LONGITUDINAL RESEARCH OF CALF MUSCLES FUNCTIONAL CHANGES FOR HEALTHY AND WITH ACHILLES TENDON RUPTURE SUBJECTS

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Abstract

Achilles tendon is the strongest tendon in human body, but despite that, it is also one of the common ruptured tendons. When the Achilles tendon rupture (ATR) occurs, strength of calf muscles, proprioception, and postural stability always decrease. It is well known that rehabilitation influences the greater recovery after Achilles tendon rupture, but despite that the probability of the Achilles tendon re-rupture one year follow up still remains. Therefore, it is very important to understand the ruptured Achilles tendon and calf muscles healing possibilities not only after applied physiotherapy, but also one year follow up. During the present longitudinal research calf muscles strength and proprioception changes of a healthy person and a person with ATR were examined.

Key words: *muscle torque variability, isometric maximal voluntary contraction torque, visual feedback.*

Introduction

Achilles tendon is the strongest body tendon (Kaya, Nyland, Toprak, & Turhan, 2012; Mafulli, Oliva, & Ronga, 2013), but despite the strength, it is the most frequently ruptured tendon in the body and comprises about 20 % of all large tendon ruptures (Hashim, Dahabreh, Bin Jemain, & Williams, 2012; Mafulli et al, 2013). Supposedly, one of the reasons of Achilles tendon rupture (ATR) may be inadequate relationship between small tendon cross-sectional area and external forces (Kongsgaard, Aagaard, Kjaer, & Magnusson, 2005). ATR causes various acute limitation and chronic adaptation such as calf muscles weakness, decreased functional ability (Bressel, Larsen, McNair, & Cronin, 2003; Maquirriain, 2011), proprioception (Salonikidis, Amiridis, Oxyzoglou, Villared, Zafeiridis, & Kellis, 2009). It is known that pathological musculoskeletal conditions after ATR may be influenced by the development of adaptive changes in motor strategies, due to mechanical and neural factors (Don, Ranavalo, Cacchio, Serrao, Costable, Iachelli, Camerota, Frascarelli, & Santilli, 2007). Mechanoreceptor activity after ATR is disturbed (Hong & Newell, 2008) Inadequate sensory feedback from mechanoreceptors in the ankle joint region distorts a person's perception of foot position (proprioception) during movement (Bressel et al., 2003).

Movement stability depends on the amount and quality of the proprioception information. Muscle torque variability (movement stability) depends on the muscle torque, task complexity and somatosensory information (Christou, Grossman, & Carlton, 2002). Disrupted afferent information from joints, muscles and tendons decreases movement stability (Harrison, Duenkel, Dunlop, & Russel, 1994). It is established that the movement during the task could be improved when it is performed with visual feedback and lasts more than 150 ms (Salonikidis et al., 2009). Information from visual feedback as well as from muscles and tendons is important to movement stability during the task (Osu, Franklin, Kato, Gomi, & Domen, 2002).

According to literature, ruptured Achilles tendon stiffness and strength can be affected most within first 18 weeks after the Achilles damage occurred. Longer period of time reduces the influence (Schepull, Kvist, Anderson, & Aspenberg, 2007). If the Achilles tendon stiffness and strength are not restored, the probability of repeated tendon rupture (Doral, Alam, Bozkurt, Thurnan, Atay, Donmez, & Maffullli, 2010; Torbert & Panchbhavi, 2009) of the same or the other leg increases. Mostly all physiotherapy protocols after ATR includes earlier weight bearing, range of motion and strengthening eccentric exercises (EE) (Maquirriain, 2011). It is established, that EE influence calf muscles torque and proprioception changes, but differences between injured and non-injured leg remain one year follow up (Finni, Hodgson, Lai, & Edgrteo, 2006; Torbert et al., 2009). However, ankle proprioception changes in an ATR population are still not well understood. In literature, EE influence on healthy person calf muscles changes is controversial. It is established that 4-6 week strengthening exercises determine structural changes in muscles (Hotermann, Roeleveld, Engstrom, & Sand, 2007). 8 weeks EE influence greater muscle hypertrophy (Farthing & Chilibeck, 2003; Duclay, Martin, Duclay, Cometti, & Pousson, 2009) and strength compared to concentric exercises (Farthing & Chilibeck, 2003). However EE have no influence to greater Achilles tendon collagen synthesis for healthy person (Roig, O'Brien, Kirk, Murray, McKinnon, Shadgan, & Reid, 2009).

