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Increased muscle stiffness after anterior cruciate ligament reconstruction – memory on injury?

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Abstract Residual impairment of knee function was tested in 25 patients 6 to 12 months after successful unilateral reconstruction of the anterior cruciate ligament. The control group comprised 25 healthy individuals. Jumping onto one foot from a height of 20 cm was taken as a prototype of similar everyday activities. We measured maximum flexion of the knee during the landing phase of the jump, and the degree of knee flexion at the time of maximum deceleration of the knee against gravity during jumping using the three-dimensional optical motion analysis system-ELITE. In the group of patients, measured parameters were significantly smaller on the operated side than on the unaffected side. These two measured values were significantly smaller on both legs in group of patients as compared to the values in the control group. The results of our study indicate that functional disturbance persisted for 6 to 12 months after anterior cruciate reconstruction. This may be due to the changed muscle activation pattern of the knee causing increased stiffness of knee muscles. It seems that re-programming of the central nervous system occurred in order to protect the injured lower extremities from another injury.

Résumé La limitation résiduelle de la fonction du genou a été testée chez 25 malades entre 6 et 12 mois après reconstruction monolatérale réussie de ligament croisé antérieur. Le groupe témoin était composé de 25 individus sains. Le saut sur un seul pied de 20 cm de hauteur a été pris comme prototype de l'activité quotidienne. Nous avons mesuré la flexion maximale du genou pendant l'atterrissage et son degré de flexion en phase de décélération maximale par rapport à la pesanteur pendant le saut moyennant le système optique tridimensionnel d'analyse du mouvement ELITE.

Les paramètres des malades étaient significativement plus bas du côté opéré que du côté sain. Ces deux valeurs étaient significativement plus petites sur les deux jambes des patients par rapport au groupe témoin.

Les résultats de notre étude indiquent que la gène fonctionnelle persiste entre 6 et 12 mois après reconstruction du croisé antérieur, probable résultat d'une modification du modèle d'activation musculaire du genou déterminant une plus forte rigidité des muscles du genou. Il semble que le système nerveux central se re-programme pour protéger les membres inférieurs blessés contre d'autres lésions.

Introduction

Injury of the anterior cruciate ligament (ACL) can be treated conservatively or by operative reconstruction, depending on the patient's symptoms, age, physical condition and sporting requirements [18]. Even with a very satisfactory graft some patients continue to complain of instability and weakness of the knee [2, 3].

The main cause of muscle weakness after ACL reconstruction is atrophy secondary to reduced activity. Other contributing factors may be pain, effusion and alteration of proprioception, causing a reduction of voluntary activity of the muscles around the knee [8, 12], and impaired sensory function of the ACL may be a source of symptoms [3, 12, 14]. Histological studies have identified four types of mechanoreceptors in the ACL [10, 13, 19] and that 1% of the ACL tissue is neural [19]. The mechanoreceptors provide feedback information to the central nervous system (CNS), regarding direction, velocity and position of the knee [1, 16]. This proprioceptive function serves to control slow movements [16]; and this control induces muscle activation patterns specific for each motor task, and contributes to muscle stiffness around the joint during motion [7, 12].

The maximum flexion and the degree of flexion at the point of maximum deceleration of the knee during the landing phase of a jump onto one leg from a height of

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20 cm were considered indicative parameters of function after ACL reconstruction. Our hypothesis was that because of reduction of sensory feedback the reaction of muscles after landing would be delayed, resulting in increased flexion of the knee.

Methods

25 patients were studied 6 to 12 months after unilateral ACL reconstruction using a 10-mm middle third patellar tendon graft. There were 14 females and 11 males, with a mean age of 26 years (15–46 yrs). The control group comprised 7 females and 18 males with no history of injury or clinical instability who participated regularly in sporting activities. The mean age of the control group was 25 years (16–30 yrs). All the operated patients followed a standard postoperative rehabilitation program and were fully weight bearing immediately after surgery. Knee brace locked in full extension was used for 3 weeks postoperatively. The brace was removed for physiotherapy and electrical stimulation was used to improve quadriceps function. All patients were assessed by means of the Lysholm questionnaire [17].

The test was performed as follows: the subject was asked to jump onto one leg from a height of 20 cm, and to keep standing on one foot for at least 3 seconds after landing. Measurements were done with the ELITE optoelectric motion analysis system [9]. Two infra red cameras were used to detect three 1 cm hemispherical retro-reflective markers attached to the subject's skin. The markers were placed in the region of the trochanter, the lateral aspect of the knee (1 cm lateral to the patella) and over the lateral malleolus. Three dimensional coordinates of each marker were calculated. The sampling rate was 100 Hz. Two cameras were placed 4 metres away from the subject. A working space of $2 \times 1.6 \times 0.6$ m was calibrated using a precision grid consisting of 30 markers placed in 3 parallel planes 0.3 mm apart. The calibration was repeated before each measurement. The system determined the position of each marker in a calibration volume of 1-mm accuracy. The movements of the markers were traced during the jump and maximum knee flexion during the landing phase and the degree of knee flexion at the time of maximum deceleration were calculated. The test was repeated 6 times for each leg, and the mean values calculated. Statistical analysis was performed using Student's t-test [6]. All patients were also evaluated clinically for muscle wasting and stability. The circumference of the musculature 10 cm proximal and 10 cm distal to the patella was measured on both the injured and uninjured leg, and the relative difference between the two calculated.

