Abstract

Influence of the dynamometer and knee joint axis of rotation alignment on the isokinetic measurements

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Objectives: Factors that could influence accuracy of isokinetic assessment deserve careful attention [1,2]. In order to develop accurate and standardized test protocols, many investigations have focused for instance on gravity correction, visual feedback, range of motion, resistance pad position. The aim of our study was to determine the consequences of an inappropriate alignment between the dynamometer and knee joint axis of rotation on isokinetic measurements.

Methods: Twelve healthy male subjects (24 ± 2 years old) participated in one session of testing (Cybex Norm dynamometer) on their dominant leg. Four conditions of proper or intentionally altered (in the horizontal plane) alignment were randomly proposed. Based on proper alignment with the knee flexed at 90°, the altered alignments were designed as follows: joint axis of rotation placed 6 cm (−6) and 12 cm (−12) behind or 6 cm (+6) in front of the dynamometer axis of rotation in the horizontal plane (Fig. 1). Knee flexors and extensors performed 3 maximal repetitions for testing at 60°/s in the concentric mode throughout a constant 100° range of motion. Subjects benefited from 3 pre-liminary submaximal trials for familiarization before the successive testing positions. Descriptive statistics and ANOVA tests were used to analyze the data.

Results: For both knee flexors (Fl) and quadriceps (Q), measurements in the properly aligned and +6 positions showed no significant difference in peak torque (PT) (Fig. 2). By contrast, the PT corresponding to the joint axis of rotation placed behind the device axis of rotation (−6 and −12) were significantly (p < 0.05) decreased for both muscle groups, most notably on the quadriceps in the −12 position (−14% for that position compared to the properly aligned).

The same observations characterized the work parameter, even though the Fl/Q ratio calculated from PT was not significantly influenced by the alignment
Fig. 2. Concentric peak torques (PT in N.m) developed by knee extensors and flexors at 60°/s: comparative study between proper or altered alignments. Different letters represent statistically significant differences (p < 0.05).

**Conclusion:** We highlighted the influence of an improper alignment between the knee joint and dynamometer axis of rotation, particularly when the joint is positioned behind the dynamometer motor in the horizontal plane. A lack of precision on that point would introduce a factor confounding accurate isokinetic assessment.

**References**


Activation EMG pattern during isokinetic knee flexion-extension assessment: Comparison between healthy subjects and chronic pain patients

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1. Introduction

Isokinetic testing has been increasingly used to assess muscle performances in patients suffering from chronic pain [7,11,13,14]. Surface electromyography (EMG) is a common scientific tool allowing an objective assessment of muscular fatigability [1,3,15,17,18,26]. Impaired maximal isometric and isokinetic muscle performances have been reported in several studies dealing with fibromyalgia and chronic low back pain patients (FM and CLBP patients) [7,10,11,13,20]. The respective influence of physiological, psychological and deconditioning factors still remains controversial [16]. EMG pattern activity during isokinetic efforts appears little documented [12,24]. According to Robertson et al., isokinetic torque values appeared correlated to the agonist muscle activation. Tesch et al. [24] described an increase of vastus lateralis (VL) and rectus femoris (RF) integrated EMG activity during an endurance knee extension test performed in concentric mode at 180°/s. EMG has been extensively used to explore muscle function in patients with chronic pain. Nevertheless, to our knowledge, no study has yet compared FM and CLBP patients with regard to muscle performances and EMG patterns.

Hence the aims of this study were as follows:

1. evaluate the isokinetic concentric strength and fatigue of knee flexors and extensors in sedentary healthy women and in women suffering from fibromyalgia or CLBP.
2. measure in these populations the EMG activity patterns during the isokinetic strength and fatigue assessments.

2. Material and methods

2.1. Populations

All subjects received a complete explanation of the investigation purposes and gave their consent. This study was approved by the Ethical Committee of the University of Liège Medical Center.

2.1.1. Control group

The control subjects were fifteen women (45 ± 10 years old, 66 ± 11 kg) without joint or muscle injury. They performed on average 0.7 hour of recreational sport activities per week.

2.1.2. FM patients group

Ten women (50 ± 5 years old, 71 ± 11 kg) meeting American College of Rheumatology Criteria for FM syndrome were included. The duration of symptoms ranged from 1 to 6 years and 3 patients were in paid jobs. The mean time spent in physical activities only reached 0.5 hour per week on average.
2.1.3. Chronic low back pain patients group

Ten women (45 ± 10 years old, 66 ± 6 kg) suffering from chronic low back pain (without pain irradiation in the leg or diffuse pain history) participated in this study. The symptom duration ranged from 1 to 5 years. Only 4 patients were in paid jobs and the mean time spent in physical activities was on average 0.6 hour per week.

2.2. Methods

After a warming-up consisting in 5 minutes of unloaded stationary cycling at 50 rotations per minute (rpm) followed by static stretching of quadriceps and hamstrings, subjects performed a concentric isokinetic test on their dominant leg by means of a Cybex Norm dynamometer (Henley Healthcare, Sugarland, Texas, USA). The range of motion during testing consisted in 100 degrees of flexion from the full active (0°) extension. Each subject was seated with the trunk and the dominant leg fixed. The dynamometer axis of rotation was aligned with the knee center of rotation (in 90° flexed position).

Submaximal efforts of knee flexors and extensors (at 120°/s angular velocity) was allowed in order to familiarize with the isokinetic exercises. Three preliminary submaximal repetitions preceded each test speed.

The testing protocol started with the strength assessment by means of 3 maximal repetitions at 60°/s and 5 maximal repetitions at 180°/s. The analysis was based on peak torques (PT in N.m) and bodyweight normalized peak-torques (NPT in N.m/kg). Thereafter, subjects performed the fatigue assessment consisting in 30 maximal-intensity knee flexions and extensions at the angular velocity of 180°/s. Fatigue was expressed by the cumulative work (CW in J/kg) determined by summing up the work developed by both muscle groups.

EMG activity was recorded from the vastus medialis (VM), rectus femoris (RF), internal hamstring (IH) and external hamstring (EH). The ground reference electrode was secured over the tibia. Prior to electrode placement, the skin was vigorously cleaned with alcohol wipes. In order to locate electrodes (silver/silver chloride surface) accurately, we identified muscle areas thanks to a maximal voluntary isometric effort from the seated (VM and RF) and prone (IH and EH) positions. The distance between the centers of the recording electrodes was 20 mm. EMG data and torque were sampled at 1000 Hz and recorded using a Noraxon Myosystem Software. All EMG signals were rectified and smoothed (RMS 50). The average root mean square (RMS) was used as a measure of muscular activity. Agonist and antagonist EMG activities (e.g. flexor muscles recruitment respectively during knee flexion and extension) were expressed in absolute (µV) and peak torque normalized values (µV/N.m).

Immediately after the isokinetic assessment, participants completed a 10 cm visual analogue scale (VAS) for pain intensity estimate: the distance was scored from 0 to 10 arbitrary units (a.u.), 0 a.u. corresponding to the absence of pain and 10 a.u. to the maximum pain.

2.2.1. Data analysis

An analysis of variance (ANOVA) was used for each variable in order to examine the difference between the 3 populations. Student’s paired t-test allowed to compare results recorded at both speeds. An ANOVA test was used to examine fatigue effects on agonist and antagonist EMG activities of each muscle group throughout the thirty repetitions.

### Table 1

<table>
<thead>
<tr>
<th>Variables</th>
<th>Test modalities</th>
<th>Control group</th>
<th>FM group</th>
<th>CLBP group</th>
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<tr>
<td><strong>Strength measurements</strong></td>
<td></td>
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<tr>
<td>FLE NPT (N.m/kg)</td>
<td>C60°/s</td>
<td>0.97 (0.27)⁹</td>
<td>0.64 (0.21)³</td>
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<td>C180°/s</td>
<td>0.71 (0.18)⁹</td>
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<td>EXT NPT (N.m/kg)</td>
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<td></td>
<td>C180°/s</td>
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<td>0.86 (0.2)³</td>
<td>1.14 (0.28)³</td>
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<tr>
<td><strong>Fatigue measurements</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLE + EXT CW (J)</td>
<td>C180°/s</td>
<td>3058 (839)⁹</td>
<td>2278 (394)³</td>
<td>2755 (564)⁹</td>
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<tr>
<td>NCW (J/kg)</td>
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<td>47 (12)⁹</td>
<td>33 (7)³</td>
<td>42 (9)³</td>
</tr>
</tbody>
</table>

Different letters represent a significant difference (p < 0.05); C, concentric.
3. Results

3.1. Isokinetic strength and fatigue

The PT, NPT, CW and NCW parameters were significantly lower in FM patients comparatively to the control group but also to the patients suffering from chronic low back pain. Impairment affected more knee flexors than knee extensors (Table 1).

By contrast, the isokinetic muscle profile did not differ significantly between the control group and the low back pain patients

3.2. EMG pattern during isokinetic strength assessment

The agonist electrical activity (expressed in absolute and normalized values) of VM, RF, IH and EH was recorded during the isokinetic strength assessment at 60°/s and 180°/s angular velocities. No significant difference was observed between the control group and both groups of chronic pain patients (Table 2).

We determined a specific EMG pattern for knee extensors and flexors, based on EMG activities recorded respectively from VM and RF and from IH and EH. The agonist recruitment of both muscle groups was significantly influenced by velocity in the control group in contrast to the chronic pain populations (Table 3).

The normalized EMG activity Ext/Fl ratio calculated in the 3 groups of subjects appeared significantly lower at low velocity (60°/s) than at high velocity (180°/s).
3.3. EMG pattern during isokinetic fatigue assessment

We determined the agonist and the antagonist EMG activities of VM, RF, IH and EH during the isokinetic fatigue assessment. Four sequences consisting in 3 consecutive flexion-extension movements were compared: 1st to 3rd repetitions, 9th to 11th repetitions, 18th to 20th repetitions and 28th to 30th repetitions.

Whatever the sequence, the agonist and antagonist EMG activities did not significantly differ between the three populations. By contrast with the steady agonist EMG activity of the knee flexors (IH and EH), we observed a moderate agonist EMG activity increase of VM and RM in the control group and in the chronic pain patients (Figs 1 and 2). The antagonist EMG activities increase at the end of the fatigue assessment reached +2% to +29% depending on the muscle and the population studied (no significant difference).

The curve profiles of agonist (Figs 1 and 2) and antagonist (Figs 3 and 4) EMG activities were similar in control group and chronic pain patients.

4. Discussion

In this study, we compared muscle performances and EMG patterns in a control group and in two groups suffering from chronic pain: fibromyalgia and chronic low back pain patients. Variables reflecting isokinetic strength and muscle fatigue resistance were significantly lower in the FM group compared to the control group and the CLBP patients.

The FM patients muscular performances impairment is well documented [7,11,13]. It could be related to the anticipation of pain, pain itself, central alterations or mechanisms induced by a deconditioning syndrome. The predominant reduction of isokinetic strength on knee flexors may be explained by our testing procedure which requires successive repetitions of knee flexions and extensions without period of rest. In contrast to other studies, knee muscles performances did not differ between healthy women and CLBP patients. Lee et al. [10] found a significant reduction in knee flexors and extensors strength in CLBP patients. Schippein et al. [21] and Trafimow et al. [25] suggested that quadriceps muscle performance limits the CLBP pa-
Evolution profile of RF antagonist EMG activity

Fig. 3. Evolution profile of RF antagonist EMG activity recorded during the isokinetic fatigue assessment (control subjects, FM patients and CLBP patients).

Evolution profile of EH antagonist EMG activity

Fig. 4. Evolution profile of EH antagonist EMG activity recorded during the isokinetic fatigue assessment (control subjects, FM patients and CLBP patients).

Patients’ ability to lift with their knee flexed. In our study, the similar isokinetic performances in the control and CLBP groups may be explained partly by our exclusion criteria (absence of leg irradiation). Furthermore, the populations were drastically paired for age, weight and daily physical activities.

To our knowledge, no comparative study of muscle performances in FM and CLBP patients appears in the literature. The comparison of both populations suffering from chronic pain showed higher isokinetic strength and muscle fatigue resistance in CLBP patients. The diffuse pain in FM patients may explain these observations. At the end of the isokinetic assessment, VAS pain score reached respectively 0.68 a.u. and 2.7 a.u. in control and CLBP groups (non significant difference). By contrast, the VAS pain score in FM averaged 5.3 a.u. (p < 0.05).