In addition, the examination of the Achilles tendon healing possibilities could help to provide a better understanding of how physiotherapy may influence the properties of scarred Achilles tendon and avoid tendon re-rupture.

The object of the study – the plantar flexion MVC and VT changes one year follow up for healthy and with ATR subjects.

The aim of this study was to estimate EE effect on the dominant leg, non-dominant leg, non-injured leg and injured leg plantar flexion muscles maximal voluntary contraction torque and movement variability changes one year follow up for healthy and after ATR persons.

Twelve men have participated in this study. Experimental group consisted of 5 participants (age 35±5), who were 6,5 weeks after Achilles tendon surgery and 10 rehabilitation procedures. Control group consisted of 7 (age 28±5) persons who had never had ankle strain, calf muscles rupture and they were not physical active.

Methods and organization

Quantitative survey of changes in plantar flexion MVC and VT were analyzed using "Biodex medical System PRO 3". All measurements for both groups were made 7 times: first time for the experimental group was – 6,5 weeks after Achilles tendon surgery and 10 rehabilitation procedures, second – after 8 weeks physiotherapy. For control group – first time before and second after 8 weeks eccentric exercises for plantar flexor muscles. All other 5 times were repeated every two months in one year period.

The sensitivity of the Biodex in torque measurements is ±1.36 Nm. The subjects were secured on an adjustable chair in a slightly reclined position: hip flexed at 75º, knee at 30º angle and strapped at the chest. The foot was held in a place by a heel block and was tightly attached to the plate by two straps. One strap was placed around the foot, 1–2 cm proximal to the metatarsophalangeal joint of the toe, and the second strap was placed around the foot, just below the ankle joint. The position of the subject was adjusted to obtain a 90º angle for the ankle (neutral position 0º). To correct the effect of gravity on the measured joint movements, the passive mass of the foot was measured in the dynamometer at 15 º ankle angles. All subjects were tested without shoes.

Plantar flexion muscles isometric maximal voluntary contraction (MVC) torque was measured in the non-injured (NIL) and injured (IL) leg as well as in the dominant (DL) and non-dominant (NDL) leg. The test started from the NIL and DL leg accordingly in control and experimental groups. Calf muscles MVC torque for each participant was tested at randomized -15º, 0º, and 15 º ankle angles. Participants at each ankle angle performed two ankle flexion and extension repetitions. Rest period between repetitions – 30 seconds, and between different ankle angles – 60 seconds.

Plantar flexion muscles isometric variability of torque (VT) was measured in the NIL, IL, DL and NDL leg. The test started from the NIL and DL leg plantar flexion, muscles VT. Calf muscles VT were tested at -15º, 0º, 15º ankle angles, which corresponded to ankle angles performed at MVC torque measurement. Isometric torque variability was established during the 20 second isometric contraction at the target torque equal to 40% of isometric MVC torque (see Figure 1). The participants were asked to perform the task as accurately as possible. Participants at each ankle angle performed three ankle flexion and extension repetitions: one with visual feedback (VF) and one without VF. Rest period between repetitions – 30 seconds and between different ankle angles – 60 seconds.

Physiotherapy took 8 weeks, three times per week; one session lasted 30 minutes. The PT program was directed towards recovery of motion, power and proprioception. All exercises were performed without pain and intensity increased over 8 week PT program period. Each session started with gentle 10 minute warm up. In pronounced ankle joint stiffness, ankle and subtalar joint mobilization was performed, in addition to increase range of motion. For gastrocnemius and soleus muscles – tendon complex stretching exercises were started gently and became more intensive. Eccentric strength training exercises (EE) were applied to increase plantar flexor muscles strength. Resistance exercise were started from and gradually increased to isokinetic close chain. Body balance as well as weight bearing on both legs exercises, were applied for proprioception improvement.

8 week EE for healthy group were performed in order to identify the exercises impact to plantar flexion muscles strength in both groups. All EE were performed three times per week twice a day, one session lasted for 15 minutes. For the first week EE were performed in close chain and stabile surface, for second 4 weeks EE were performed in close chain and not stabile surface.

