Author(s): Peter, Annamaria; Hegyi, Andras; Tihanyi, József; Cronin, Neil

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1.Szerő: Péter Annamária
1.Szerző munkahelye: (1) Testnevelési Egyetem Biomechanika, Kineziológia és Informatika Tanszék, Budapest; (2) University of Jyväskylä, Department of Biology of Physical Activity
1.Szerző e-mail címe: annamaria.a.peter@jyu.fi

2.Szerő: Hegyi András
2.Szerző munkahelye: (1) Testnevelési Egyetem Biomechanika, Kineziológia és Informatika Tanszék, Budapest; (2) University of Jyväskylä, Department of Biology of Physical Activity
2.Szerző e-mail címe: andras.a.hegyi@jyu.fi

3. Szerző: Tihanyi József
3. Szerző munkahelye: Testnevelési Egyetem Biomechanika, Kineziológia és Informatika Tanszék, Budapest
3. Szerző e-mail címe: tihanyi@tf.hu

4.Szerő: Neil Joseph Cronin
4.Szerző munkahelye: University of Jyväskylä, Department of Biology of Physical Activity
4.Szerző e-mail címe: neil.j.cronin@jyu.fi

Function of the flexor hallucis longus muscle – what do we know?

A flexor hallucis longus izom működése – mit tudunk róla?

Szerkesztőséggel kapcsolatot tartó neve: Péter Annamária
Levelezési címe: Ristonmäenrinne 19, 40500, Jyväskylä, Finland; annamaria.a.peter@jyu.fi

Összefoglaló

A flexor hallucis longus (FHL) izomnak számos szerepet tulajdonítanak, melyek többek között a boka talpi hajlítás, nagylábujj hajlítás, hosszanti lábboltozat fenntartásának támogatása.

Eddig csak néhány tanulmány alkalmazott nem invazív vizsgáló módszert a FHL izom működésének vizsgálatára in vivo, habár korábbi vizsgálatok eredményei arra utalnak, hogy a FHL izom megfelelő működése hozzájárulhat a sportteljesítmény növeléséhez, megváltozott működése Achilles-ín problémához vezethet, valamint egyéb klinikai esetekben, például lúdtalp esetén funkciója megváltozik.

Jelen ismereteink szerint a FHL izom működése multifunkcionális, továbbá ugyanazon funkciók kivitelezéséhez egyéb aktív és passzív struktúrák is hozzájárulnak segítve a komplex láb finom, gördülékeny működését. A különböző lábstruktúrák és a FHL izom multifunkcionális működéséből adódóan nehéz meghatározni az izom fő szerepét illetve szerepeit különböző típusú feladatok során. Ezekből adódóan azt is nehéz meghatározni, hogy különböző morfológiai változások miként befolyásolják magának az izomnak az egyes funkcióit.

Jelen összefoglalóban azokat a tanulmányokat foglaljuk össze, melyek a FHL izom funkcióját vizsgálták, fókuszálva az in vivo vizsgálatokra. A FHL izom anatómiai és funkcionális változásainak lehetséges hatásaira térünk ki, továbbá javaslatokat teszünk jövőbeli vizsgálatok lefolytatására, melyek segítségül szolgálhatnak jelen ismereteink hiányosságainak betöltésére.

Kulcsszavak: FHL izom, lúdtalp, Achilles-ín

Summary

Flexor hallucis longus (FHL) muscle has several functions, including plantarflexion of the ankle, flexion of the big toe and support of the medial longitudinal arch.
To date, only a few studies have used non-invasive methods to examine FHL behavior during real-life movements, although the proper functioning of this muscle may be important to increase sport performance, the altered FHL function may contribute to the susceptibility to Achilles tendinopathy and the function of FHL is altered in other clinical conditions such as flatfoot.
FHL seems to be multifunctional but other active and passive structures also contribute to the same functions. Because of the multifunctionality of the foot structures and FHL itself, it is hard to define the main role of FHL during certain kinds of tasks and real-life movements. It is also more difficult to determine how morphological changes in the FHL affect its function.
In this review we summarise studies that have examined FHL function focusing particularly on functionally relevant in vivo measurements, and possible effects of FHL anatomical and functional changes. Furthermore we make suggestions regarding studies that are needed in the future to fill the gaps in our knowledge about the role of FHL.