Agonist electrical activities of VM, RF, IH and EH recorded during the isokinetic strength assessment were not significantly different among our populations. Simons and Mense [23] reported no rest EMG activity increase in patients suffering from chronic pain. Silvonen et al. [22] described a trunk flexors and extensors activity decrease, in CLBP patients, when they had an agonist function in dynamic movements.

In the control group, we demonstrated a significant influence of velocity on agonist EMG activity of knee flexors and extensors. According to Robertson et al. [19], torque production is strongly related to EMG activity in the biceps femoris and vastus lateralis. These authors observed that increased torque was associated with increased EMG activity. Croce et al. [2] found that knee flexors PT was higher when the ankle was fixed in dorsiflexion compared to plantarflexion. This increased PT was not combined with concomitant EMG activity increase. However, according to these authors, the results were not in contradiction with Robertson’s study. Croce et al. [2] suggested that the higher knee flexors PT was due to a greater gastrocnemius contribution as knee flexors, which explained the absence of repercussion in hamstring EMG activity. In our study, no significant relation between PT (which were significantly reduced at 180°/s compared to 60°/s) and EMG activity was observed in the two populations suffering from chronic pain. These results suggested that
chronic pain syndrome may influence the motor units recruitment.

We determined the knee flexors and extensors EMG pattern. The normalized Ext/Fi ratio of EMG activity increased significantly with speed in the 3 groups. This observation may be related to the muscular typology; Garret et al. [5] demonstrated a higher proportion of fast twitch motor units in hamstrings than in the quadriceps. Faulkner et al. [4] suggested that, at high contraction velocities, slow twitch motor units were less able to contribute to power than at slow contraction velocities. Therefore, FT motor units contribution may be more important at 180°/s. This fact may also explain that knee flexors EMG activity increases less than quadriceps muscle EMG activity (composed of a higher number of ST motor units) when speed gets higher. Results of the present study indicated a normalized EMG activity Ext/Fi ratio inferior to 1 in the control group. This observation may also be related to the different fiber types proportions in knee flexors and extensors. In fact, Gerdle et al. [6] reported a positive correlation between RMS and the percentage of type II muscle fibers during 100 maximal dynamic knee extensions at 90°/s. The higher ratio found in our chronic pain populations may be explained by a modified typology consecutive to a deconditioning syndrome or a reduction of daily physical activities.

In the isokinetic fatigue assessment, we examined the agonist and antagonist EMG activities throughout 4 serials of contractions. The signal amplitude (RMS) reflects the recruitment of motor units. The literature describes a RMS increase during prolonged static submaximal contractions [8]. EMG pattern during repeated dynamic movements is less documented. Larsson’s study showed good reproducibility for maximal isokinetic knee extension PT and RMS during three sets of 10 contractions [9]. Lindström and Gerdle [12] investigated the interrelationships between RMS and peak torque throughout 100 successive maximal isokinetic contractions of both knee flexors and extensors. They reported a RMS increase during the initial 20 contractions, followed by relatively stable RMS levels throughout the subsequent contractions [12]. At the end of the test, a tendency towards decreased levels appeared [12]. According to these authors, no significant difference in EMG behavior between extensor and flexor muscles existed. Contrarily, our study revealed that unlike the knee flexors activity (IH and EH activities), the agonist EMG activity of VM and RM moderately increased. Our results may differ from those of Lindström and Gerdle, due to our specific protocol. Several mechanisms may be responsible for changes in the RMS and it remains difficult to interpret the EMG activity measured during maximal dynamic effort. Unexpectedly, agonist and antagonist activities of the chronic pain groups did not differ from those of the control group for each repetitions serial investigated in the present study.

Curve profiles of agonist or antagonist EMG activities were similar in the control group and the chronic pain patients. Consequently, the chronic pain syndrome appears to be not related to the EMG pattern during isokinetic fatigue assessment.

5. Conclusion

FM patients isokinetic muscular performances were significantly decreased in comparison with the control and the CLBP groups. Results of these last two populations did not differ significantly. Agonist electrical activities recorded during the isokinetic strength assessment were similar in the 3 studied groups. In the control subjects, we demonstrated a significant influence of velocity on agonist EMG activity of knee flexors and extensors. The normalized EMG activity Ext/Fi ratio increased significantly with speed in the 3 populations. During the isokinetic fatigue assessment, the curve profiles of agonist and antagonist EMG activities were identical in the control group and the chronic pain groups. In contrast with the knee flexors agonist EMG activity, we observed a moderate agonist EMG activity increase of VM and RF.

References


Abstract

Electromyographic activity of the knee flexors and extensors in sedentary women during isokinetic strength and fatigue assessments

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Introduction: Isokinetic dynamometers are reputed to provide accurate measurement of muscle strength and fatigue. The study of EMG patterns during such isokinetic testing represents a complementary approach which seems particularly relevant [1]. The objective of our study was to assess concentric muscle strength and fatigue during knee flexion and extension using an isokinetic dynamometer combined with analysis of leg muscles EMG patterns.

Methods: Fifteen healthy females (45 ± 10 years old; 66 ± 11 kg) without history of lower limb injury were included in the study. After a familiarization period on the dynamometer (Cybex Norm), all subjects performed a concentric isokinetic test on their dominant knee flexors (Fl) and extensors (Ext). The assessment was conducted along a constant range of motion from 0° to 100° of flexion. Isokinetic muscle strength (peak torque, PT in N.m) was first evaluated by means of 3 repetitions at 60°/s and 5 repetitions at 180°/s. The fatigue protocol consisted in 30 maximal-intensity contraction cycles at 180°/s. Fatigue was analyzed using cumulative work (CW, in J) and bodyweight normalized cumulative work (NCW, in J/kg) determined by summing up the work developed by both muscle groups. Electrical activities of the vastus medialis (VM), rectus femoris (RF), internal hamstrings (IH) and external hamstrings (EH) were recorded from surface electrode using a standard surface EMG procedure (Noraxon Myosystem). All electrical activities were rectified and smoothed (RMS 50). They were expressed in absolute (µV) and PT normalized values (µV/N.m).

Results: Intra-session reproducibility of EMG activities was calculated by comparing the 3 first repetitions of isokinetic strength (180°/s) and fatigue assessments. Coefficients of variation did not exceed 7%. PT and EMG activities were influenced by velocity, the whole data decreasing significantly at the angular velocity of 180°/s compared to 60°/s. We determined a separate EMG pattern of knee flexors and extensors by means of EMG activities respectively recorded from IH and EH and from VM and RF. Normalized EMG activity Ext/Fl ratio appeared significantly influenced by velocity (Ext/Fl ratio equal to 0.55 at 60°/s versus 0.68 at 180°/s). The fatigue protocol showed a significant reduction of flexors and extensors PT at the end of 30 contraction cycles. In contrast, agonist and antagonist EMG activities (e.g. flexor muscles recruitment respectively during flexion and extension) recorded during isokinetic fatigue assessment did not significantly change throughout thirty repetitions neither for flexors, nor for extensors (Figs 1 and 2).

Discussion and conclusion: In repeated EMG analysis procedures, reliability of EMG activities appeared satisfactory with CV inferior or equal to 7%. This study demonstrated a significant influence of velocity on torque and EMG activity. Comparison between knee flexor and extensor muscles showed higher flexor EMG activity (Ext/Fl ratio < 1). This ratio significantly increased with velocity (0.55 at 60°/s to 0.68 at 180°/s).
Agonist and antagonist EMG activities were not significantly modified throughout isokinetic fatigue session. However, in contrast with the agonist EMG activity of IH and EH, we observed a moderate increase of agonist EMG activity of VM and RF.

**Reference**

Abstract

Isokinetic assessment of complete proximal hamstring tendon rupture: Case reports

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Complete hamstring tendon rupture is a rare clinical entity, reported particularly among water skiers [1]. The functional outcome seems uncertain and most authors recommend surgical repair of the injury [2,3]. In our work, we investigated two cases consisting of water skiing-related hamstring injury with a complete tendon rupture. Patient A (male, 47 years old) was non-operatively treated and patient B (male, 33 years old) benefited from surgical repair one year after the injury. In both cases, the clinical diagnosis was confirmed by magnetic resonance imaging. No bony lesion from the ischium was observed after the injury and electromyographic examination excluded any motor recruitment abnormality.

The standardized isokinetic assessment included concentric measurements at 60°/s and 240°/s for both flexors and quadriceps. Afterward, flexor muscles were subjected to eccentric angular speeds of 30°/s and 120°/s. The resulting analysis consisted of bilateral comparison of peak torques permitting determination of asymmetries expressed in percentages and flexor/quadriceps (Fl/Q) ratios.

**Patient A**, managed with conservative treatment (classical physical therapy), still reported marked subjective complaints and disability on return to sports 5 months after the injury. The first isokinetic assessment took place at that time and revealed a major deficit of maximal strength (Fig. 1). He started an isokinetic strengthening program that was individually established on the basis of his own strength profile. After 20 training sessions, a second isokinetic testing did not show any improvement in performance, whatever the contraction mode.

After surgery, **patient B** was instructed by the surgeon to progressively perform peddling and swimming activities, but he was not allowed to receive any rehabilitation treatment! Due to a poor functional outcome, he was submitted 3 years postoperatively to a first isokinetic assessment that revealed a decrease in strength performance higher than 50% (Fig. 1). After a first period of isokinetic training (10 sessions) the peak torques (measured through a second isokinetic test) improved, mainly in concentric. By contrast, a second period of 15 training sessions did not allow any further recovery in strength. The residual deficit finally reached 29% in concentric (at 60°/s) and 48% in eccentric (at 30°/s).

Both patients were characterized by very low Fl/Q ratios meaning a persistent agonist/antagonist imbalance. These observations concur with the concept that non-operative treatment leads to profound impairment in strength and function among patients with complete proximal hamstring tendon rupture. Our follow-up also suggests that surgical repair does not systematically lead to a total recovery in muscle performance, particularly when the postoperative rehabilitation phase is neglected.

**References**

Fig. 1. Evolution of peak torque (PT) deficits (%) on injured muscles through successive isokinetic assessments. C60 = concentric at 60°/s; E30 = eccentric at 30°/s.
Abstract

Muscle activation after ACL reconstruction: Influence of the resistance pad position

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Objectives: The question of anterior tibiofemoral joint shear force during active extension of the knee must be tackled with great attention when managing the rehabilitation of surgically reconstructed anterior cruciate ligament (ACL). The contraction of the quadriceps when the resistance pad of the isokinetic dynamometer lever arm is placed at the distal tibia tends to force the proximal end of the tibia anteriorly with respect to the distal femur [1]. This mechanism could damage the graft after a surgical repair. The magnitude of anterior shear force is significantly reduced when the resistance pad is moved closer to the proximal extremity of the tibia. Hence, practitioners frequently use either a proximal placement or an anti-shear device aimed at reducing the anterior shear, thus protecting the graft in the early phase of exercise. Nevertheless, as we demonstrated in a previous publication [2], the position of the resistance pad on the tibia influences the estimation of the strength deficit through a bilateral comparison. The aim of this study was to investigate the influence of the resistance pad positioning on the electromyographic (EMG) activity pattern of the flexor and quadriceps muscles after ACL reconstruction.

Methods: Twelve male subjects (28 ± 7 years old) with unilateral knee surgery were studied. All of them underwent an ACL reconstruction using a patellar tendon graft. The mean time between the surgery and the study examination was 24 weeks (range 22–26 weeks). Each patient benefited from a pain free bilateral isokinetic assessment for knee flexors and quadriceps in the concentric mode at 60°/s and 240°/s. Two different positions of the resistance pad either distal (dist) or proximal (prox) on the tibia were successively used for testing (order randomly assigned). At the same time, EMG activity was measured on the vastus medialis (VM), the rectus femoris (RF), the respective mass of internal hamstrings (IH) and external hamstrings (EH) using surface electrodes. EMG data were sampled at 1000 Hz and recorded using Noraxon Myosystem Software. Signals were rectified and smoothed (RMS 50). The average root mean square (RMS) represented muscle activity.

