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Plantar pressure differences between cases with symptoms of clinically diagnosed chronic exertional compartment syndrome and asymptomatic controls

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ABSTRACT

Background: Anterior chronic exertional compartment syndrome of the leg has been hypothesised to develop due to excessive muscle activity and foot pronation. Plantar pressure variables related to lower limb muscle activity and foot type may therefore provide insight into this condition.

Methods: 70 male cases and 70 asymptomatic controls participated. A clinical diagnosis was established from typical symptoms, with clinical examination excluding other pathologies. Plantar pressure variables during walking, hypothesised to be related to foot type, toe extensor activity or had shown predictive validity for general exercise-related lower leg pain, were extracted.

Findings: Cases were shorter in height (mean difference 2.4 cm), had greater body mass (mean difference 4.4 kg) and had reduced ankle dorsiflexion range of motion than controls (mean difference 1.5 cm). Plantar pressure variables indicative of foot-type and toe extensor activity did not differ between groups ($P > 0.05$). The magnitude of medial forefoot loading was the strongest plantar pressure predictor of the presence of chronic exertional compartment syndrome (Odds ratio:0.87, $P = 0.005$). There was also some evidence of greater lateral heel loading at 5% of stance time ($P = 0.049$–0.054).

Interpretation: The lack of association with foottype-related and toe extensor activity-related plantar pressure variables suggest that these are not risk factors for the development of chronic exertional compartment syndrome, contrary to earlier hypotheses. The greater lateral to medial loading could theoretically represent increased Tibialis anterior muscle activity at heel strike but a subsequent loss of control as the ankle is lowered. Future studies directly investigating muscle activity and function are now required.

1. Introduction

Chronic exertional compartment syndrome (CECS) is an overuse condition presenting as pain in the lower limb. It has been described in numerous compartments of the body, although the anterior compartment of the lower leg is most commonly affected (Reneman, 1975). In up to 98% of cases the condition is bilateral (Reneman, 1975). While the condition is often described as an overuse injury; the mechanism of injury is unclear.

Increased muscle activity has recently been hypothesised to be the underlying cause of pain in CECS rather than a pathological increase in intramuscular compartment pressure (Franklyn-Miller et al., 2014, Roberts and Franklyn-Miller, 2012). However, a case-control study has since demonstrated higher resting standing pressures when anterior compartment muscle activity is minimal implying a structural aetiology (Roscoe et al., 2015). Nevertheless, excessive anterior compartment muscle activity is still a likely candidate as a risk factor for the development of CECS. Despite this, the function of the anterior compartment musculature during gait has never been investigated in this population.

Plantar pressure measurement provides a method of investigating the impact of both muscle activity and anatomy on the forces applied to the foot. It has previously been demonstrated to be related to lower limb muscle activity (Ferris et al., 1995, Morag and Cavanagh, 1999) and foot type (Caravaggi et al., 2014, Cavanagh and Rodgers, 1987, Sánchez-Rodríguez et al., 2012). Foot type has also been observed to have an effect on Tibialis anterior muscle activity in several studies (Murley et al., 2009a, 2009b). Using plantar pressure, foot type has been directly characterised by the calculation of a dynamic arch index

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(Cavanagh and Rodgers, 1987). The impulse under all the metatarsals has also been demonstrated to have a strong correlation to two other measures of foot type: medial longitudinal arch range of motion (Caravaggi et al., 2014) and arch height (Teyhen et al., 2009).

Activity of the toe extensor muscles may also be characterised by plantar pressure. Pressure underneath the toes has previously been demonstrated to be affected by simulated flexor hallucis longus and flexor digitorum longus activity (Ferris et al., 1995). It seems reasonable to assume that activity of the antagonists located in the anterior compartment (extensor hallucis longus and extensor digitorum longus) would have a similar effect (i.e. reduction of toe pressures).

One previous study has investigated plantar pressure in 20 patients with CECS (Roscoe et al., 2016). They observed reductions in stance time and the time from initial foot contact to initial full forefoot contact that may be a result of alterations in anterior compartment activity/function. A greater understanding of foot function related to ankle dorsiflexor and toe extensor activity in this condition is now needed.

This study therefore aimed to compare, in a case-control study, the plantar pressure variables described above that have previously been associated with foot type, toe-extensor activity or had shown predictive validity for all-cause exercise-related lower leg pain (Willems et al., 2006). A secondary aim was to compare the variables investigated by Roscoe et al. (2016) in a larger cohort. We hypothesised that those plantar pressure variables indicative of: a more pronated foot type, greater toe-extensor activity and the development of all-cause exercise-related lower leg pain would be greater in cases with CECS than healthy controls.