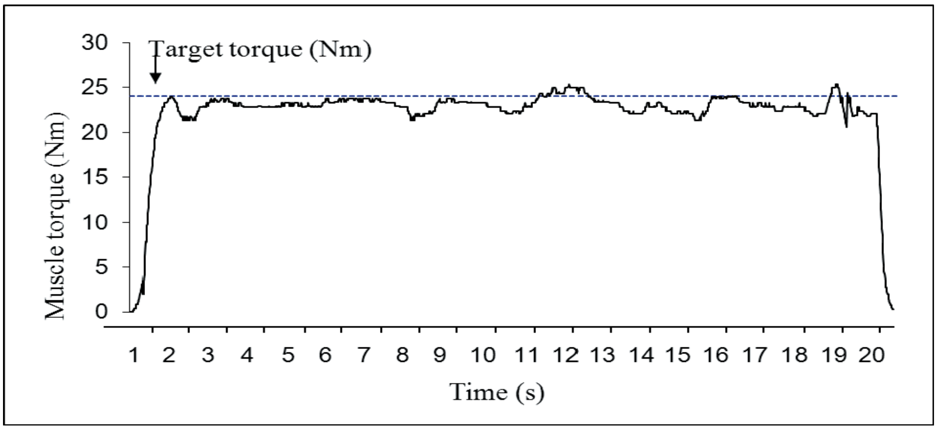

Figure 1. Calf muscle torque VT and target torque sample

Mathematical statistics. The research data were processed employing Microsoft Excel 2010 software for mathematical statistical analysis. The data are reported as group mean values ± standard deviations (SD). Changes between the injury effect (the INL and NL as well as DL and NDL), time impact (before and after 2, 4, 6, 8, 10 month), the task (with or without visual feedback) were evaluated using Student's test ($p<0,05$ level of significance).

Results

At -15° ankle angle, **plantar flexion muscles MVC torque** (see Figure 2) was greater ($p<0,05$) in DL than in NDL at 6 month, and in NIL than in IL at 8 month. MVC torque was greater ($p<0,05$) in DL than in NIL and NDL greater ($p<0,05$) than in IL, at 1, 2, 8, 10, 12 month. Having compared results in first and other month, MVC torque increased ($p<0,05$) in IL after 6 month, but decreased ($p<0,05$) in DL after 2 month.

At 0° ankle angle, **plantar flexion muscles MVC torque** (see Figure 3) was greater ($p<0,05$) in DL than in NDL at 6, 10 month and in NIL than in IL at 4, 12 month. MVC torque was greater ($p<0,05$) in DL than in NIL at 1, 2, 8, 10, 12 month also NDL greater ($p<0,05$) than IL, at 1, 8, 10, 12 month. Having compared results in first and other month, MVC torque increased ($p<0,05$) in NDL after 4 month.

At 15° ankle angle, **plantar flexion muscles MVC torque** (see Figure 4) was greater ($p<0,05$) in DL than in NDL at 10 month and in NIL than in IL at 2, 10, 12 month. MVC torque was greater ($p<0,05$) in DL than in NIL at 1 month, also NDL greater ($p<0,05$) than IL, at 1, 2, 8 month. Having compared results in first and other month, MVC torque increased ($p<0,05$) in DL after 12 month, in NDL after 8 month, in IL after 4, 6, 10 month.

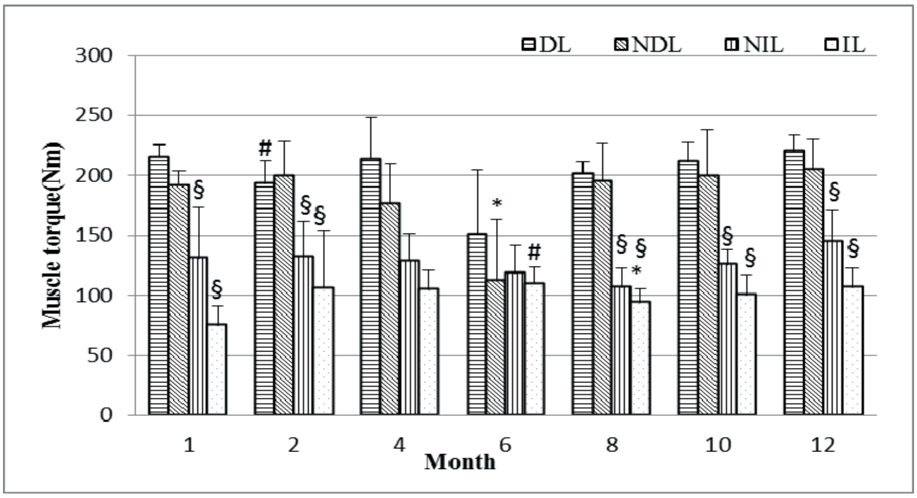

Figure 2. MVC torque of plantar flexion muscles changes at -15° ankle angle; * - p<0,05, changes between the injured and non-injured leg as well as dominant and non-dominant leg; # -p<0,05, changes between first test time and after 2, 4, 6, 8, 10, 12 month; § - p<0,05, changes between dominant and non-injured leg, as well as non-dominant and injured leg.