Results: The isokinetic strength deficits of the quadriceps (through a bilateral comparison) appeared significantly increased when the test was performed in a distal position of the resistance pad compared to a proximal position (at low velocity only). The quadriceps deficit at 60°/s averaged respectively 36 ± 14% and 19% ± 13% in the distal and proximal positions (p < 0.05). Strength deficit magnitude on flexors was not influenced by resistance pad position (respectively 10 ± 7% and 7 ± 8% in the distal and proximal positions at 60°/s). The VM and RF activation pattern during isokinetic knee extension at maximal intensity was also modified by the resistance pad position on the tibia. At low velocity (60°/s), the prox/dist EMG activity ratio of both quadriceps muscle heads (Fig. 1) was significantly increased on the operated leg compared to the contralateral healthy side. By contrast, the prox/dist
EMG activity ratio of the IH and EH during flexion did not show significant difference between the two legs. **Conclusion:** We concluded that, after an ACL reconstruction, the position of the resistance pad on the tibia during maximal isokinetic knee extension at a low angular velocity significantly influences quadriceps torque production and activation. Based on these observations, isokinetic users must reflect on the following points when they have to define the resistance pad position: (1) the safety of the graft referring to the anterior shear forces; (2) the true estimation of the quadriceps deficit; (3) the optimal modalities in strengthening, taking into account inhibition phenomena.

**References**

Abstract

Randomized comparison of isokinetic dynamometry and electromyographic activity (sEmg) after anterior cruciate ligament reconstruction between semitendinosus and gracilis or patellar tendon autograft

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Objectives: There is still a lack of agreement regarding the choice between hamstring or patellar tendon autograft techniques for the reconstruction of the anterior cruciate ligament [4]. The goal of our study was to compare isokinetic parameters, 3 months post-operatively, after ACL reconstruction with hamstring tendon graft or with patellar tendon versus a healthy control group.

Materials and methods: Twenty healthy male students participated in the study. They were compared to thirty patients who had surgery for ACL reconstruction with hamstring tendon (n = 20) or patellar tendon (n = 10) autograft precisely 3 months before the assessments. The mean age and morphometric parameters were similar in each three samples. The tests were performed using a Cybex Norm® and consisted in 3 maximal dynamic contractions at 180°/s and 60°/s in concentric mode (Con) for both flexor muscles and quadriceps and at 30°/s in eccentric mode (Ecc) for flexors exclusively. During these tests, the sEmg activity was recorded from the vastus lateralis (VL), vastus medialis (VM) rectus femoris (RF) and hamstrings using a Noraxon Myosystem 2000. Parameters were sequenced at every 10° on a range of motion from 0° to 105°. The influence of independent variables (group and limb) was assessed using analysis of variance (ANOVA).

Results: In the present study, both surgical procedures induced a significant loss of strength of 30% for hamstring muscles in concentric and eccentric modes (Table 1). For the quadriceps, we observed a significant deficit for both samples but in the patellar tendon population, the decrease of strength was more important and reached 54%, 60% at 180°/s and 60°/s respectively, in the concentric mode. At 60°/s, sEmg activity showed significant differences for the quadriceps (RF, VL, VM) from 15° to 85° of knee flexion between patellar tendon graft and the two other groups.

Discussion: As expected at 3 months post-op, the involved knee presented a significant weakness of the hamstrings and quadriceps compared to the uninvolved knee. This loss of strength is more important after patellar tendon graft. Nevertheless at this stage of recovery it is probably to early to predict better functional outcome between these two surgical procedures. Thus, it is necessary to reevaluate the presented parameters at one year and to correlate them with a functional score.
Table 1
Mean ± standard deviation of quadriceps and hamstrings Peak Torque ± PT)

<table>
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<tr>
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<th>Control</th>
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<td>Quad PT Con 180°/s</td>
<td>156 ± 21</td>
<td>150 ± 37</td>
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<td>Ham PT Con 180°/s</td>
<td>99 ± 12</td>
<td>89 ± 22</td>
<td>72 ± 23*</td>
</tr>
<tr>
<td>Ham PT Con 60°/s</td>
<td>136 ± 15</td>
<td>122 ± 26</td>
<td>100 ± 32*</td>
</tr>
<tr>
<td>Ham PT Ecc 30°/s</td>
<td>182 ± 27</td>
<td>185 ± 27</td>
<td>137 ± 44*</td>
</tr>
</tbody>
</table>

* = Comparison between control legs and uninvolved-involved legs for both technical surgery at level $p < 0.05$.

References


Isokinetic evaluation of anterior cruciate ligament reconstruction using a free fascia lata graft strengthened by gracilis tendon

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Abstract. Anterior cruciate ligament (ACL) reconstruction is used to restore knee stability. Objective: To evaluate the functional outcomes following anterior cruciate ligament reconstruction using a free fascia lata graft strengthened by gracilis tendon. Methods: 60 patients met the inclusion criteria (age over 16, minimum 1 year follow-up). The isokinetic test on Cybex II consist of a concentric evaluation at 60\degree/s, 180\degree/s and 240\degree/s and an eccentric one at 30\degree/s. A Satisfaction index, Lysholm-Tegner score and IKDC score completed the evaluation. Results: 55 patients were examined (91.6%), mean age 31 years, 69% of men and a mean follow up of 30 months; only 50 had isokinetic test. 81.8% were really/very satisfied. Mean Lysholm knee score is 96/100 with 93% of excellent and good results; mean Tegner activity level is 7 (8 before ACL injury) with 71% return to their previous sport level. IKDC global score noted 98% of good (22% B grade) and very good (76% A grade) results. In concentric test, 56% of patients have a hamstring muscle strength loss, with a mean deficit of 9% at 60\degree/s and 8.8% at 180\degree/s; 76% had a quadriceps strength loss, with a mean deficit of 15% at 60\degree/s and 11% at 180\degree/s. The hamstring and quadriceps deficit is around 9% in eccentric test. The ratio hamstring/quadriceps are symmetrical between the treated knee and the healthy one. No significant difference is related.

Discussion-Conclusion: These results are in accordance with the principal series in the literature. The agonist-antagonist muscular obtained balance shows a fairly good analytical muscular recovery. The functional outcomes agree with other studies. Thus, this technique of anterior cruciate ligament reconstruction is reliable, respect extensor system and does not disturb hamstring muscle recovery.

1. Introduction

Anterior cruciate ligament (ACL) rupture, a frequent accident affecting mostly young people practising contact and pivot sports (around 30,000 persons per year in France) is responsible for a chronic knee instability and exposes to meniscus and osteo-cartilaginous lesions, making the bed for osteoarthritis in the long term.

Anterior cruciate ligament reconstruction is the proposed surgical treatment to restore knee functional stability and to limit degenerative lesions. Numerous techniques of reconstruction exist, but the most frequently used are the bone-patellar tendon-bone graft harvested from the middle third of the patellar tendon, derived from Kenneth-Jones operation and the 4-strand semitendinous and gracilis tendon (hamstring) graft with metal interference screw fixation; each of them has advantages and drawbacks. Functional outcomes are all in all similar, but morbidity is less with the hamstring graft and laxity is better corrected by the patellar tendon graft [1,6,7].

A strip of fascia lata has also been used (Lemaire, McIntosh, Jaeger). Since 1999, Mabit has proposed an original alternative to the two reference techniques with the use of a fascia lata free graft, with a bone stick harvested from the tibial intercondylar tubercle (bone-tendon graft) strengthened by 2-strand gracilis tendon.
Whatever the technique chosen, the muscular strength and functional recovery remain the first pre-occupation/priority, a challenge all the more essential these young sportsmen set very high standards for themselves. The evaluation of the maximal muscular strength with an isokinetic dynamometer is used by many surgical or rehabilitative teams to follow their patients outcomes.

The purpose of our study is to evaluate the functional outcomes and the consequences on hamstring and quadriceps muscular strength following anterior cruciate ligament reconstruction using a free fascia lata graft strengthened by gracilis tendon, with a mean 2.5 years postoperative follow-up.

2. Methods

This study involves 60 patients with a chronic knee anterior laxity, and who underwent arthroscopically assisted anterior cruciate ligament reconstruction using a free fascia lata graft strengthened by gracilis tendon by the same surgeon, Mabit, between January 1999 and May 2002 at Limoges University Hospital.

The patients are all over 16 years old and the post-operative follow-up had to be above one year long. 55 patients were physically re-examined, which means a review rate of 91.6%; for geographical reasons, 4 were not examined and only answered phone questionnaires. Only one person was lost to follow-up.

The 55 group is composed of 38 men (69%) for 17 women with a mean age of 31 years (20–59). The mean postoperative follow-up is 30 months (14–49) and the mean delay between initial injury and surgery is 41 months (3 months to 20 years). The right knee was involved in 30 cases (54.5%) and the left knee in 25 cases. The different circumstances for the ACL rupture were football for 27%, handball (17%), basketball (13%), ski (13%), other sports for 23% and traffic accident for 9%.

2.1. Isokinetic evaluation

Knee flexors and extensors muscular performance is measured by a Cybex II dynamometer. After a 20 minutes warming-up on cycloergometer, the patient sits on the dynamometer with straps around the trunk; the tested leg is strapped around the thigh, with a countersupport above the malleolus. The contralateral leg is blocked behind a support to avoid it to move freely. The leg weight is taken into account to correct gravity effect. The knee joint motion is adjusted to have a range of motion of 90°, with the same reference frame for both knee. The system axis is adjusted to the joint rotation axis. The test is made without visual feedback. Before starting the test, a training is done at the different speeds that will be used for the concentric evaluation. The healthy knee is first tested. The same physiatrist has made all the isokinetic evaluation.

The evaluation on concentric mode is composed of 4 repetitions at 60°/s, 4 movements at 180°/s followed by an endurance test with 20 repetitions at 240°/s, with 2 minutes’ rest between each series. The parameters analysed are peak knee flexion and extension torque or maximum knee flexion and extension moments and the flexors/extensors ratio. A percentile torque deficit in relation to the corresponding non-involved knee is calculated.

For the eccentric mode evaluation, after a training, 3 repetitions at 30°/s are performed, with the analysis of the same parameters quoted above.

For professional unavailability of 5 of them, only 50 patients over the 55 were tested on the isokinetic dynamometer.

2.2. Clinical and functional evaluation

An orthopaedic surgeon, distinct from the surgeon who made the ACL reconstruction, records the subjective symptoms and performs the clinical examination of the patients and then the radiographs to allow for completion of the IKDC 1999 score, with each of the 7 parameters quoted in 4 grades (A “normal”, B “almost normal”, C “abnormal”, D “severely abnormal”) and a global score also quoted in 4 grades. A measure with the KT-1000 arthrometer indicates the residual anteroposterior laxity (mean of three successives measures). A Lysholm knee score, with total score over 100 points, determines three levels of performance (good/excellent between 84 and 100, medium between 65 and 83 and bad under 65); the Tegner activity level that gives the physical and sports activity level (from 1 to 10) is evaluated a posteriori for the pre-injury period and then at the study time.

At last, a satisfaction index is established by the patient with three levels (very satisfied, satisfied, non satisfied).

2.3. Statistical analysis

The Student t-test, Chi 2 test or Fisher exact test were used to compare qualitative data. The link between ordinal quantitative data is studied by the correlation test (linear correlation). $P < 0.05$ was regarded as significant for all the tests.
3. Results

3.1. Clinical and functional results

The patients consider the results of their operations as very satisfying; the satisfaction index (Fig. 1) shows 45 persons very satisfied (81.8%), for 9 satisfied (16.4%), and one who is not satisfied (1.8%), suffering of instability and subjective and objective pains.

The mean Lysholm knee score (Fig. 2) at follow-up is 96 (75–100), with 51 good and excellent results (93%) and only 4 medium ones.

On Tegner activity level, the mean level of physical and sports activity preinjury was 8; after the surgery, when review is performed, the mean level is 7 (3–9). Thirty-nine patients (71%) have recovered their previous sport activity level and practise sport then at the level they had before the injury. On the other hand, 16 persons (29%) have taken up sport again but at a lower level. An actual functional deficiency of the knee is the cause for only four of them; 8 patients (7.2%) have slightly reduced their sporting activity for fear of getting injured again. The last four have limited their activity only for professional reasons (Fig. 3).