Keywords: FHL muscle, flat foot, Achilles tendon

Introduction

Flexor hallucis longus muscle (FHL) is located on the fibular side of the leg, originates from the distal 2/3 of the fibula and the membrane interossea, and inserts on the distal phalanx of the big toe on the plantar surface of the foot while crossing over the ankle joint (behind the medial malleolus) and the 1st metatarsophalangeal joint (Gray, 1980). This multi-articular muscle flexes every joint of the hallux, plantarflexes the ankle and supinates the foot (Ferris et al., 1995). It also supports the medial longitudinal arch of the foot (Sarafian et al., 1993; Waldeyer and Mayet, 1993). The cross-sectional area of FHL is the largest among all long and short toe flexor muscles (Friedrich and Brand, 1990; Kura et al., 1997). Toe flexors have been suggested to have a role in accelerating the center of mass during locomotion (Goldmann et al., 2013). Furthermore, long toe flexor muscles are also responsible for force transmission from the foot to the ground (Ferris et al., 1995). The importance of the FHL muscle in locomotion is highlighted by the estimation of Jacob (2001): the forces under the first metatarsal head and big toe are about 53% of body weight during the push-off phase of walking, which means that the first ray (which is crossed by the FHL) has prime importance in propulsion. Jacob (2001) estimated that the force along the FHL tendon in walking is 52% of body weight.

Mechanical behavior

Isometric muscle function requires less energy than concentric contraction (Fisher, 1931; Ryschon et al., 1997), which makes muscle work economical. During the push of phase of walking, running and jumping there is plantarflexion at the ankle and dorsiflexion at the metatarsophalangeal joints (Bobbert and van Ingen schenau, 1988; Leardini et al., 1999; Stefanyshyn and Nigg, 1998), meaning that the ankle and metatarsophalangeal joints work in opposite directions during the stance phase (Leardini et al., 1999). Based on cadaver studies it has been suggested that FHL muscle is capable of transferring energy from the proximal leg extensor muscles to the distal part of the foot while working in a near-isometric manner (Kirane et al., 2008; Hofmann et al., 2013). Hofmann et al. (2013) found that FHL and flexor digitorum longus muscle (FDL) function near-isometrically during the stance phase of normal locomotion because of the small (7.18 mm) tendon excursion. Furthermore, muscle architecture usually can be a good predictor of how the muscle works (Lieber and Ward, 2011). The ratio of muscle fiber length to muscle-tendon unit length is 0.20 for the FHL (Ward et al., 2009). This small ratio predicts that the muscle belly shortens minimally during contraction which suggests near-isometric function. Our recent unpublished in vivo ultrasonography measurements confirm that fascicle length change of FHL is minimal during walking (Péter et al., 2015, unpublished observations).

Muscle activity

In real-life movements electromyography (EMG) is the most frequently used method to examine the activity of a muscle. There are only a few studies of FHL muscle function in real-life conditions such as during locomotion. There are two basic methods to measure muscle electrical activity: surface and indwelling recordings. According to in-dwelling EMG measurements, FHL muscle is active during the mid-stance phase of walking, with activity terminating just after toe-off (Perry, 1992). Goldmann et al. (2006), using the same method, studied the timing of peak activity and found that FHL activity was highest in the late stance phase during walking and in the early stance phase in running. It has to be noted that these methods are invasive, potentially painful and cannot be reliably used to examine isotonic contractions that occur during human movement (Brown et al., 2009; Disselhorst-Klug et al., 2000; Finsterer, 2004; Jan et al., 1999). Pain can change movement execution and thus may affect the results. Surface EMG measurement could be a solution to this problem because it is a non-invasive, painless technique. Behind the medial malleolus the FHL lies in the superficial area. Previous studies (e.g. Bojsen-Møller et al., 2010) demonstrated that FHL EMG activity can be recorded from this area with minimized cross-talk from other muscles using 16 mm inter-electrode distance. In our recent study (Péter et al., 2015) using surface EMG, we found that increased walking speed was associated with increased FHL EMG activity, which was related to a subsequent increase in the vertical force under the big toe. We also found that the relative importance of FHL may increase with speed compared to other structures contributing to propulsion of the body.