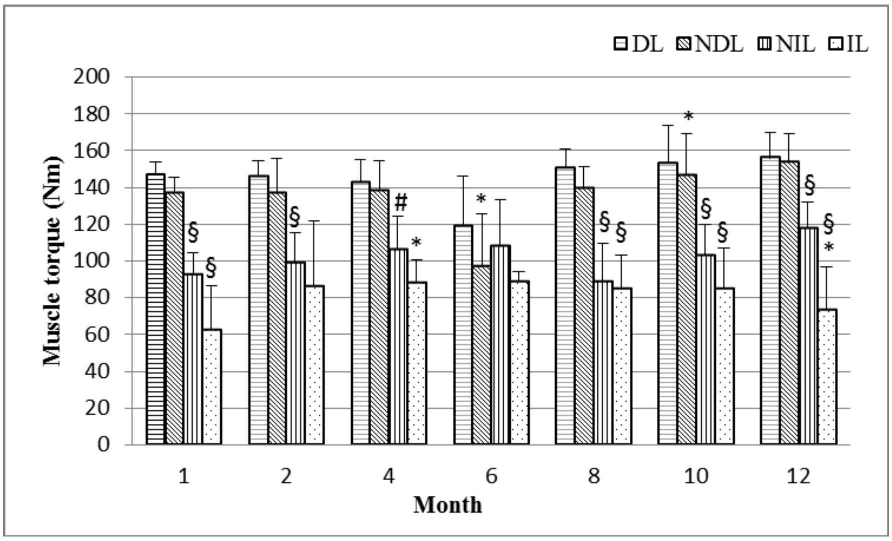

Figure 3. MVC torque of plantar flexion muscles changes at 0° ankle angle; * - p<0,05, changes between the injured and non-injured leg as well as dominant and non-dominant leg; # -p<0,05, changes between first test time and after 2, 4, 6, 8, 10, 12 month; § - p<0,05, changes between dominant and non-injured leg, as well as non-dominant and injured leg.

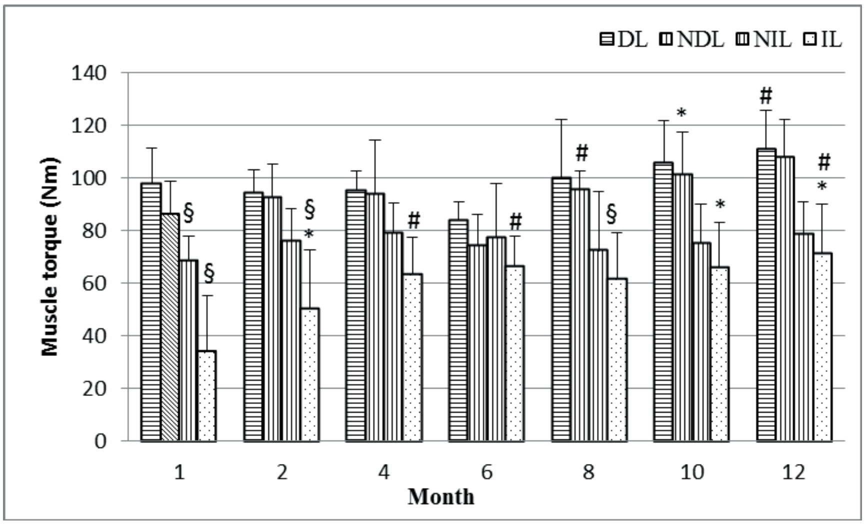

Figure 4. MVC torque of plantar flexion muscles changes at 15° ankle angle; * - p<0,05, changes between the injured and non-injured leg as well as dominant and non-dominant leg; # -p<0,05, changes between first test time and after 2, 4, 6, 8, 10, 12 month; § - p<0,05, changes between dominant and non-injured leg, as well as non-dominant and injured leg.