According to the clinical criteria of IKDC, the knee function is considered as normal (grade A) for 42 patients, almost normal (grade B) for 12 of them, and abnormal (grade C) for only one (Fig. 4). We have obtained 98% of good and excellent results. None of the 7 parameters is quoted D. Only one patient shows a residual effusion (grade C). The passive motion of the knee is normal for all the patients. A moderate residual laxity exists for 12 patients (grade B) (Fig. 5); it is confirmed by the measure with the KT-1000 arthrometer.

3.2. Isokinetics results

At this postoperative 2.5 years follow-up, for isokinetic concentric muscular evaluation, the extensors
Table 1
Isokinetic concentric muscular evaluation

<table>
<thead>
<tr>
<th>Extensors</th>
<th>Extensors</th>
<th>Flexors</th>
<th>Flexors</th>
<th>Ratio flex/ext</th>
<th>Ratio flex/ext</th>
</tr>
</thead>
<tbody>
<tr>
<td>healthy side</td>
<td>operated side</td>
<td>healthy side</td>
<td>operated side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak torque</td>
<td>188 +/- 58</td>
<td>170 +/- 52</td>
<td>111 +/- 36</td>
<td>109 +/- 37</td>
<td>61% +/- 13</td>
</tr>
<tr>
<td>Peak torque</td>
<td>130 +/- 37</td>
<td>121 +/- 35</td>
<td>87 +/- 24</td>
<td>83 +/- 25</td>
<td>68% +/- 12.8</td>
</tr>
</tbody>
</table>

Maximal peak torque in Nm.

Fig. 5. Laxity IKDC score.

peak torque deficit is moderate, with a mean deficit of 15.3% at 60°/s and 11.3% at 180°/s. But 48 patients over the 50 tested (76%) present this extension peak torque deficit. The flexors peak torque deficit is non significant, with a mean deficit of 9.1% at 60°/s and 8.8% at 180°/s; and only 28 persons over fifty show this flexion peak torque deficit. The flexors/extensors ratio are similar between the operated knee and the healthy one (Table 1).

For isokinetic eccentric muscular evaluation, the peak torque deficit on the treated side is about 9%, non significant. The flexors/extensors ratio are equivalent comparing the treated knee and the non-injured one (Table 2).

3.3. Inter-parameter correlation

No significant difference has been pointed up for isokinetic results, IKDC scores, Lysholm ones and Tegner activity levels regarding age and sex.

But, even without any significant difference, it seems that Lysholm scores and IKDC ones are better when the preoperative instability period is shorter.

4. Discussion

The sample of the current study is comparable with other series regarding age, sex, sports involved in the injury, period of preoperative instability and mean post-operative follow up of 2.5 years [1,5,6,8,10,15].

The findings of the study are generally consistent with those of similar trials that have been published recently. There is no significant difference between this original surgical technique using fascia lata and gracilis and the reference ones using bone-patellar tendon-bone or combined semitendinos and gracilis hamstrings tendon grafts in terms of functional outcomes at 2 or 3 years [4,9,12,15]. Even more our functional results are better [3,6,8].

The rates of return to preinjury levels of physical activity (71%) is high compared with other studies [6,14,15]. Feller [6] reports that only 55% of hamstring tendon patients return to their preinjury sport compared with 69% of bone-patellar tendon-bone graft patients. We used preinjury rather than preoperative levels of activity as a baseline to postoperative comparison; we think that preinjury level is a more relevant parameter because the patient’s sports level is often lower after the injury.

Isokinetic performances do not differ from the ones after bone-patellar tendon-bone or hamstring tendon grafts. In recent studies [1,5,6,10,15] often comparing the two reference surgical procedures, the quadriceps deficit is around 10 to 15% at low speed, a little less at high speed. Feller [6] and Aune [1] found that this deficit is higher in the patellar tendon group than in the hamstring tendon one. Some authors [2,14] note a more important quadriceps deficit, from 25 to 35%. Concerning hamstring muscular strength, the deficit of 9% is in accordance with the results of other series [1,9,13,15]. This deficit seems higher in hamstring tendon technique [1,6]. In other reports, a reduced hamstring muscle strength has not been really noted even when the hamstring tendons are used as graft material [5,14], which means a good hamstring strength recovery.
In our study, only 3 patients (5.5%) suffer from femoro-patellar pain. All the authors recognize that anterior knee pain is more frequent after harvest of a patellar tendon graft [1,6].

A larger sample size would perhaps allow to identify significant differences. To maximize the strength of our study we used strict inclusion criteria; a single surgeon performed all the procedures to reduce variability in surgical technique and the evaluation was always made by the same independent observers to limit detection bias.

This report is also limited by the fact that there is no control group. The uninvolved knee is used as control and is so supposed to be healthy.

After the ACL reconstruction using a free fascia lata graft strengthened by gracilis tendon, the rehabilitation protocol does not differ from usual protocol after ACL reconstruction.

5. Conclusion

The results of this study demonstrate that this surgical procedure of ACL reconstruction using a free fascia lata graft strengthened by gracilis tendon is a reliable technique, with low morbidity, and low functional and muscular deficit. The extensors are respected. The hamstring strength recovery is not disturbed. The knee laxity is well controlled.

Thus this technique of ACL reconstruction is a good alternative to the reference surgical procedures.

References


Abstract

Isokinetic and functional muscle performances among football players: A transversal study

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Athletic physical conditioning demands an ever increasing scientific approach. Isokinetics allows us to objectively quantify muscular strength. However such an evaluation remains analytical and only provides us with partial information about the athlete’s functional skills. The opto-jump system assesses the strength-speed factor in different ways (dash running and jumps), therefore allowing a functional analysis of the muscle performance. The goal of this study dealing with football players was the transverse analysis of the functional and isokinetic variables in different age groups and the correlation analysis between analytical and functional variables.

57 football players, fit for intense sport practice, were included into 3 subsets: pro-group (PG: 22-years-old or older; \(n=20\)), minor leaguers (ML: 18 to 21-years-old; \(n=20\)), juniors group (JG: 15 to 17-years-old; \(n=17\)). The isokinetic strength of the knee’s flexor-extensor muscles was measured in concentric mode (60 and 240°/s) as well as eccentric (30 and 120°/s). Field tests were also achieved: 10-meter dash running and squat-jump series. These tests were performed by use of an optical measuring system that measures flight and ground contact times (opto-jump). A one criterion variant analysis, combined with the Bonferroni test, enabled us to compare the performances and correlative studies were carried out.

Focusing on the absolute performance of the quadriceps strength at low speed, our results showed significant differences (\(p<0.05\)) between ML and JG. This difference also exists between PG and JG (non-significant). At high speed, the absolute value of the quadriceps strength also showed significant differences between PG and JG as well as differences between ML and JG. The same statistical differences between PG-JG and ML-JG were reported for the squat-jump data.

In the pro-group, the squat-jump appeared significantly correlated with extensor peak torques at 60°/s (\(p<0.001\) and \(r=0.64\)) and at 240°/s (\(p<0.0001\) and \(r=0.63\)). The 10-meter dash running was not linked to any isokinetic variables of the 3 player groups.

The maturation of the muscle system and intense weight lifting sessions have most likely contributed to the significant differences between the 3 tested groups. Intensive body-building surely affects the squat-jump results in all groups. The absence of correlation between dash running and isokinetic variables could be explained by the not strength-related factors such as reaction time, ground contact duration, gesture frequency.

Conversely to the 10-meter dash running test, the squat-jump and the isokinetic assessment of the football player appear to be discriminating tests towards the age feature.
Despite the close relationship between some of their parameters, isokinetic and opto-jump can be complementary measurement tools: the opto-jump system allows a thorough functional evaluation of the lower limbs muscle performances and the isokinetic evaluation permits to assess analytical strength of each muscle group. For instance, if the field test results do not match with normal values, isokinethical evaluation could identify a muscle group deficiency. By contrast, if the isokinetical values stand normal, a neuromuscular coordination deficiency would be evoked.
Lateral specificity in knee muscle function in competitive high jumpers compared with untrained individuals

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Abstract. The preferential training of dominant over non-dominant limbs is usually associated with an increase in muscle function. The aim of this study was to examine the effect of chronic high jump training on lateral dominance in knee muscle function. Nine national high jumpers (5 females, 4 males) and fourteen controls performed maximal knee flexions and extensions (0° to 180°.s\textsuperscript{-1}) with dominant and non-dominant legs. Male high jumpers were stronger (p < 0.001) but more asymmetric than controls during maximal isometric knee extension (+17% for the dominant leg, p < 0.01) in contrast with maximal concentric knee extensions (−5% to +2%, p > 0.05). Additionally, levels in agonist and antagonist EMG activity during knee extensions were similar across groups. These results suggest that neither neural activation or typology were responsible for the laterality observed in male high jumpers. According to current knowledge on the effects of plyometric training and functional characteristics of power-athletes, we hypothesized that this muscle- and velocity-specific lateral dominance in competitive male high jumpers was related to differences in terms of muscle volume and/or muscle stiffness. Further studies are needed to examine these assumptions with suitable techniques over a larger sample of competitive high jumpers.

Keywords: Training, high jump, take-off leg, isokinetic torque, countermovement jump, electromyography, gender

1. Introduction

High jumping (HJ) is a complex motor task including a run-up and a one-legged vertical jump toward a bar to clear. HJ involves the lower limbs intensely and particularly the take-off leg whereas the contralateral leg i.e. the leg raised at take-off has been ascribed to lead the movement with upper limbs [1]. Thus, according to the principles of training specificity [16], the preferential use of take-off leg due to chronic unilateral training is probably associated with higher functional changes and particularly for muscles crossing the knee joint. Surprisingly, numerous studies have investigated mechanical and muscular factors influencing vertical jump performance but only during two-legged jumps, assuming laterality balance [30,32,38,39,47]. Indeed, to the best of our knowledge, only two studies have been carried on one-legged vertical jump performance [5,60]. Van Soest et al. [5] reported a one-legged countermovement (CMJ) jump height that was only 58.8% of the two-legged CMJ jump. They suggested that the performance deficit during two-legged jump was mainly due to reduced neural drive to knee extensor and plantar flexor muscles. However, these authors did not test the non-preferred limb alone and the tasks considerably differed in kinematics variables (e.g. push-off duration). Young et al. [60] did not restrict the raised-leg swinging during one-legged CMJ, which makes difficult comparison between unilateral and bilateral stretch-shortening cycle performances.
Interestingly, unilateral adaptations have been reported through single-joint isokinetic testing in athletes such as soccer, tennis or water-polo players [25,56, 61]. More recently, Siqueira et al. [15] did not show functional asymmetry in competitive long and triple jumpers during maximal concentric isokinetic actions of knee flexor and extensor muscles (60°–240°.s⁻¹). Although these jump events may have technical characteristics similar to high jumping, the question of whether chronic high jump training induces difference across lower limbs has not been addressed yet. Only Amiridis et al. [28] compared knee extensor muscles between high jumper athletes group and sedentary subjects during different maximal isokinetic contractions. However, they did not study the non-dominant leg.

Therefore, the present study was designed to examine whether high jump training induced marked difference in terms of laterality with reference to control group. Maximal isometric and isokinetic torques of knee extensors and flexors were performed by sedentary subjects and highly-trained high jumpers engaged in periodic unilateral plyometric training and high jumping. We hypothesized that lateral differences would probably be more marked in elite high jumpers without gender interference.

2. Methods

2.1. Subjects

Two groups of subjects with no prior history of knee pathology participated in the study. A control group (C) consisted of fourteen non-trained but physically active subjects [7 men (27 ± 2 years old) and 7 women (25 ± 1 years old)]. Nine competitive high jumpers [4 men (25 ± 3 years old) and 5 women (23 ± 2 years old)] competing at the French national level in the International Association of Athletics Federation (IAAF) took also part in this study. All jumpers had trained and competed regularly in high jump for 2–6 years about five times a week. The physical characteristics of the participants are shown in Table 1. Best high jumping performances (seasonal and personal best) and associated points according to the IAAF table are shown in Table 2 for high jumpers. All subjects agreed to participate in the study on a voluntary basis and signed an informed consent form.