Results

Patients in the control group showed no statistical difference between right and left knees with regard to the maximum knee flexion during jumping, the degree of knee flexion at the point of maximum deceleration and muscle wasting. Thus the left and right knees in the control group considered together, amounted to a total of 50 knees. In the operated group, maximum knee flexion during the landing phase of the jump was statistically smaller ($P < 0.001$) on the operated side (40.1 ± 7.4 SD) than on the contralateral side (45.8 ± 6.7 SD). Also maximum knee flexion during the landing phase was statistically smaller for both, the operated leg ($P < 0.001$) and the contralateral leg ($P < 0.01$) compared to the control group (50.9 ± 7 SD) (Fig. 1).

Fig. 1 Maximum flexion of the knee during the landing phase of the jump and degree of knee flexion at time of maximum deceleration against the gravity during a jump on one leg from the height of 20 cm compared between groups of patients with ACL reconstructed knees ($n=25$), with contralateral ACL uninjured knees ($n=25$) and control group with both intact knees ($n=50$). The degrees of knee flexion were found smaller on ACL reconstructed leg compared to those on contralateral uninjured leg in group of patients ($P < 0.001$). They were found smaller on the ACL reconstructed ($P < 0.001$) and on the contralateral uninjured leg ($P < 0.05$) when compared to those in the control group

In the operated group the degree of knee flexion at the time of maximum deceleration was significantly smaller ($P < 0.01$) on the operated side (39.1 ± 7.5 SD) than on the contralateral side (44.7 ± 6.9 SD). It was also significantly smaller when comparing the results of the operated leg compared to the contralateral leg ($P < 0.05$) to those in the control group (48 ± 6.9 SD). (Fig. 1).

In 24 of the 25 (96%) patients, there was wasting of the musculature when comparing the operated and the non-operated legs, indicating muscle wasting. The mean difference was $2.1 \text{ cm} \pm 1.2 \text{ cm}$ for the thigh (range 0.5–5 cm, $n=23$) and $0.9 \text{ cm} \pm 0.3 \text{ cm}$ for the calf (range 0.5–1.5 cm, $n=17$).

There was a negative correlation between atrophy of the thigh on the operated side and the degree of knee flexion during jumping onto the operated leg ($p=0.01$).

A smaller, yet significant negative correlation was found between atrophy of the thigh on the operated leg and the degree of knee flexion during jumping onto the unaffected contralateral leg ($p=0.05$). The mean Lysholm score was 86.7 ± 10.7 .

Discussion

It has been established that in spite of successful ACL reconstruction, patients may have persistent laxity and diminished motor skills for two reasons, impaired proprioception [2, 3] and muscle wasting [12]. Absence of proprioceptors, which are normally located in the ACL has been reported in the ACL deficient knee [1, 2, 4, 5]. Hypoactivity after ACL rupture leads to muscle atrophy and muscle imbalance [12, 5]. Postoperative atrophy is more pronounced in the quadriceps muscles than in the hamstrings [5].

We found that the degree of knee flexion during a jump onto one leg from a height of 20 cm was smaller on the operated side. Stroeve [20] reported that reduced feedback information during movement causes contraction of antagonist muscles, thus resulting in increased joint stiffness. All our subjects were tested 6–12 months after surgery, and according to Corrigan et al [5] there should have been persistent functional disturbances due to impaired proprioception. Diminished afferent impulses result in combined contraction of quadriceps and hamstring muscles, causing limitation of movement of the knee. The influence of mechanoreceptors on muscle activity was alluded to by Hill in 1960. [11].

Our results indicate that muscle stiffness around the knee correlates with muscle atrophy; the more pronounced the atrophy the smaller the degree of knee flexion during the jump onto both the operated and the contralateral uninjured leg ($P < 0.05$). Dyhre-Poulsen et al reported [7] that response latencies of the ACL reflex in humans are long and are thought to be polysynaptic, or long loop reflexes giving the central nervous system ample opportunity for adjustment of responses.

A feeling of instability in an otherwise stable knee, persisting 6–12 months after ACL reconstruction was reflected in the Lysholm score (86.7 ± 10.7). This score, however, does not indicate whether the instability is due to muscle atrophy, lack of proprioceptive function, fear of further injury or a combination of these factors.

Our results emphasise the role of specific rehabilitation after ACL reconstruction and we think it should be focused on the following points:

- Muscle wasting can be improved by a properly designed fitness program. During rehabilitation following ACL reconstruction, submaximum voluntary contractions are required to improve muscle activity [15].
- Some rehabilitation centres provide proprioceptive training as part of their rehabilitation programs. Barrack et al [1] maintain that proprioception spontaneously improves after one year of rehabilitation, and according to Corrigan et al [5] this improvement is due to reinnervation of the ACL graft. This process may be accelerated by special training which should be part of the rehabilitation program [13].
- Psychological training should also be encouraged to overcome the patient's fear of repeated injury.

In conclusion altered patterns of knee muscle activation are present for one year after ACL reconstruction, resulting in increased muscle stiffness of the thigh, both on the operated and the unaffected side. The presence of muscle wasting renders it impossible to identify the role of impaired proprioception.

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