At -15° ankle angle, **plantar flexion muscles VT torque** (see Figure 5) was greater (p<0,05) in DL than in NDL at 1, 6, 8 month with VF. MVC torque was greater (p<0,05) in NDL than in IL at 10, 12 month without VF. Having compared results in the first and other months, VT torque decreased (p<0,05) in DL after 6, 8, 10, 12 month and in IL after 6, 8 month with VF. Having compared data between tasks, VT torque was greater (p<0,05) in task without VF in DL at 1, 4, 8, 10, 12 month, in NDL at 1, 10, 12 month, in IL at 4, 12 month.

At 0° ankle angle, **plantar flexion muscles VT torque** (see Figure 6) was greater (p<0,05) in DL than in NDL at 1 month without VF. MVC torque was greater (p<0,05) in DL than in NIL at 8 month with VF and 10, 12 month without VF. MVC torque was greater (p<0,05) in NDL than in IL at 6, 8 month without VF. Having compared results in first and other month, VT torque decreased (p<0,05) in DL after 2, 8 month with VF. Having compared data between tasks, VT torque was greater (p<0,05) in task without VF in DL at 2, 8 month, in NDL at 8, 10, 12 month, in IL at 6 month.

At 15° ankle angle, **plantar flexion muscles VT torque** (see Figure 7) was greater (p<0,05) in DL than in NDL at 10 month with VF, and NIL than in IL at 6 month with VF and at 12 month without VF. MVC torque was greater (p<0,05) in DL than in NIL at 1, 2 month with VF and at 4 month without VF. MVC torque was greater (p<0,05) in NDL than in IL at 1, 2 month with VF and at 10, 12 month without VF. Having compared results in the first and other months, VT torque decreased (p<0,05) in NDL after 2, 6, 8 10, 12 month with VF and at 2 month without VF. VT torque increased (p<0,05) in IL after 2 month with VF. Having compared data between tasks, VT torque was greater (p<0,05) in task without VF in DL at 4 month, in NDL at 6, 10, 12 month, in NIL at 2 month, IL at 6 month.

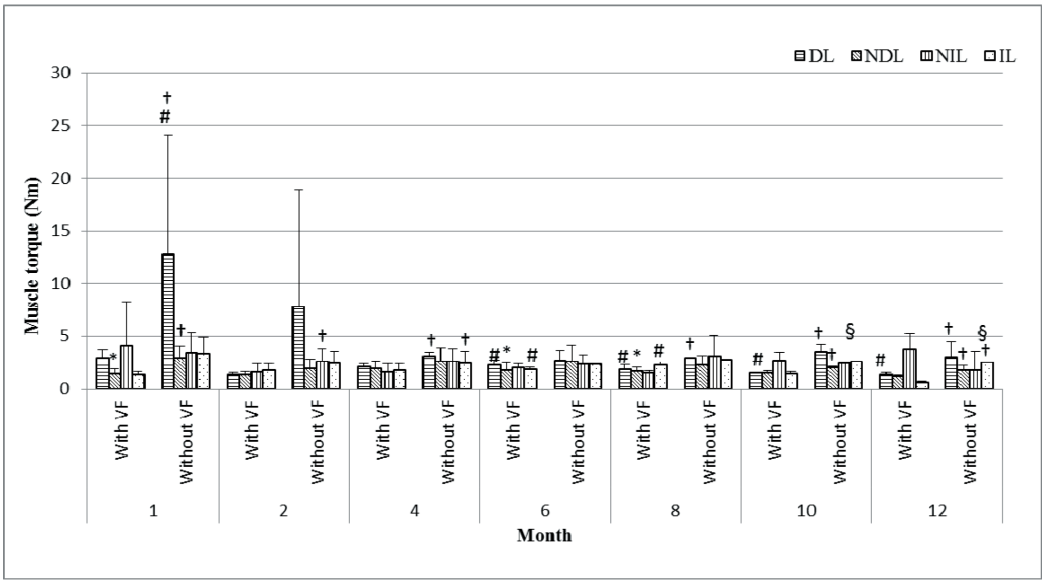

Figure 5. VT of plantar flexion muscles changes at -15° ankle angle; * - p<0,05, changes between the injured and non-injured leg as well as dominant and non-dominant leg; # - p<0,05, changes between first test time and after 2, 4, 6, 8, 10, 12 month; § - p<0,05, changes between dominant and non-injured leg, as well as non-dominant and injured leg.

