflexed foot unsupported, both knees extended, hands resting on a mirror in front of the body. A pulley with ligth weights (3–3.5 Ibs) is fixed at the ankle of the unsupported leg. The resistance is applied in opposite direction to that of the movement.
*Performance:* Abduction of hip through maximum range of movement. Movement performed rhythmically concentric/excentric.

Exercise no. 10.
*Training:* Postural reactions.
*Position:* Standing on the floor, one foot resting on the floor.
*Performance:* Steeping with the other foot in different directions in relation to body. 25 repetitions of stepping with both legs.

The intensified training comprises:
- jogging forwards, backwards, stop
- running, turning on non injured leg/injured leg
- running sideways, stop
- running up and down the stairs (being timed)
- jumping on a trampoline supported/unsupported by hands.

*Home training program F*

The intensity of hometraining differs from one patient to another depending on clinically judged factors such as postural reactions during performance of exercises.

These two movements are of fundamental importance:

Exercise no. 2.
*Training:* Hip extensors.
*Position:* Lying supine with one leg slightly flexed resting on a box 25 cm high (instead of a ball), the other leg on the floor.

The opposite leg on the floor with the knee joint extended, the hands beside the trunk on the floor.
*Performance:* Extension of the hip and dorsiflexion of the foot. The leg on the box is loaded by lifting both the pelvis and the opposite leg off the ground at the same time.

Exercise no. 4.
*Training:* Hip extensors, abductors, adductors, knee extensors, trunk muscles.
*Position:* Lying supine with knees flexed, a ball (20 cm) between the knees, feet supported.
*Performance:* Keeping feet supported, lifting the pelvis, extending the hips, adducting the thighs and then extending one knee while loading one foot only in order to get the proximal muscular activation which is the keystone of this training model.

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