<p>| Table 1: Physical characteristics of the male and female high jumpers (HJ) and controls (C) |
|---|---|---|</p>
<table>
<thead>
<tr>
<th>N</th>
<th>Age (years)</th>
<th>Body mass (Kg)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HJ women</td>
<td>5</td>
<td>23 ± 2</td>
<td>65 ± 9 **</td>
</tr>
<tr>
<td>HJ men</td>
<td>4</td>
<td>25 ± 3</td>
<td>74 ± 9 **</td>
</tr>
<tr>
<td>C women</td>
<td>7</td>
<td>25 ± 1</td>
<td>58 ± 6</td>
</tr>
<tr>
<td>C men</td>
<td>7</td>
<td>27 ± 2</td>
<td>66 ± 5</td>
</tr>
</tbody>
</table>

HJ were taller and weighted more than controls ($p < 0.001$) with regard to gender (men > women, $p < 0.001$).

2.2. Functional performance

A force platform (LG-6-4-1, AMTI, Newton, MA) was used to perform vertical jump tests. To estimate the ability to jump, subjects were asked to perform maximal two-legged squat jump (SJ) and counter-movement jump (CMJ). The initial position for the SJ was the upright position with the knee flexed at 90°. During CMJ, subjects executed the counter movement until 90° of knee flexion. All jumps were performed barefooted and the subjects were instructed to keep their hands clasped behind their back and to jump as high as possible. As jump verticality was especially important, the subjects were instructed to pay particular attention to keep the head and trunk vertically during the jump and to land at about the same place on the force platform. Trials in which these instructions were not respected were rejected. The highest jump of three trials was retained for further analysis jump height, defined as the difference between the height of the mass center of the body at the apex of the jump and the height of this mass center when the subject was standing upright with heels on the ground, was calculated from the following formula [10, 45]:

\[ \text{SJ and CMJ height} = \frac{1}{8}T_f^2g \times \frac{1}{2}, \text{where g: gravity force; } T_f: \text{flight time.} \]

Pre-stretch augmentation was calculated as [100*(CMJ – SJ)/SJ] to reflect elastic recoil efficiency [4].

2.3. Isokinetic testing

A Biodex System II isokinetic dynamometer® (Biodex medical, Shirley, N.Y., USA) was used to perform knee isometric and concentric isokinetic tests. This apparatus was calibrated according to the procedure recommended by the manufacturer using the standard calibration (sensitivity level and gravitational correction feature for knee joint analysis). A second PC unit was used to collect surface electromyographic (SEMG) signals. A specific software was designed in our laboratory to store synchronously Biodex® me-
Table 2
High Jumpers personal best (PB) and seasonal best (SB) and related points according to the IAAF table score

<table>
<thead>
<tr>
<th></th>
<th>PB (m)</th>
<th>Points</th>
<th>SB (m)</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>High M</td>
<td>2.27</td>
<td>1128</td>
<td>2.18</td>
<td>1040</td>
</tr>
<tr>
<td>jumper N</td>
<td>2.12</td>
<td>982</td>
<td>2.10</td>
<td>962</td>
</tr>
<tr>
<td>men S</td>
<td>2.07</td>
<td>933</td>
<td>2.05</td>
<td>914</td>
</tr>
<tr>
<td>A</td>
<td>2.10</td>
<td>962</td>
<td>1.95</td>
<td>818</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>2.1 ± 0.1</td>
<td>1001 ± 87</td>
<td>2.1 ± 0.1</td>
<td>934 ± 93</td>
</tr>
<tr>
<td>High C</td>
<td>1.78</td>
<td>967</td>
<td>1.75</td>
<td>934</td>
</tr>
<tr>
<td>jumper M</td>
<td>1.77</td>
<td>956</td>
<td>1.60</td>
<td>773</td>
</tr>
<tr>
<td>women G</td>
<td>1.88</td>
<td>1076</td>
<td>1.88</td>
<td>1076</td>
</tr>
<tr>
<td>A</td>
<td>1.70</td>
<td>880</td>
<td>1.60</td>
<td>773</td>
</tr>
<tr>
<td>S</td>
<td>1.68</td>
<td>858</td>
<td>1.60</td>
<td>773</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>1.76 ± 0.08</td>
<td>947 ± 86</td>
<td>1.69 ± 0.13</td>
<td>866 ± 137</td>
</tr>
</tbody>
</table>

2.4. Experimental procedure

Prior to the actual test, subjects were trained to familiarize with the experimental procedure. The main experiment was designed as follows. A full test session, including rest periods, lasted about 30 minutes and comprised: (i) an explanation of the tests, (ii) preparation of the subject, (iii) habituation to the tests, (iv) the actual tests.

First, surface electrodes were located on the rectus femoris (RF) and biceps femoris (BF) muscles of both lower limbs considering the recommendations of SENIAM project (1999). Inter-electrode impedance was reduced to less than 10 kΩ with standard skin preparation procedures. Then, after a standardized warm-up on the cycle ergometer, the subject was placed on the seat in order to test knee flexors and extensors of one lower limb. The trunk, pelvis, shoulders, and the upper portion of the thigh of the leg were stabilized with special restraint systems to minimize superfluous body movements. The axis of the shaft rotation of the dynamometer was visually aligned with the lateral femoral condyle of the knee. The leg was fixed to the dynamometer lever arm with a padded cuff just next to lateral malleolus. The general posture of the subject during the experiment was with the hip angle joint set at 115° and the knee angle joint set at 120° for isometric tests (180° corresponding to knee maximal extension position). For the isokinetic test, a range of motion of 90° (between 90° and 180°) was defined for full leg extension-flexion movements.

Three maximal isometric knee extension trials followed by three maximal isometric knee flexion trials were performed with each limb randomly chosen. Each isometric contraction lasted maximally 3 seconds and 1 minute of rest was respected between each trial. Finally, the subject was asked to achieve three maximal isokinetic knee extension-flexion movements at 180°·s⁻¹. During all tests, the subjects had oral and visual feedback and were instructed to work as hard as possible.

2.5. Data processing

Whatever the subject, the take-off leg was defined as the preferred leg used to take an impulse during a one-legged jump. For isometric tests, the best torque value of the three trials was retained as the actual maximal voluntary contraction (MVC). Moreover, for isokinetic contraction, the trial with the highest peak torque was identified in each subject and selected for further analysis. During isometric and isokinetic contractions, SEMG were used to calculate the root mean square (RMS) amplitude reflecting the level of agonist and antagonist muscle activity. During isometric contractions, RMS amplitude was averaged over a 1-s period during which the maximal torque was approximately constant. During concentric contractions, SEMG signals were analyzed over a range of motion which excluded 30° at the beginning and at the end of the movement, so that only isokinetic activity was included and calculated every 0.10 s in consecutive windows. Agonist activity was normalized to the maximum RMS EMG obtained during its respective maximal voluntary isometric torque. Coactivation level was expressed as a percentage of the muscle’s maximal activity recorded during its respective MVC.
2.6. Data reduction and statistical analysis

When not specified, data were reported as means ± SD. Squat jump (SJ) and countermovement (CMJ) height differences were analyzed using a three-way ANOVA (gender by group by type of jump) (Statistica 5.1., Statsoft, France). Bravais Pearson linear correlations coefficients were calculated between variables of interest. Four-way ANOVA (gender by Group by side by velocity) was performed for knee extension and flexion separately (torque, agonist and antagonist EMG activity). Significance was accepted at $p < 0.05$ for all statistical tests.

3. Results

3.1. Jump performances

Jump performances were higher in high jumpers with reference to controls (+36%, $p < 0.001$) and sex-depndant (+23% for men, $p < 0.001$, Fig. 1). SJ height was significantly lower than that of CMJ ($p < 0.001$). However, pre-stretch augmentation was similar across groups and genders (+23%, $P > 0.05$) suggesting that the tendon stiffness of the knee extensor muscles was comparable among groups (Fig. 1). Pooled data of CMJ and SJ performances were significantly correlated with extension torque of either take-off leg or raised leg ranging between $0.36 < r^2 < 0.69$ ($p < 0.05$). For pooled high jumpers, CMJ and SJ height were correlated with personal or seasonal best performances, accounting for 58 to 78% of their explained variances.

3.2. Maximal voluntary torque-velocity curves and associated EMG activity

3.2.1. Knee extension

Knee extensor muscles torques decreased significantly with velocity ($p < 0.001$) and were higher for HJ than controls with respect to gender ($p < 0.001$). ANOVA revealed a four-factor significant interaction indicating that gender influenced the knee extensor torque-velocity curves when considering laterality ($p < 0.01$). Thus, separate analysis for each gender was performed. The take-off leg of HJmen was stronger than that of controls especially at the highest velocity (15% at $0.8\cdot s^{-1}$, $p < 0.05$; 29% at $1.8\cdot s^{-1}$, $p < 0.01$). In contrast, maximal isometric torque generated by the raised leg (non-dominant) was not different across groups (5%, $p > 0.05$) but HJmen raised leg was stronger than that of their counterparts only during maximal concentric contractions (19% to 32%, $p < 0.05$). Then, the take-off leg of HJmen was stronger than the raised leg during isometric condition (17%, $p < 0.01$). HJ women were stronger than their counterparts (51 to 68%, $p < 0.01$) and a group by velocity interaction ($p < 0.01$) indicated a flattened torque-velocity curve i.e. no difference between isometric and low-torque velocities for untrained women in contrast with athletes (Fig. 2).

During knee extensions, absolute RMS EMG was lower for women compared with men (mean difference: 58%, $p < 0.01$). The normalized RMS EMG of rectus femoris increased significantly with velocity about 30–47% from isometric value ($p < 0.001$) but was not influenced by side, gender or group ($p > 0.05$). Neither absolute nor normalized coactivation of biceps femoris was different upon gender, group, side or velocity, accounting on average for 29% of EMG activity obtained during maximal isometric flexions ($p > 0.05$).

3.2.2. Knee flexion

Knee flexion torques decreased significantly with velocity ($p < 0.001$) and were 46% higher for HJ group compared to controls ($p < 0.001$) (Fig. 3). Men were stronger than women (+45%, $p < 0.001$) but there was no significant side effect ($p > 0.05$). During knee flexions, normalized BF EMG activity increased with velocity about 15–23% maximal isometric agonist RMS EMG ($p < 0.05$) but was unaltered by either group, gender or side ($p > 0.05$). Absolute RMS EMG of BF was lower for women compared with men (mean difference: 87%, $p < 0.01$). RF coactivation reached on average 10% of maximal RMS EMG obtained during maximal isometric knee extensions irrespective of gender, group or side ($p > 0.05$).

4. Discussion

The aim of this study was to examine whether asymmetry of the strength of the muscles crossing the knee joints was more prominent in high jumper athletes than in controls. We expected greater functional differences between take-off and raised legs in competitive high jumpers without gender interaction. Our results revealed that male high jumper athletes were more asymmetric during maximal isometric knee extensions than controls but not females. The following discussion will focus on the interpretation of these findings...
in relation to current knowledge on plyometric training induced-adaptations and functional characteristics of power-trained athletes.