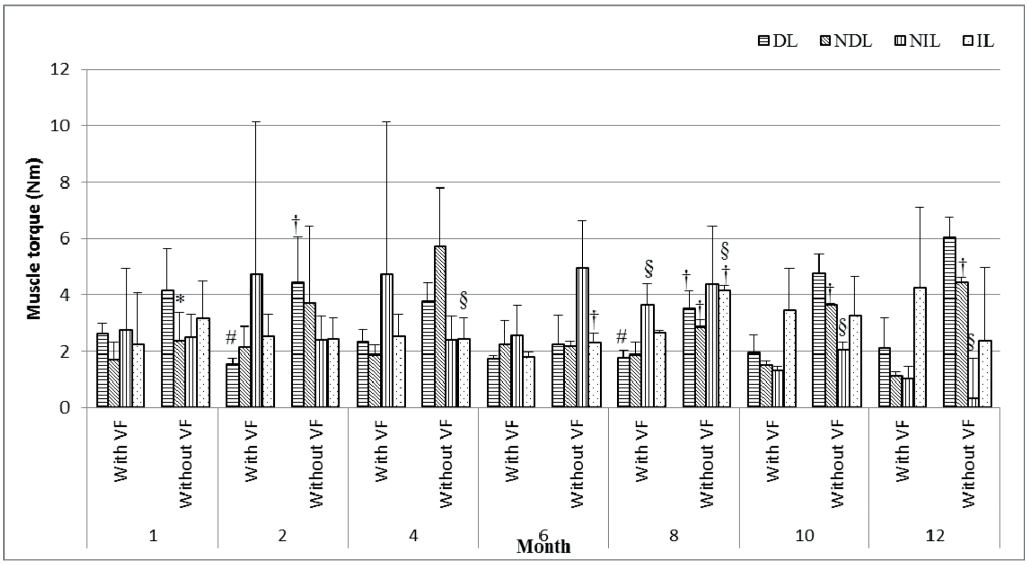

Figure 6. VT of plantar flexion muscles changes at 0° ankle angle; * - p<0,05, changes between the injured and non-injured leg as well as dominant and non-dominant leg; # - p<0,05, changes between first test time and after 2, 4, 6, 8, 10, 12 month; § - p<0,05, changes between dominant and non-injured leg, as well as non-dominant and injured leg.

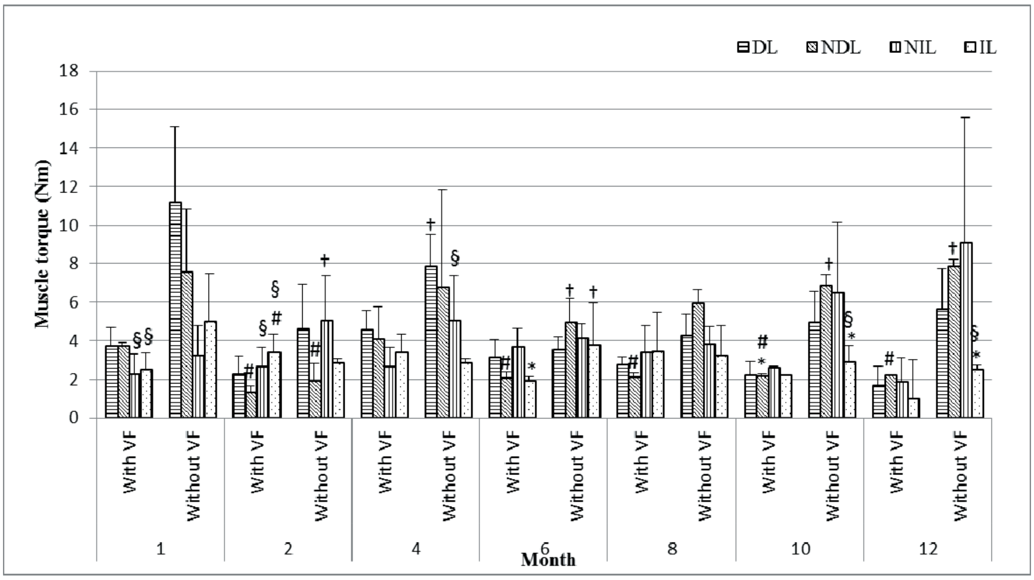

Figure 7. VT of plantar flexion muscles changes at 15° ankle angle; * - p<0,05, changes between the injured and non-injured leg as well as dominant and non-dominant leg; # - p<0,05, changes between first test time and after 2, 4, 6, 8, 10, 12 month; § - p<0,05, changes between dominant and non-injured leg, as well as non-dominant and injured leg.