Possible consequences of altered FHL function

The functional adaptability of the major leg extensor muscles in response to strength training has been widely investigated in the literature (Arampatzis et al., 2007; Maffiuletti and Martin, 2001). Additionally it has been reported that long and short toe flexor muscles have an important role in force transmission to the ground in the push-off phase (Hamel et al., 2001). Therefore, it seems logical that stronger toe flexor muscles could be able to transmit energy more effectively to the ground during locomotion compared to weaker muscles, and thereby contribute to performance enhancement. To test this hypothesis, Goldmann et al. (2013) examined the effects of heavy resistance toe strength training on functional adaptability, the effects of increased strength on foot and ankle joint function during walking, running and jumping, and on the potential of athletic performance enhancement. During the training program (7 weeks, 4 times/week and 4 sets of 5 repetitions/occasion), the subjects performed toe flexor muscle isometric plantarflexion contractions with 90% (calculated weekly) of maximal voluntary isometric force with both limbs. The ankle joint was in neutral position and the metatarsal phalangeal joint was dorsiflexed at 25 degrees. The authors found increased toe flexor muscle strength and horizontal jump distance, but other performance outcomes such as walking and running performance (maximal metatarsal phalangeal- and ankle joint dorsiflexion moments) and vertical jump height did not improve. Strength training increased toe flexor muscle strength within a few weeks and contributed to improvements in tasks where the metatarsal phalangeal joints worked at near-optimal joint angles. It was concluded that toe flexor muscle strengthening may be an important part of sport training because these muscles may contribute to body propulsion in lean-forward movements, such as horizontal jumps, sprint starts and cutting maneuvers. FHL muscle has the largest cross-sectional area among all long and short toe flexor muscles (Friedrich and Brand, 1990; Kura et al., 1997), which suggests that this muscle may have made a large contribution to the observed athletic performance enhancement.

In another study, increased cross-sectional area (4-5%) of long and short toe flexor muscles and consequently increased toe flexor muscle strength (≈20%) were found after regularly wearing minimalist footwear for five months (Brüggemann et al., 2005). This cross-sectional area increment was highest in FHL, suggesting a main role of this muscle in flexor muscle strength improvement. The researchers concluded that minimalist shoes affect mechanical loading by increasing mechanical stimuli to the foot. The strength and cross-sectional area of the muscles which were most active when wearing minimal footwear increased significantly as a biological response to the higher load. However, too much load on the foot structures may increase the risk of certain injuries such as plantar fasciitis (Teyhen et al., 2010). This may be prevented by cushioning of the footwear, and changing the shoes after 500-800 km because of alterations in their mechanical properties (Teyhen et al., 2010).

During one leg standing Tanaka et al. (1996) found significantly greater (two times more) peak pressure under the big toe than under the other toes and a significant linear relationship between big toe pressure and body sway parameters. They suggested that the strength of the toe muscles and somatosensory information of the foot and ankle are important for standing balance. Furthermore it is believed that atrophy of plantar foot muscles and the related imbalance development between foot flexor and extensor muscles is the primary cause of toe deformities (such as prominent metatarsal heads, claw and hammer toes) (Myerson and Shereff, 1989). In older people it has been reported that toe deformity doubles the risk of falling (Mickle et al., 2009). According to these findings it seems to be important to have adequate foot muscle strength to decrease the prevalence of toe deformities, which is not only an aesthetic problem, but may also increase the risk of falling and related injuries. Moreover, age- and gender-effects on absolute toe flexor muscle strength were examined previously and a significant age-related reduction (28.9%) (Endo et al., 2002) and gender differences were found (men had 39.1% higher toe strength than women). Callisaya et al. (2008) found that the reduction of muscle strength was larger in elderly women than in elderly men. Furthermore, according to a recent study (Masumoto et al., 2015), the risk of falls increases with age in both genders but is higher for women. These findings suggest that appropriate toe flexor and extensor muscle strength is an issue of primary importance in the maintenance of healthy foot function, especially for women.

10-25 % of the adult population have flat foot (Huang et al., 2004), which can be symptomatic or asymptomatic. During weight-bearing standing, flatfooted people have a depressed or absent medial longitudinal arch. Flat foot can increase the risk of lower limb overuse injuries because it alters the motion of the foot during walking, causing greater pronation (Levinger et al., 2010). As noted above, if mechanical stimuli to a muscle increase, muscle strength and cross-sectional area tend to increase as well. In flatfooted subjects, FHL and FDL muscles were found to be larger (in terms of cross-sectional area) and thicker compared to normal footed subjects (Angin et al., 2014). The researchers suggested that this phenomenon might be a compensatory activity to try to maintain proper foot position (the shape of the medial longitudinal arch and/or supination of the foot, which demands a greater contribution from FHL and FDL muscles). If this suggestion is correct, a consequence of it may be to induce hypertrophy in FHL and FDL (Kirane et al., 2008; Wacker et al., 2003). Others have suggested that hypertrophy of FHL may serve to compensate for atrophy of tibialis posterior muscle in patients with pes planus (Wacker et al., 2003).