A limited number of reports in the literature are available on functional asymmetry in well-trained athletes and their results are conflicting. Lateral isokinetic torque balance in well-trained athletes have been observed for trunk muscles in elite sailors [8] and limb muscles engaged in sports such as skiing, rowing, running, gymnastic or even in long and triple jumpers [15, 20,36,52]. Similarly to non-trained subjects or physical students [15,50], these aforementioned studies did not show significant differences between dominant and non-dominant legs. From the available data, lateral asymmetry has not been displayed in sedentary subjects or athletes practising rather bilateral sports given that both legs are equally used either moderately in daily life or maximally during such sports. In contrast, some studies indicated higher maximal torque generated by the dominant upper limb in tennis, water-polo players and canoeists [7,56,61]. Lateral dominance of lower limbs has mainly been examined in soccer players but the results are equivocal, partly related to gender differences or level of practise. Indeed, some studies have reported higher hamstring and/or quadriceps muscle torques in favour of the kicking leg for elite male soccer players depending on their field position [13,25,29,33,44]. In contrast, this was not the case for younger nine to 21-years-old players [34,35] or for females [2]. Our findings are in agreement with those of previous studies indicating a rather low but significant (<10%) lateral dominance in favour of the dominant leg in athletes [7, 13,25,33,56,61]. To the best of our knowledge, this is the first cross-sectional study examining the effects of chronic high jumping on functional asymmetry of muscles crossing the knee joint. Our findings showed that the knee extensor muscles of the dominant leg i.e. the take-off leg generated greater muscle force than its contralateral i.e. the raised leg during isometric condition only (+17%, \( p < 0.01 \)). In contrast, no such laterality was found for concentric knee extension torques as well as for knee flexion torques. These findings suggest that there was a muscle- and velocity-specific lateral dominance in competitive high jumper athletes. Furthermore, this functional imbalance was not observed for high jumper females. Indeed, all males but only three female among five high jumpers exhibited this asymmetry in quadriceps MVC. A gender-difference in terms of functional laterality due to training adaptations has also been reported for isokinetic elbow flexor torques in junior tennis players and in female soccer players [2,56]. In the present study, the higher level of expertise of high jumper men according to the current international table (Table 2) may have mainly explained this sex-dependence.

Although it is quite possible that this lateral dominance was genetically conferred, alternatively it may be the result of specific adaptations related to the preferential use of the dominant limb. The rather higher torque imbalance for male high jumpers compared with previous results based on other athletics populations gives support to this lateral training-induced specificity as reported by cross-sectional studies on unilateral training (e.g. Taniguchi [64]). During actual high jump competitive event, it has been recently shown that the free limbs (arms and raised leg) in very high skilled high
Fig. 2. Knee extension torque – velocity curves for take-off leg and raised leg in high jumper men and women; in male and female sedentary subjects. Men were stronger than women (p < 0.001) and high jumpers were stronger than controls (p < 0.01). # p < 0.01 significant between leg difference. ∗, †, ‡: p < 0.05, p < 0.01, p < 0.001: significant difference from maximal isometric torque (0°.s−1).

jumper men contributed only 8% to the vertical velocity at take-off, pointing out the importance of the take-off leg in generating muscle power during this particular unilateral jump [1]. Thus, the training regimen for high jumpers consists of bilateral moderate to heavy-load plyometric exercises that are the essential factors improving vertical jump performance combined with resistance and flexibility training [26,47,54]. In addition, unilateral stretch-shortening cycle exercises performed with the take-off leg account for a non-negligible part of the training program.

Although the underlying mechanisms responsible for this lateral specificity cannot be directly assessed in the present study, increases in maximal voluntary torque are usually associated with adaptations occurring in the central nervous system and/or at the muscle level [57]. A number of investigations have utilized SEMG to examine the neural adaptations associated with increases in torque indicating either increases [12,51,57] or no changes with strength training [31,58]. Our results indicated that neural activation of rectus femoris (normalized RMS SEMG) during maximal knee extensions was not different across high jumpers and controls whereas torque differences ranged between 15 to
Fig. 3. Knee flexion torque – velocity curves for take-off leg and raised leg in high jumper men and women; in male and female sedentary subjects. Torque decreased significantly with speed ($p<0.001$). Men were stronger than women ($p<0.001$) and high jumpers were stronger than controls ($p<0.001$). No between-leg difference was found.

30% for athletes males. Similarly, Amiridis et al. [28] showed that EMG amplitude of the dominant monoarticular knee extensor muscles (vastus medialis and lateralis, VM and VL respectively) was not different across high jumpers and sedentary subjects during maximal isometric and concentric extensions even though a 28 to 44% higher torque generation was found for high jumpers at 14 angular velocities ($-120$ to $300^\circ.s^{-1}$). In contrast, these authors showed that EMG amplitude of VL and VM was significantly lower during eccentric actions compared with isometric activity only in sedentary subjects, suggesting the presence of a tension-regulating mechanism in untrained controls as reported previously using neurostimulation techniques [19,21, 28,55]. Recent evidence indicates that the level of antagonistic cocontraction is modifiable with training that has also been proposed as a mechanism responsible for the greater torque-producing capabilities of muscle after isometric training [6] in contrast with eccentric training effect [49]. On competitive high jumpers, Amiridis et al. [28] reported a three-fold lower level of activation of the internal knee flexor muscle (semitendineous, ST) vs. untrained (13% vs. 38%) independent of velocity or action type. On the contrary, our
findings indicated similar antagonistic coactivation of the biceps femoris across groups or between dominant and non-dominant legs (≈29% of agonist maximal activity) probably due to functional differences in muscle investigated (BF vs. ST). However, the observed lateral difference in high jumpers MVC can not be ascribed to a likely difference in the coactivation level of ST between the take-off leg and raised leg because a similar difference in torque would have also been expected during concentric actions (60 to 180°). These above observations suggest that agonistic and antagonistic neural activation may not have been the mechanisms underlying the lateral dominance observed in high jumper males. However, a recent study showed that voluntary EMG measured during maximal contraction as an index of the level of neural activation is quite questionable when comparing endurance-, power-trained and sedentary subjects [19]. Despite the lack of difference across groups in the EMG amplitude in VL and VM muscles measured during maximal isometric contraction, athletes exhibited a significant higher activation level (≈15%) using superimposed twitch technique [19].

Another interesting finding was the lack of between-leg difference in peak torque at the faster concentric speed (180°.s⁻¹) probably related to similar fibre type proportion between the take-off and raised leg in high jumpers. The higher torque differences with increased velocity between athletes and sedentary subjects (Fig. 1) indicate a higher percentage of fast fibres in power athletes compared with untrained men [22, 25] that has also been significantly related to squat and countermovement performances [9]. Indeed, recent studies have demonstrated that maximal isokinetic knee extension torque normalized to muscle volume obtained at velocity of movement higher than 120°.s⁻¹ was positively related to the proportion of fast twitch fibres [3,25,42]. These observations prompted us to suppose that this lateral isometric specificity in male high jumpers is related to other factors than neural activation and fibre type transition.

The maximal force-generating capacity during isometric and low-concentric actions (<30°.s⁻¹) of a given muscle is generally related to its physiological cross-sectional area (PCSA) and have been extensively discussed [24,41,46,53]. Hypertrophy is also associated with increased muscle fiber pennation angle and/or muscle thickness [14,43,62]. Recently, Kearns et al. [14] reported significant higher fascicle length and muscle thickness of gastrocnemius medialis of the kicking leg in soccer players. Theoretically, an increase in pennation angle and/or muscle thickness allows for attachment of more contractile tissue to the tendon, which may lead to increased strength. Therefore, it can be speculated that difference in MVC could be due to a greater PCSA of the dominant knee extensor muscles.

Alternatively, a difference in terms of torque-angle shape may have partly explained this lateral dominance in isometric condition only. Inter-subject differences (61 ± 4°) have been reported on the same muscle group for untrained individuals [63]. Similarly, cross-sectional studies have shown different torque-angle curve across different athlete’s populations such as runners and cycling athletes or skaters [27,59] or even for non-trained subjects [40] of their dominant limb. These observations give support to the length-at-use hypothesis that specific training can modify the shape of the MVC-angle relationship. This might be explained by between-leg difference in tendon stiffness because during even fixed-end isometric conditions, muscle fibers shorten until the slack of series elastic components such as tendinous tissues is taken up [37]. Thus, a lower tendon stiffness of the non-dominant quadriceps femoris would result in a leftward shift of the torque-angle curve of the knee extensors. This would place the contractile component at a non-optimal point on the force-length curve [18] and thus altering their potential for joint moment generation. Lower tendon stiffness would also delay the angle at peak torque during dynamic contractions [63]. In the present experiment, high jumpers exhibited a systematic angle at peak torque during isokinetic contractions at more extended positions for the raised leg than the take-off leg (up to 11°, data not reported) that gives support to the aforementioned assumption. In addition, previous studies have shown an increase in musculo-tendinous stiffness of upper and lower limbs measured during active conditions by quick-release or oscillations techniques after plyometric training probably related to an increase in tendon stiffness [11,23,48]. A higher musculo-tendinous stiffness of the take-off leg may be suitable for transmitting the force more effectively [17] and further enhance the release of potential energy during the push-off by shortening the coupling time i.e. the time between touchdown and take-off. No data about adaptations of tendon properties before and after plyometric training in humans are available to support such a hypothesis and requires further study.

5. Conclusion

Male high jumpers were more asymmetric than non-trained subjects during maximal isometric knee exten-
sions but not during concentric action type or knee flexions. These results suggest that chronic high jump training may have induced greater imbalance in knee extensor torque probably due to the preferential use of the leg at take-off over the raised leg. Our results seem to indicate that this lateral dominance is probably explained by peripheral differences (muscle volume, pennation angle, tendon stiffness) rather than either neural factors or fibre composition. Future studies examining these assumptions on a larger sample size with suitable in vivo technique such as ultrasonography are warranted.

References


Abstract

Relation between muscle strength and age in a sample population of 80 soccer playing children aged from 10 to 15 years

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Introduction: The evolution of muscle strength with age is very well documented for adult, but not for children. Gobelet reports a decrease of the knee flexors/extensors ratio between 10 to 15 years, then an increase under the influence of training [1]. Kellis et al. [2] report for young soccer players a correlation between dominant knee flexors and extensors and age, height, weight and puberty.

Objectives: To analyse the evolution of knee flexors and extensors of young soccer players and to research a relation with age, morphology and puberty.

Population: 80 young subjects, without any disease, voluntary, who take part in a special school for practice and education to sports, and aged from 10 to 15 years (age mean 12.78 years ± 2.88).

Method: For each subject are performed a clinical evaluation (age, weight, height, BMI, Tanner scale of puberty) and a bilateral evaluation of knee flexors and extensors muscle strength with an isokinetic dynamometer.

Results: There is a strong significant correlation ($p < 0.0001$) between age, height, weight, BMI and Tanner level of puberty and all peak torques at different angular velocities. Between 11 and 15 years, the peak torque values increase from 50% and more between 12 to 14 years. The knee flexors/extensors ratios are equivalent but there decrease significantly between 14 and 15 years. The ANOVA reveals that puberty level is an important factor on the different peak torques for all angular velocities ($p < 0.0001$), but without effect on the ratio values. Muscle strength increases largely between Tanner level 1 and level 5, particularly between level 2 and level 4.

Discussion: The evaluation of muscle strength during growth is difficult and requires longitudinal studies. There is a large individual variation. The increase of muscle strength between 11 to 15 years is in accord with others results in the literature. But, for you, no study has very well analysed the evolution of puberty for this sample of young sportsmen. But, this period is clinically difficult to analyse, and it will be probably necessary to associated to our analyse, an hormonal measure of testosterone and a radiological evaluation of the puberty level.

References


Interest of eccentric isokinetic exercises in cases of calcanean tendinosis and thigh muscular injuries: Prospective study results

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Abstract. Musculo tendinous injuries are frequent pathologies in sport medicine. Rest and classical treatments are, very often, not enough to succeed a good healing and return to sport activities. The aim of this prospective study is to demonstrate the interest of eccentric isokinetic exercise in the treatment of sub acute injuries of the calcanean tendon and of the thigh muscles. Complementary with classical kinesitherapy treatment, isokinetic work allowed a complete healing and return to anterior sport activities, without any recurrent injuries for a majority of the patients. We suggest in conclusion a specific protocol to care these pathologies using an isokinetic dynamometer in eccentric mode.

Keywords: Calcanean tendon, muscle, reeducation protocol, isokinetic, eccentric, prospective study, sport medicine

1. Introduction

Tendinitis and muscle injuries occur frequently in sport medicine: with professional soccer players, muscle injuries represent 34% of accidents and tendinitis 4% [6,14]; hamstrings injuries correspond to 50% of muscular injuries for runners and 40% for soccer. Main etiological factors consist in: static unbalance [11], muscular unbalance (bilateral asymmetry, unbalance ratio between agonist and antagonist) [4], impairment of musculotendinous stretchness [11,12,16], poor hydration, poor practice conditions, during sport activity (equipment, environmental conditions, training) [11]. William Stanish, used the first, eccentric exercises for the treatment of patella tendinitis and calcanean tendinosis (CT) [15], showing that traction exercises in eccentric conditions allow to improve the tendinous eccentric resistance to stretch when occurring during sport activities. More precisely, eccentric exercises contribute to improve tendinous and muscular injuries healing process. These eccentric exercises stimulate the fibroblast and Mauro’s satellite cells growth and help to the alignment of the new fiber in the axis of traction [8,9]. Alfredson reports in 2003 excellent results using manual and daily eccentric exercises to care chronic CT [1].