Discussion

The main finding of this study was that (1) eccentric exercises programme decreases calf muscles MVC torque but movement stability becomes greater for healthy person also (2) muscles MVC torque differences between IL and NIL one year follow up for persons with ATR still remain.

Plantar flexion muscles isometric MVC. Calf muscles isometric MVC torque was greater in the DL compared to the NDL as well as in the NIL compared to IL. Plantar flexion muscles isometric MVC torque was greater at -15º (6 month), 0º (6, 10, month), 15º (10 month) ankles angles in the DL compared to the NDL. Some of the authors propose that there is no statistical significant difference in calf muscle strength between legs (Damholt & Termansen, 1978; Moraux, Canal, Ollivier, Ledoux, Doppler, Christine Payan, & Hogrel, 2013). The present results are similar to the ones of investigators. The authors of the present research did not establish any statistical significant difference between DL and NDL in first testing time, the difference between DL and NDL was established after 6 and 10 month of participating in investigation. It is well established that 4-6 weeks exercises influences muscle structural changes (Hotermann et al., 2007). 8 week eccentric exercises may influence muscle hypertrophy (Farthing et al., 2003; Duclay et al., 2009) and greater muscle strength (Farthing et al., 2003). It can be supposed that calf muscle MVC torque between DL and NDL were influenced by 8 weeks muscle strengthening programme. Plantar flexion muscles isometric MVC torque was greater at -15º (8 month), 0º (4, 12 month), 15º (2, 10, 12 month) ankles angles in the DL compared to the NDL. It is proved that isometric muscle torque differences between NIL and IL remain one year after Achilles tendon rupture surgery (Maquiriain, 2011). Finni (2006) with co-authors examine NIL and IL isometric MVC torque differences of nine persons after Achilles tendon rupture. Results show that after 8 week rehabilitation, plantar flexion muscles isometric MVC torque of the IL increased but still remained lower than of the NIL. Don (2007) with co-authors examines NIL and IL isometric MVC torque differences of

49 persons after Achilles tendon rupture. Results show that MVC torque differences between IL and NIL remain for more that two years. The present results are similar to the ones of the investigators; it can be supposed that it may be the result of inequality muscle spindle (Bressel et al., 2004; Don et al., 2007) which was influenced by immobilization (Bressel et al., 2004).

After 8 week EE programme calf muscles isometric MVC torque decreases in DL leg at -15º ankle angle. Results data of EE influence in healthy person muscle strength is controversial. Some authors propose that EE increases muscle strength (Farthing et al., 2003; Duclay et al, 2009; Roig et al, 2011). However intensive EE exercises may induce loss of muscle strength, range of motion, and/or myoglobin concentration in the blood (Chen, Lin, Chen, Lin, & Nosaka, 2011). The present research results are similar to the ones of the investigators; it can be supposed that it may be the result of increased calf muscles tendon stiffness (Duclay et al., 2009). The authors of the present research also established that IL and NIL leg muscles isometric MVC torque increased accordingly at -15º (6 month); 0º (4, 12 and 6 ,8 month); 15º (2, 10, 12 and 10 month) ankle angles. PT program consisted of eccentric muscles strengthening exercises. It is established that six week eccentric muscle strengthening exercises increased concentric and eccentric muscle strength (Kaminski, Wabbersen, & Murphy, 1998). Gastrocnemius and soleus muscles complex can perform 65% of the total 100% MVC force during the plantar flexion movement (Finni et al., 2006). It can be supposed that NIL and IL muscles isometric MVC torque increased due to muscles strengthening exercises.

Muscles isometric variability of torque VT. It is identified that muscles isometric VT shows movement stability during the task (Kaminski et al, 1998). Plantar flexion muscles isometric VT was greater in DL compared to NDL at 15º 0º ankle angles as well as NIL compared to IL at 15º ankle angle. Separate studies on different subject samples indicate that torque variability depends on muscle torque level, type of contraction and muscle group as well as on variability in discharge rate among active motor units (Skurvydas et al, 2010). It is known that during the tendon injury mechanoreceptors (Kaminski et al, 1998) are disrupted, and this disturbs optimal afferent impulse emanation to CNS (Hong & Newell, 2008). However, it was recently concluded that motor output variability may have beneficial or adverse effects (Stergiou, Harbourne, & Cavanaugh, 2006). An optimal amount of variability of motor performance is beneficial because it reduces the risk of injury (Skurvydas, Masiulis, Gudas, Dargevičiūtė, Parulytė, Trumpickas, & Kalesnikas, 2010). It can be supposed that greater plantar flexion muscles isometric VT in DL may be influenced by CNS as “protecting mechanism” from risk of injury. And greater muscle VT in NIL compared to IL may be influenced by intensive healing process in ruptured Achilles tendon.