2. Materials and methods

70 male cases with symptoms consistent with CECS of the anterior compartment of the leg and 70 asymptomatic controls participated following informed consent. A consensus diagnosis of CECS was established from typical symptoms, with clinical examination excluding other pathologies. Controls were recruited from the British Armed forces. Cases were recruited from two military rehabilitation centres. Ethical approval was granted by the MOD Research Ethics Committee.

Cases required the following: symptoms of exercise-induced leg pain consistent with a diagnosis of anterior compartment CECS; no diagnosis other than CECS more likely; absence of multiple lower limb pathologies; and, no previous lower limb surgery. While intramuscular compartment pressure measurement is considered the gold standard for diagnosis (Roscoe et al., 2015); clinical examination alone has been suggested to provide an accurate diagnosis for referral for surgery (Ali et al., 2013, Orlin et al., 2013, van den Brand et al., 2005). As pressure measurement was not available for this study, a clinical diagnosis was used. Controls were included when they had no history of musculoskeletal leg pain in the previous 12 months; and no current pain at any site, including during exercise activities.

Participants completed the Short Pain Inventory that measures both current physical pain and the emotional consequences of pain (Kilminster and Mould, 2002). Participant age, height (stadiometer; SECA, Birmingham, UK) and body mass (medical grade scales; SECA, Birmingham, UK) were recorded. A weight-bearing dorsiflexion device (Jones et al., 2005) was used to measure the anterior-posterior distance between the knee and the hallux during a weight-bearing lunge; anatomical parameters that could influence this distance were therefore also recorded (UK shoe size/lower leg length (tibial tuberosity to lateral malleolus)).

2.1. Plantar pressure measurement and data extraction

Participants were asked to walk over a 2 m × 0.4 m × 0.02 m pressure plate (RSScan International, Olen, Belgium) fitted flush to the floor of the laboratory; and were free to choose the order of foot placement. Participants completed a dynamic calibration and familiarisation traverses of the laboratory. Data was then collected at a natural, relaxed, self-selected walking velocity until a minimum of 3 valid foot contacts for both left and right feet had been captured at 125 Hz (De Cock et al., 2006). Each foot was automatically divided into 10 zones (Hallux (T1), lesser toes (T2–5), metatarsals 1–5 (M1,M2,M3,M4,M5), midfoot, medial/lateral heel (HM/HL)) by Footscan® (v7.97, RSScan International) software; these were used to calculate all loading-related variables. Data was extracted from Footscan® using the default exports. These data were then processed within Scilab (v5.3.2; INRIA, France) to generate mean values of each plantar pressure variable described below for left and right feet.

2.2. Primary variables

1. Arch index
2. Impulse under all the metatarsal zones
3. Toe contact area at mid-stance
4. Peak force and impulse under the hallux
5. Peak force and impulse under the lesser toes
6. Medio-lateral centre of force (COF) position at last foot contact
7. Antero-posterior COF position at initial foot contact
8. Medio-lateral pressure ratio during forefoot contact phase (initial metatarsal contact to first instant all metatarsals make contact)
   a. $[(HM + M1 + M2)-(HL + M4 + M5)]/(HM + HL + M1 + M2 + M3 + M4 + M5 + T1)$

Primary variables 1–2, 3–5 and 6–8 are indicative of foot type, greater toe-extensor activity and the development of all-cause exercise-related lower leg pain respectively.

2.3. Secondary variables

1. Stance time
2. Foot progression angle
3. Mean medial-lateral displacement of COF during stance
4. Time from initial foot contact to initial full forefoot contact
5. Medial-lateral distribution of pressure under the heel at at initial foot contact, 5% of stance time and time of initial full forefoot contact
6. HM / (HM + HL)
7. Mean ratio between 1st and 5th metatarsal loading during stance
   a. $[(M1 - M5) / ((M1 + M5) / 2)] * 100$

2.4. Statistical analysis

Bootstrapped t-tests were carried out on all variables using the bias-corrected and accelerated method (Efron, 1987). Significant variables were then entered into a forward stepwise multinomial logistic regression model. The statistic (Likelihood ratio, Wald statistic, and conditional statistic) used in the test for variable inclusion did not affect the variables in the final model. Means and 95% CIs are reported unless otherwise stated. SPSS (v21; SPSS Inc., USA) was used for all analyses with alpha set to 0.05.

3. Results

Cases reported relatively low levels of pain (mean severity score 0.66) at rest although significantly more than controls ($t = 5.09$, $P = 0.001$). This was accompanied with reports of significantly greater sadness (mean difference = 0.53, $t = 2.53$, $P = 0.016$) and anxiety (mean difference = 0.49, $t = 2.21$, $P = 0.028$) than controls. Pain was not reported to be aggravated by cases or controls during testing demonstrating that sufficient rest was provided between each traverse.

Cases (28(5) years) were marginally younger than controls (32(6) years). Cases (1.759(6.8)m) were 2.4 cm shorter than controls (1.783(7.3)m) although this was marginally higher than the accepted