The 3 aims of this prospective study [13] are:

1. To confirm the interest of eccentric exercises at our clinic (Centre de Medecine du Sport de Lyon Gerland-cmslg), thanks to the data of an isokinetic dynamometer to evaluate patient’s and PT’s perceptions along the period of treatment.
2. To precise the value of data allowing the return to sport activities.
3. To elaborate appropriate eccentric protocol on the isokinetic dynamometer in conjunction to the results obtained.

2. Materials and methods

2.1. Patient population (Table 1)

Twenty-one patients aged 30+/− 9 years (18 men, 2 females, 1 teenager); 11 soccer players, 5 runners, 5 others sports.

Nine of them suffer calcanean tendinosis (8 of mid portion tendon, 1 insertional calcanean tendon pain).
Eight of them suffer hamstrings muscular injuries (tears or level 3).

Four of them suffer quadriceps muscular injuries (3 level 3, 1 level 4-partial rupture).

All these musculotendinous pathologies lasted less than 6 months. It was either a first care or consecutive to anterior treatment failure (sport rest, kinesitherapy, NSAi). Positive diagnosis result from clinical examination and echography or MRI for 50% of the patient group.

2.2. Isokinetic equipment

The isokinetic dynamometer is a CYBEX® Norm. It is operated in CPM mode. The patient is taught to resist (eccentrically) against the dynamometer movement with the muscle involved and to be passive during the movement back to the initial position.

Patient positioning depends on muscle involved:

- calf contraction is realised in prone position, knee straight; max ROM is from $50^\circ$ plantar flexion to $20^\circ$ dorsiflexion.
- soleus contraction in supine position, hip and knee $90^\circ$ flexed.
- hamstrings contraction in seated position, from anatomical zero to $135^\circ$ flexion max.
- quadriceps contraction in seated position, from anatomical zero to $135^\circ$ flexion max.
- hip flexors contraction in supine position, from anatomical zero to $120^\circ$ flexion max.

At any time the controlateral limb is fixed and strapped to avoid joint center of rotation displacement.

3. Experimental protocol

- number of treatment session depends of each patient and symptomatology evolution but minimum frequency is 2 session per week.

- each session of eccentric exercise on dynamometer associated with classical kinesitherapy (cryotherapy, physiotherapy, NSAi, deep travers massage, progressive passive musculotendinous stretching, manual eccentric exercise and proprioception exercises).

- The 1st day of treatment, patients benefit of isokinetic eccentric assessment on non involved side at the 3 speeds used on reeducation ($5^\circ$/sec, $10^\circ$/sec and $15^\circ$/sec).

- Initial force assessment is only on non involved side to prevent pain and myo tendinous healing.

- No pain rule is strictly respected during all the treatment period. If such occurs during the session or after, we came back to none pain anterior level of exercise and slowed the progression of the treatment.

- 10 minutes of warm up on a bicycle is achieved before each session, cool down, recovery and muscular passive stretching follows each of the session.

- each session consists in an eccentric exercise for healing goal at $5^\circ$/sec of speed, ROM is 45% of max, with torque survey around $-50$ Nm (average). The different parameters (torque, ROM, speed and number of repetitions) are increase progressively staying under the pain level; only one parameter is increase at the same time. During the treatment speed is increased from $5^\circ$/sec to $10^\circ$/sec and then to $15^\circ$/sec. ROM are patient dependant inside the conditions above described.

- Rest time between series is from 30 sec to 60 sec.

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**Table 1**

<table>
<thead>
<tr>
<th>Study patient characteristics</th>
<th>Total</th>
<th>Calcanean tendon</th>
<th>Quadriceps</th>
<th>Hamstrings</th>
</tr>
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<tr>
<td></td>
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<td>(n = 8)</td>
<td>(n = 1)</td>
<td>(n = 8)</td>
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<tr>
<td>Age (years)</td>
<td></td>
<td>34 ± 5 30</td>
<td>33 ± 11 24</td>
<td>25 ± 8 30</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td></td>
<td>82 ± 9 70</td>
<td>78 ± 11 60</td>
<td>72 ± 9 78</td>
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<tr>
<td>Anteriority of symptomatology (days)</td>
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<td>(20–165)</td>
<td>(7–120)</td>
<td>(2–165)</td>
</tr>
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<td></td>
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<td>1 Runners 72</td>
<td>5 Soccers 51</td>
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<td></td>
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<td>Anterior treatment</td>
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<td>0 0</td>
<td>1 1</td>
</tr>
<tr>
<td>Diagnosis</td>
<td>Symptomatology duration</td>
<td>Number of sessions</td>
<td>Reeducation period</td>
<td>Return to run</td>
</tr>
<tr>
<td>----------------------------</td>
<td>-------------------------</td>
<td>--------------------</td>
<td>--------------------</td>
<td>---------------</td>
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<td>20</td>
<td>3.5 months (± 5)</td>
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<tr>
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<td>2 months (± 2)</td>
<td>19</td>
<td>3 months (± 5)</td>
<td>12 (± 4)</td>
</tr>
<tr>
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</tr>
<tr>
<td>Quadriceps</td>
<td>2 months (± 2)</td>
<td>18</td>
<td>3 months (± 5)</td>
<td>9 (± 3)</td>
</tr>
</tbody>
</table>

Table 2

Mean duration of musculo-tendinous reeducation
4. Evaluation procedure

The prospective study at the CMSLG lasted 6 months. Each of the patient benefit a weekly follow-up by the clinician. An enquiry form was filled up, including comfort score, pain score and daily activity level items. It was done: at the beginning of the treatment, during the treatment session and when return to sport activities. Usual clinical examinations followed the questionnaire (inspection, palpation, isometric contraction against resistance, passive stretching).

The weekly examination was associated to a regular clinical survey operated by the sport clinician specialist referent.

After 6 months, each patient has been interviewed to evaluate the sport activities return conditions.

After 9 months (3 months later the first interview) a new interview has been done for eventual recurrent problem.

5. Results

Clinical evolution (Table 2)

5.1. Calcanean tendinosis (CT)

Five among the 9 patients recovered clinical normalisation (pain free during daily life and clinical examination without abnormality), 3 among the 9 shown clinical improvement (pain free during daily life, persistency of tendon thickness or sensitivity during palpation) Theses improvements occurred 2 months (average 12 sessions) after the beginning of the treatment with a peak torque value around 76% of controlateral value.

One among the 9 patients (the subject with insertion calcanean tendon pain) didn’t get any clinical improvement in spite of correct torque isokinetic values.

Patients get back to sport training with a peak torque value around 83% of the controlateral value. Fifty percent of the patients with CT were runners, they came back to their specific sport activity one week after the run recovery. Only 2 soccer players achieved up to 20 sessions of treatment, so they return to competition with an isokinetic peak torque at 114% of controlateral value.

Among the 9 patients,

– 2 of the 9 return to competition with a different feeling concerning the tension and thickness of calcanean tendon while 2 patients did not succeed to recover their previous sport: one because of a intercurrent pathology, the other one because of the absence of improvement in his enthesopathy of calcanean tendon.

To summary during an average of 8 months (3 to 16 months) period of follow up only one among the 9 patients presented a recurrent pathology. This patient had a CT and complained about discomfort at his soleus insertion on involved side during the reeducation time. Echography did not show any lesion. This patient reported a recurrent pain on soleus 2 months after return to sport activities.

5.2. Muscles injuries (MI)

After 10 sessions (5 weeks average) of reeducation, 9 patients among the 12, succeed clinical normalisation (i.e. no pain at all during daily life and clinical examination without abnormality). 3 patients among the 12 reported clinical improvement (i.e. no pain during daily life, tension feeling on muscular envelop without sign at clinical examination).

Return to run has been effective when involved isokinetic peak torque reached 78% of controlateral side. This result happened after an average time of 31 days corresponding to 8 eccentric isokinetic sessions (average).

Sport training return has been effective when involved isokinetic peak torque reached 85% of controlateral side corresponding to 11 eccentric isokinetic sessions.

Competition return has been effective at 95% of controlateral peak torque, corresponding to 14 sessions (average).

Nine patients among the 12 recovered the same level sport activity as before the pathology, even better (better feeling, increase in muscular performances). 2 patients return with apprehension feeling but without pain. 1 patient faced to intercurrent pathology during the reeducation period and interrupted sport activity.

During 8 months period of follow up no one of the patients reported recurrent lesion.

5.3. Follow up of isokinetic dynamometer results

At the end of reeducation, CT patients reported an increase of involved side isokinetic peak torque of 295% compared to initial values.
These values correspond to 102% of contralateral side.
MI patients reported an increase of 196% compared to initial value and 93% of contralateral side.

6. Discussion

First of all we faced a long delay between the beginning of the pathology and the beginning of our treatment: 3 months for CT, 2 months for MI.
This long delay results from patient’s negligence or failure of anterior classical treatments.
In spite of this long delay, the functional recovery of musculo tendinous structures after eccentric isokinetic exercises has been completed, in comparison to the involved side either for clinical approach as for the muscle force (respectively 102% for CT, 93% for muscle injury). These results are a good point to prevent the recurrent risk, as Croisier [5] results.
Back to running exercises is possible early (2 months for CT, 1 month for muscles injuries), but return to anterior sport training level and to competition level is delayed significantly except for runners (probably because of no need of technical exercises compared to other sports with specific needs, as typically team sports).
Total time for complete recovery is longer for CT (4 months) as for muscle injury (2 to 3 months). This difference explains the higher peak torque obtains for CT compared to MI. But the MI group (majority of soccer) needs, because of this sport requirement, progressive and specific training before to return to competition. This specificity explains the longer time between return to training and return to competition.
The number of eccentric session per week is a key factor, 3 times a week is a minimum as shown in a previous study by Cotte [3] CMSLG.
Patients who had only 2 eccentric sessions per week because of professional or personal commitments came back later to sport activities.
Delay between injury and treatment doesn’t seem to interact the quality of the healing but increase the total time of rehabilitation.
Literature point out that total rest and too early mobilisation is negative for correct healing [10]. Contrary, several authors reported the interest of early work on traction (eccentric), aligned with muscle mechanical axis, to care CT and MI [2,8]: thanks to proteinic synthesis activation, reinforcement of conjunctive tissues envelope and muscle fiber alignment.

Isokinetic dynamometer is an accurate and precise tool for adjustment and management of protocols parameters (speed, ROM, duration, torque-threshold and limits) allowing individual and precise exercises. It is also used to quantify objectively the force level required for sport activity return [7].
These are the reasons why we used isokinetic dynamometer for CT and MI care, with positive results.
This treatment failed on the case with enthesopathy of the calcanean tendon (no pain decrease no return to sport activity in spite of the increase of peak torque after treatment). This confirms the results of Alfredson [1] who reports positive results of eccentric work for 89% of CT and only 32% success with insertional pain.
Our results allow the establishment of specific protocols parameters for sub-acute muscular and tendinous injuries of lower limb, using eccentric contraction with isokinetic dynamometer.
Protocol must include
– the 1st day of treatment a muscle force assessment on non involved side, on eccentric conditions at the same speeds used during for the treatment: 5, 10, and 15°/sec.
– No pain rule respected.
– Warm up before each session and cool down recovery on ergometric bicycle and stretching exercise after each session. Treatment must include classical manual physiotherapy.
– 12 to 20 isokinetic eccentric sessions are recommended at a frequency of 3 times per week. Treatment starts with isokinetic eccentric exercise for healing goal: at 5°/sec of speed, ROM limited at 45% of max ROM, intensity at 35% of peak torque of non involved side (this corresponds to $-50\text{ Nm}$ or $-0.66\text{ Nm/kg}$, if the 2 sides are involved.
– Increase of speed is 5°/sec to 10°/sec after 5 isokinetic eccentric sessions. This change of speed must correspond at the time where peak torque reach 75% of none involved value.
– Increase of speed from 10°/sec to 15°/sec is when peak torque reach 90% of none involved side peak torque, in the same conditions.
Treatment must go on at 15°/sec up to the time to obtain the same torque value as the non involved side.
Then the eccentric exercise must be continued with higher speed (30°/sec and 60°/sec) in order to target more physiological conditions.
Return to run can be suggested, with no pain rules, when peak torque reaches 83% of bilateral performance for CT and 78% for MI.
Return to sport training and to competition are linked to patient’s clinical feeling and total recovery of normal eccentric isokinetic values.