Movement stability depends on working muscles strength, quality and amount of visual feedback, complexity of task (Smigielski et al, 2008), amount and impulse frequency of recruited motor units (Kaminski et al, 1998). There is non-linear affiliation between isometric muscle torque and isometric muscle VT. Muscles isometric VT increased at 20 – 60% of muscles isometric MVC torque and decreased at 60 – 80% of muscles isometric MVC torque (Christou et al, 2002). Training-induced strength improvement is accompanied by an enhancement of motor-unit synchronization in the agonist muscle as well as reduction of the coactivation of antagonists (Salonikidis et al., 2009). The present results show decreased calf muscles isometric VT (movement stability during the task was improved); it can be supposed that it was influenced by increased DL and NDL as well as in NIL and IL calf muscles isometric MVC torque.

It was found that visual feedback information is important for the continued maintenance of muscle strength (Hong & Newell, 2008). If the movement was performed with visual feedback and lasted longer than 150 ms, proprioception information allows improving movement stability during the task (Salonikidis et al, 2009). Information about movement stability during the task is received from many sources: spinal cord, muscles, tendons, joints, skin, eyes (Finni et al, 2006). Movement stability decreases when it is performed without visual feedback (Kaminski et al, 1998). The present results show that visual feedback improved DL, NDL, NIL and IL movement stability during the task.

Conclusions

After eight week muscle strengthening programme calf muscles isometric MVC increased in IL, but decreased in DL. Movement stability improved in NIL at 0°; 15° and IL at 15° ankle angles. After one year isometric muscle MVC torque increased in DL, NDL and IL at 15° ankle angle. Movement stability improved in NDL at 15° ankle angle. However, calf muscles isometric MVC as well as isometric muscles VT remain greater in the DL than in the NDL as well as in NIL than in IL. Also after one year MVC torque differences between IL and NIL leg still remain

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Summary

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Achilles tendon is the strongest body tendon, but despite the strength, it is the most frequently ruptured tendon in the body and comprises about 20% of all large tendon ruptures. It has been established that EE influence calf muscles torque and proprioception changes, but differences between injured and non-injured leg remain one year follow up. However, ankle proprioception changes in an Achilles tendon rupture population are still not well understood. The examination of the Achilles tendon healing

possibilities could help to provide a better understanding of how physiotherapy may influence the properties of scarred Achilles tendon and avoid tendon re-rupture. **Aim of the study** was to estimate EE effect on the dominant leg, non-dominant leg, non-injured leg and injured leg plantar flexion muscles maximal voluntary contraction (MVC) torque and movement variability (VT) changes one year follow up for healthy and after Achilles tendon rupture persons.

Twelve males divided in two groups have been measured. Experimental group consisted of 5 participants, who were 6,5 weeks after Achilles tendon rupture and 10 rehabilitation procedures. Control group consisted of 7 persons who had never had ankle strain, calf muscles rupture and they were not physically active. Control and experimental group performed isometric ankle flexion force accordingly with injured leg, non-injured leg and non-dominant leg and dominant leg. MVC torque and VT were measured at -15°; 0°; 15° angles. The variability of target force was 40% of MVC torque. Both groups performed 8 weeks calf muscles strengthening programme. Calf muscles MVC torque and VT were observed 7 times one time in two month in one year period.

The results of the research. It has been determined that after 8 week muscle strengthening programme calf muscles isometric MVC increased in injured leg, but decreased in dominant leg. Movement stability improved in non-injured leg at 0°; 15° and injured leg at 15° ankle angles. After one year isometric muscle MVC torque increase in dominant leg, non-dominant leg and injured leg at 15° ankle angle. Movement stability improved in non-dominant leg at 15° ankle angle. However, calf muscles isometric MVC as well as isometric muscles VT remain greater in the dominant leg than in the non-dominant leg as well as in non-injured leg than in injured leg. Also after one year MVC torque differences between injured leg and non-injured leg still remain.