Session 2: Neuropathy and Motor Control

Co-Moderators: Sicco Bus, PhD (University of Amsterdam) and Paolo Caravaggio, PhD (Instituto Ortopedico Rizzoli)

11:00AM *2-1:* Bus, Sicco A., et al. Plantar pressures, footwear adherence and ulcer recurrence in patients with diabetes and a Charcot midfoot deformity

11:10AM *2-2:* Caravaggi, Paolo, et al. Multisegment foot kinematics and EMG analysis in the type 1 and type 2 diabetic patients

11:20AM *2-3:* Guiotto, A., et al. Combined finite element modeling & musculoskeletal modeling can improve diabetic foot preventive management

11:30AM *2-4:* Marc, Janin. System and Dysproprioception. Clinical evaluation of participation.

11:40AM *2-5:* Needham, Robert A. et al. Coupling angle mapping to assess multi-segment foot coordination and coordination variability during gait

11:50AM *2-6:* Reeves, Joanna, et al. What are the immediate effects of foot orthosis geometry on tibialis posterior EMG activity and foot biomechanics?

Plantar pressures, footwear adherence and ulcer recurrence in patients with diabetes and a Charcot midfoot deformity

Sicco A. Bus[1], Renske Keukenkamp[1], Ruth Barn[2], Tessa E. Busch-Westbroek[1], Jim Woodburn[2]
[1]Academic Medical Center, Amsterdam, [2]Glasgow Caledonian University, Glasgow
Email of Presenting Author: s.a.bus@amc.uva.nl

Disclosures: None

INTRODUCTION: Charcot midfoot deformity is a severe complication of diabetes and a significant risk factor for plantar foot ulceration. However, minimal data is available on footwear management and clinical outcomes in patients with Charcot neuroarthropathy and midfoot rocker deformity, while footwear is an important component in the prevention of foot ulcer recurrence. The aim was to analyze plantar foot pressures, footwear adherence and plantar foot ulcer recurrence in diabetic patients with a Charcot midfoot deformity.

METHODS: Data from a previous footwear trial[1] was used to compare 20 patients with diabetes, peripheral neuropathy, plantar foot ulcer history, and Charcot midfoot deformity, to 118 diabetic patients with the same risk factors but without Charcot diagnosis and midfoot deformity. The institutional review board approved the study and informed consent was obtained from all patients. All patients wore fully custom-made footwear. Barefoot (Emed-X) and in-shoe plantar pressures (Pedar-X) were measured at trial entry. Daily step count (StepWatch) and custom-made footwear use (@monitor) was measured over 7 days, with footwear adherence defined as the percentage of steps that the custom-made footwear was worn. Plantar foot ulcer recurrence was assessed at 18 months. Dependent upon the distribution of the data, independent samples t-tests or Mann-Whitney U tests were used to compare differences between study groups. Proportions were compared using Fisher's exact test. For all tests, a significance level of $P<0.05$ was use.

RESULTS: Median [IQR] barefoot and in-shoe midfoot peak pressures were significantly higher in the Charcot than in the non-Charcot group (barefoot: 756[260,1267] vs. 146[100,208] kPa, $P<0.001$; in-shoe: 152[104,201] vs. 119[94,160] kPa, $P=0.03$). Other foot regions showed significantly lower plantar pressures in the Charcot group. Both groups exhibited similar activity levels (approximately 6600 step counts per day), with no significant group differences present ($P=0.82$). The Charcot group was significantly more adherent (95 [82, 98] % vs. 78 [55,92] %), especially when being at home (94 [86, 95] % vs. 68 [27,89] %) compared to the non-Charcot group ($P=0.001$. Forty percent of the Charcot group patients had a recurrent plantar foot ulcer in 18 months, versus 47% in the non-Charcot group ($P=0.63$); midfoot ulcers occurred more in the Charcot group (4 out of 8 vs. 1 out of 55, $P=0.002$).