7. Conclusions

This 21 patients study on CT and MI pathologies shows that musculo-tendinous injuries are still to much neglected: medical examination practised too late (average 2 months) and after inefficiency of a rest sport period and/or failure of classical medical care. Rest only is not efficient and classical care is often also not efficient.

Any delay in start of care increases the after-effects and recurrent risks.

So we do remind the importance of diagnosis and early care of musculo-tendinous injuries.

We succeed proven results, in case of late treatment and case of failure of classical care for 4 patients:

- Healing has been completed for 20 patients (pain free, peak torque balance with non involved side or normal at the end of treatment).
- Only one of the 21 patients did not have improvement in spite of normalization of his isokinetic peak torque values and his insertional calcanean pain tendon needed surgery.
- 18 patients of the group return to their anterior sport activities: 14 of them in the same conditions as before injury (same performances, totally pain free) or even better (better feeling of muscular capabilities); 4 patients return to sport with subjective asymmetry feeling or apprehension.
- 1 patient did not return to anterior sport activities because of inter-current pathology.
- 1 patient faced to recurrent injury 2 months after return to sport.

Return to sport practises is based on clinical examination and values of isokinetic data collected during treatment [7]. The aim of this prospective study is to help the optimization of musculo-tendinous treatment.

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References

Review

Pertinent issues regarding the isokinetics of the ankle complex

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1. Introduction

Serious research concerning isokinetic testing of the ankle goes back to the early 80’s with a series of studies coming from Sweden [6,8]. This series has been followed by extensive research that focused on different aspects of ankle isokinetics. Surprisingly even to date, most of the technical problems are not resolved, a tribute to the complexity of this joint system, its optimal testing protocol and the incompatibility of various commercially available isokinetic dynamometers. In this short review I will try to dwell on a number of pertinent points, specifically on the use of ankle muscles strength ratios.

2. Protocol aspects

These concern the muscles under consideration, test position, the range of motion and test velocities. Typically, 4 muscle groups have been investigated: the plantarflexors (PF), dorsiflexors (DF) Invertors (IN) and Evertors (EV). Among these, the PF and DF are more amenable to isokinetic evaluation whereas IN and EV pose a serious methodological problem.

As for the PF and DF, the design of the specific dynamometer dictates often the test position. However, it seems that most professionals preferred the supine or prone lying position. The advantage of the ‘horizontal’ testing is twofold: first it allows a measure of self stabilization by virtue of the weight of the subject. On the other hand care must be taken prevent forward/backward sliding of the subject on the plinth which is often observed in eccentric testing of the DF. In addition this test position enables the placing of the knee in a comfortable degree of flexion while strapping the shank in order to provide added distal stabilization. Admittedly, the latter may not equally apply upon testing at the prone position. Second, it allows the examiner more freedom in aligning the bimalleolar axis with that of the lever-arm. This test position has been adopted in most of ankle isokinetics studies. An alternative test position for the PF which has been originally proposed by the author was later examined in a systematic manner [16]. In this position, the knee is placed at 90° flexion while the foot is supported by a wedge (from below) which is located on an elevated surface (stool). With a fulcrum now at the region of the heads of metatarsal bones, concentric contraction of the PF lifts the shank while eccentric contraction is associated with lowering of the foot, much like the events that take place in functional activities of the foot. The scores derived from this protocol have been shown to be highly reproducible. The RoM used for PF/DF testing is variable, typically between 30 and 45°. However the velocities applied ranged 60–180°/s which for the high end and the corresponding RoM would indicate a largely non-isokinetic conditions. Unfortunately, this issue was never properly addressed with respect to these muscles.

The situation regarding IN/EV strength is somewhat more complicated, resulting first and foremost from the unavoidable misalignment between the abovementioned axes. Eversion and inversion are compound
movements involving simultaneously numerous instantaneous axes that cannot be fitted with a singular axis. Moreover, it would be particularly difficult to adjust the position of the lever-arm to accommodate substantially these axes. As a result the IN/EV ‘plane’ of movement is defined based on the performance capability of the dynamometric system as a whole (motor, seat, and attachments). Typically the subject is in the supine position while the lever arm is facing the feet rather alongside them. Maintenance of some flexion in the knee prevents contribution from hip rotators since with a fully extended such co-activation could take place. The action that is being measured may be described in terms of rotation in a plane that is generally orthogonal to the axis of the tibia. The RoMs and velocities that were used in previous studies were similar to those applied in PF/DF testing with the obvious implications. A different approach using short RoM testing has been recently applied to IN/EV testing. In a study of patients who have undergone ORIF for bimalleolar fractures, the RoM was limited to 20° while the velocities corresponded to nominal movement times of 2 and 0.5s namely 10 and 40°/s, thus rendering alignment less problematic [5].

3. Strength ratios

In assessing the integrity of the musculoskeletal apparatus the best estimates may be derived when the compromise in unilateral namely the involved side is compared to the unininvolved side using identical strength testing protocol (Sapega 1990). This axiom is equally valid for ankle muscles. However when the compromise is bilateral comparison to so-called ‘normative’ values is largely irrelevant. Another issue that in recent years saw a conspicuous development is that of within joint (side) strength ratios. These relate initially to the conventional agonist/antagonist strength or power ratios namely concentric (agonist) vs. concentric (antagonist) or eccentric vs. eccentric, respectively. However in view of the particular importance attributable to the dynamic control ratio (DCR) defined as the concentric strength of the agonist vs. the eccentric strength of the antagonist with respect to knee musculature [1,4], similar application has already been attempted with respect to the ankle INs and EVs. Both the conventional ratios and the DCRs were applied for investigating what may probably is the most pressing problem of the ankle complex: chronic instability.

4. Isokinetic correlates of chronic ankle instability

The issue of chronic ankle instability (CAI) which refers to repetitive incidences of lateral ankle instability resulting in numerous ankle sprains [10] occupies, justifiably, a specific niche in the isokinetic literature. CAI engulfs two well established concepts, that of mechanical and functional ankle insufficiency (MAI and FAI, respectively). Rather than two distinct entities MAI and FAI are probably complementary in nature. Hertel [10] suggests that MAI, which relates to structural changes following an initial ankle sprain that predispose the ankle to CAI, consists of 4 elements: pathologic laxity, arthro-kinematic restrictions, degenerative changes and synovial changes. On the other hand, FAI, which relates to a compromised neuromuscular apparatus consists of impaired proprioception, postural and neuromuscular control and strength deficits. It is the latter element that has been the focus of a number of studies which have largely applied isokinetic dynamometry. The reason for attaching specific importance to the ankle muscle complex and its level of performance is the critical dependence of ankle stability on dynamic muscular control. Although its ligamentous protection is far more robust compared to other joints that suffer from inherent instability (e.g. the glenohumeral) the mechanical demands put on this joint system are immense. The combination of a high center of gravity and hence a relatively large gravitational lever arm, uneven surfaces and speed of motion as well as sudden high velocity impacts may result in a biomechanical combination that exceeds the physiological tolerance of the latera aspect. This in turn leads to various degrees of collapse of the passive defense provided by the lateral ligaments of the ankle. Together with the lateral ankle ligaments: the anterior talofibular, calcaneofibular, posterior talofibular, talocacaneal and cervical, the peronei muscles act to counteract the external inversion-supination moment. As the peronei contract they also elongate and given the fast nature of this contraction it is feasible that the force generated within these muscles is near or at its maximum. Hence the pivotal role eccentric testing has in the muscular assessment of the ankle in general and cases of instability, in particular.

4.1. Strength variations in CAI

There is a controversy regarding weakness of the peronei in CAI. In one of the first studies of its kind Tropp [19] compared EV strength in subjects with FAI.
Significant reduction in peak moment was revealed and attributed to inadequate rehabilitation and atrophy. Using concentric tests, Lentell et al. [13], Ryan [18], Lentell et al. [14], Wilkerson et al. [20], McKnight and Armstrong [15] and Porter et al. [17] reported no selective weakness in the EVs of the involved side in patients presenting with CAI although tests covered substantially the full spectrum of test velocities (30–210°/s). In variance with the findings associated with EV strength Ryan [18] and Wilkerson et al. [20] reported a seemingly unexpected weakness in IN strength among CAI patients. This weakness was explained by compression of the deep peroneal nerve, an outcome of lateral sprain, and reduced ability to control the lateral displacement of the foot due to compromised lateral ligaments. As a result, eccentric conditioning of the IN group was suggested [20]. Eccentric testing in patients with CAI was conducted by Bernier et al. [2] and Kaminski at al. [10]. In the previous study no differences in either the INs or the EVs was noted. The latter study returned similar findings with respect to EV strength.

On balance, these studies deny a specific weakness of the EVs but point out to a possible compromise to the INs. Though the absence of expected EV insufficiency may reflect a genuine situation, it is possible that a number of factors conceal a real problem. First, as mentioned above, the possible misalignment of axes (biological vs. motor) as well as the test position for EV-IN and may not impose a pure external counter-moment in the same way it does, for instance, during testing of the PF/DF. This misalignment, which due to their design and construction takes place in all dynamometers, could put the force vectors of the EVs and INs in an off-plane position and consequently allow recording of only a fraction of their true potential. In much the same way testing in the seated position is in variance with the functional demand and the static effect of gravity. In other words, the operating muscles may already be under a ‘bias level’ of tension. It is not at all clear whether the test protocols employed have incorporated a sufficient isometric pre-activation bias. In addition to these lateral ankle sprain normally occurs within a very short duration, typically shorter than what is needed for a reflex arch to activate the muscle. Thus, enhanced strength may not offer enough protection in such situations, anyway. On the other hand, lower velocity threats may be averted by higher performance muscles and a better tuned proprioceptive apparatus. These indeed are the major objective of CAI rehabilitation.

4.2. Dynamic control ratios (DCR) applied to ankle muscles

Whereas same mode strength ratios were largely unremarkable with respect to CAI, there was some hope that DCR type ratios will allow a clear differentiation between involved and uninvolved sides. Specifically targeted was the EV_{ecc}/IN_{con}, which relates to the effect the peronei exert while attempting to control the turning (inversion) moment produced by the invertors [3, 11] upon performance of an angular (‘open chain’) isokinetic test. However, both studies failed to establish a specific role for either the EV_{ecc}/IN_{con} or the EV_{con}/IN_{ecc} ratios.

A different light was shed on the ankle-related DCRs by a recent study which focused on isokinetic performance of the EVs and INs in patients 6 to 12 months following surgery of malleoli fractures [5]. Invertors and EVs strength was bilaterally measured concentrically (con) and eccentrically (ecc). Absolute strength of the involved limb was significantly lower than values of the sound limb, for both muscle groups ($p < 0.001$). However, strength reduction was significantly greater for the INs (27.6–37.5%) than the EVs (14.4–24.3%) ($p = 0.0005$). The EV/IN conventional ratios of the sound limb (89–102%) were significantly lower than ratios obtained for the involved limb (111–141%, $p < 0.0001$). Of particular note, the clinical status of the limb was found to have a significant effect on all DCRs: EV_{ecc}/IN_{con}, IN_{ecc}/EV_{con}, EV_{con}/IN_{ecc} and IN_{con}/EV_{ecc}: $p < 0.0001$, $p = 0.0032$, $p = 0.0001$ and $p = 0.0015$, respectively. Thus, a significant compromise in the DCR was apparent in this group of patients which still exhibited a conspicuous functional deficit as indicated by Ankle-Hindfoot Scale. Thus although DCR-type ratios may not have a parallel role in ankle neuromotor evaluation as they fulfill in the shoulder and knee, further research is certainly deserving.

References

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