Finni et al. (2006) used velocity-encoded phase-contrast MRI to examine the relative contribution of plantarflexor muscles to plantarflexion in Achilles-tendon ruptured and healthy subjects. They found that the relative contribution of FHL of injured patients was very high in both the injured and uninjured sides compared to healthy subjects. This may be a consequence of an overload mechanism to adapt to the altered triceps surae muscle loading requirements. The cause of the higher FHL contribution in the uninjured leg is unclear. However, Masood et al. (2014a) found contradictory results: higher relative FHL activity was observed only in the injured leg. This intervention study indicated that the altered FHL contribution may develop after the injury as a compensatory mechanism, i.e. the load is higher on the FHL since the primary ankle plantarflexors' force output cannot be transmitted to the foot effectively. Thus, rapid recovery in plantarflexor force production after AT injury may not be primarily due to recovery of the tendon. In spite of the minor differences between studies, it seems that a common finding is that the relative contribution of plantarflexor muscles can change after Achilles tendon rupture.

Although FHL muscle has many remarkable functions, 'FHL tendon transfer' is a popular method to reconstruct chronic Achilles tendon rupture (Lee at al., 2009; Hahn et al., 2008; Park and Sung, 2012; Yeoman et al., 2012). During this operation the FHL tendon is cut and fixed to the calcaneus anterior and the insertion of the Achilles tendon, and then sewn together with the Achilles tendon. This method is frequently used as it requires a single incision and is a simple procedure (Maffulli and Ajis, 2008), although its functional consequences are not well studied. After this surgery, FHL still contributes to ankle plantarflexion during locomotion but its other functions are lost. Oksanen et al. (2014) examined the effect of FHL tendon transfer on plantar flexion force and FHL muscle hypertrophy. According to their results, FHL was able to produce adequate plantar flexion force during walking after the surgery but after 2 years this force was still less than on the healthy side. Furthermore, Oksanen et al. found that FHL muscle cross-sectional area increased by 52% after surgery, which may have been caused by the need for high plantarflexion torque production. Their results suggested that FHL can adapt to altered conditions regarding plantarflexion torque. However, to date it has not been examined how the loss of the other functions of FHL alters the mechanical load distribution within the foot structures, and what the long term functional consequences of this operation are.

Summary and future directions

The aim of this review was to highlight the importance of the multifunctional FHL muscle. Previous studies focusing on FHL muscle function used mostly indirect or cadaver methods. The few studies using direct methods in real-life movements are described in this review. Due to the lack of functionally relevant studies in this field there are still many unanswered questions that should form the basis of further investigations to reveal the roles of FHL in different tasks. Task-dependent inter-muscular coordination of the foot muscles, including the FHL, was found in a recent study (Zelik et al., 2015), which highlights the importance of investigating muscle function in functional movements. Recent studies show that FHL function can be investigated using non-invasive methods even in real-life movements, such as walking. Firstly, muscle activity can be measured using surface EMG (for description see Péter et al., 2015). Secondly, kinematic behaviour of the muscle-tendon unit can be measured using 3D motion analysis, while muscle fascicle behaviour can be investigated using ultrasonography (Péter et al., unpublished).

Previous studies support the idea that high individual differences exist in *a)* the use of FHL muscle during isometric plantarflexion tasks (Finni et al., 2006, Masood et al., 2014b, Péter et al., 2015), *b)* maximal voluntary force production of toe flexors (Goldmann & Brüggemann, 2012), and *c)* force transmission mechanisms between the triceps surae and FHL (Bojsen-Møller et al., 2010). It should be mentioned that the results of each study are based on small sample sizes. To reveal the source of individual differences, measurements using a large sample size should be performed in the future, where functional outcomes (muscle activity, operating length of the fascicles) can be related to morphological and functional properties of the foot and shank structures. Using recently adapted methods for measuring FHL behaviour in real-life movements, there is great potential for investigating FHL muscle function in clinical conditions such as Achilles tendon rupture, toe deformities, flatfoot, and the functional effects of FHL tendon transfer, as well as in lean-forward movements. This information may contribute to injury prevention and rehabilitation as well as performance maximization in sport.

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További információ:
Teljes név: Péter Annamária
Titulus: PhD hallgató
Munkahely neve: (1) Testnevelési Egyetem Biomechanika, Kineziológia és Informatika Tanszék, Budapest; (2) University of Jyväskylä, Department of Biology of Physical Activity
Munkahely címe: (1) Budapest, Alkotás utca 44, 1123, Magyarország; (2) Jyväskylä, Viveca 234, Rautpohjankatu 8, 40700, Finland
Telefonszám: 0036202090600
E-mail cím: annamaria.a.peter@jyu.fi