DISCUSSION: The data suggest that while in-shoe midfoot peak pressures are considered to be low and substantially improved from barefoot peak pressure, and while footwear adherence is almost optimal, this does not necessarily protect patients with midfoot Charcot deformity against plantar foot ulcer recurrence. Significantly higher midfoot plantar pressures may explain the relatively more midfoot recurrent ulcers in the Charcot group. Further improvement of the custom-made footwear for the midfoot region and the use of region-specific target pressures may be required to improve clinical outcome for these patients..

SIGNIFICANCE/CLINICAL RELEVANCE: Relatively low in-shoe peak pressures and high adherence does not necessarily protect against plantar foot ulcer recurrence in patients with diabetes, midfoot Charcot deformity and plantar foot ulcer history. Further improvement of the custom-made footwear seems indicated, in particular in the midfoot region

ACKNOWLEDGEMENTS: The authors acknowledge the contribution of Mark Arts and Roelof Waaijman for collecting and analysing data for the study.

REFERENCES:
Bus SA, Waaijman R, Arts M, de Haart M, Busch-Westbroek T, van Baal J, Nollet F. Effect of custom-made footwear on foot ulcer recurrence in diabetes: a multicenter randomized controlled trial. Diabetes Care. 2013 Dec;36(12):4109-16. doi: 10.2337/dc13-0996. Epub 2013 Oct 15. PMID: 24130357

Multisegment foot kinematics and EMG analysis in the type 1 and type 2 diabetic patients

Paolo Caravaggi[1], Claudia Giacomozzi[2], Giada Lullini[1], Giulio Marchesini Reggiani[3], Luca Baccolini[3], Maurizio Ortolani[1], Alberto Leardini[1] and Lisa Berti[1]

[1]Movement Analysis Laboratory, Istituto Ortopedico Rizzoli, Bologna, Italy; [2]Department of Cardiovascular, dysmetabolic and aging-associated diseases, Italian National Institute of Health, Rome, Italy; [3]Hospital Policlinico Sant'Orsola-Malpighi, Bologna, Italy

Email of Presenting Author: paolo.caravaggi@ior.it

Disclosures: Paolo Caravaggi (N), Claudia Giacomozzi (N), Giada Lullini (N), Giulio Marchesini Reggiani (N), Luca Baccolini (N), Maurizio Ortolani (N), Alberto Leardini (N), Lisa Berti (N).

INTRODUCTION: Diabetic foot refers to a complex set of physiological and mechanical alterations characterizing feet of type 1 and type 2 diabetic patients. Providing a comprehensive scenario of the effects of diabetes mellitus on foot biomechanics is not trivial, due to the number of factors that characterize this pathology, such as illness duration and glycosylated hemoglobin level which is associated to the presence and severity of neuropathy. Kinematic, kinetics and EMG analyses have often been performed in isolation, or on a number of limited sample-size diabetic subgroups. This situation has created a fragmented scenario where the available information can hardly be arranged in a coherent picture of diabetic foot biomechanics. In the present study, we aimed at collecting joints motion, force and plantar pressure data from a relatively large population of patients affected by different forms of diabetes mellitus. In this paper the effect of diabetes type 1 and type 2 on foot joint kinematics and EMG activation of leg muscles is reported.

METHODS: From January 2016 a wide sample of patients with diabetes mellitus were visited by an experienced diabetologist and were clinically classified as type 1 or type 2, with or without peripheral neuropathy. 74 patients (25 type 1, 49 type 2; 40 M, 34 F; age 57 ± 12 years; BMI 28.7 ± 6.4 kg/m^2) underwent functional evaluation via gait analysis using a validated foot and ankle kinematic protocol with integrated pressure measurements [1, 2]. This allowed measurement of ankle, midtarsal, tarso-metatarsal, and the first MTP joint kinematics during normal walking (Vicon, 100hz). Maximum voluntary contraction (MVC) and gait-cycle activation of the tibialis anterior and gastrocnemius medial head muscles were recorded via wireless sEMG (Cometa, 2000hz). EMG envelopes during walking were normalized in amplitude to the corresponding peak of EMG in MVC. 27 healthy subjects (11 M, 16 F; age 53 ± 9 years, BMI 24.2 ± 3.5 kg/m^2) were analysed according to the same protocol and were used as control. Principal component analysis was performed on the foot joints range of motion (ROM), separately, for the control, type 1, and type 2 diabetic groups. Non-parametric Mann-Whitney and Kruskal-Wallis tests were used to assess differences in ROM and EMG maximum activation between diabetic groups and control. Approval was granted by the Ethical committee of the hosting Institute for the gait analysis, and informed consent was signed by all participants in the study.

RESULTS: The peak of tibialis anterior and of gastrocnemius activation during MVC tests were lower in the diabetic type 2 group with respect to the control ($p < 0.05$). In stance, however, the tibialis anterior showed larger MVC-normalized EMG activation than control. The pooled type 1 and type 2 diabetic patients presented lower mobility in several foot joints with respect to the control (e.g. midtarsal flexion ROM: diabetes=13.5 ± 3.7 deg; control = 15.5 ± 3.3 deg; $p < 0.05$). Transverse-plane motion of the ankle and first MTP joint dorsiflexion in type 2 diabetic group showed reduced motion with respect type 1. The first four principal components described 83%, 84% and 80% of the variance in foot joint kinematics for the control, type 1 and type 2 subgroups, respectively. The principal components of the control and of the diabetes type 1 joint kinematics were comprised of almost identical sets of ROM variables. Three principal components describing diabetes type 2 kinematics showed significant loadings (> 0.25) for ankle joint sagittal- and frontal-plane ROM and for midtarsal joint frontal plane ROM, which were not present in the principal components describing the variance of diabetes type 1 and control kinematics.

DISCUSSION: This paper is part of a larger investigation on the effects of diabetes mellitus on foot and ankle biomechanics. In accordance with previous kinematic investigations, diabetic feet showed restricted ROM in stance compared to age-matched control feet, but differences were also found between type 1 and type 2 diabetes. It could be speculated that a larger activation of the main plantar/dorsiflexors at the ankle joint during stance would be necessary to compensate for the reduced maximum force exerted by these muscles as recorded in MVC tests. Sagittal- and frontal-plane ROM of the ankle and frontal plane ROM of the midtarsal joint resulted significant factors to describe foot mobility in type 2 diabetes.

SIGNIFICANCE/CLINICAL RELEVANCE: Deeper understanding of multisegment foot kinematics and muscle performance in type 1 and type 2 diabetes may help driving early rehabilitation treatment, as well as a better understanding of the multiple alterations in foot loading which likely occur at a later stage of the disease.

REFERENCES:

1. Giacomozzi C, et al. In Handbook of Human Motion, *in press*
2. Caravaggi P, et al. J Biomech. 49(14): 3485-3491

Combined finite element modeling and musculoskeletal modeling techniques can improve diabetic foot preventive management

Guiotto A.[1], Spolaor F.[1], Bellè F.[1], Guarneri G.[2], Avogaro A.[2],Sawacha Z.[1]
[1]Dept of Information Engineering, University of Padua, Italy, [2] Dept of Medicine, University of Padua, Italy
Email of Presenting Author: zimi.sawacha@dei.unipd.it

INTRODUCTION: Complications of diabetes that affect the lower extremities are common, among them foot ulceration is the most frequently recognized one, and unfortunately also ulcers recurrence is common [1]. Therefore prevention of ulcer and its recurrence is one of the most important topics in the current approach to diabetic foot disease [1]. The best approach is considered a early detection of subjects at risk through a good understanding of the factors that predict ulcers and its recurrence. Knowledge of the predictors can be used to optimize the preventive management [1]. Repetitive stresses both on the plantar surface of the foot and at the level of internal tissues can be detected through finite element modeling (FEM) techniques. Such measurements can also be used to plan therapeutic footwear for preventive management. Recently the authors demonstrated that the development of foot FEM can be enhanced on diabetic subjects by adopting both subject specific geometries (MRI based) and boundary conditions acquired during gait [2]. Furthermore by including lower limb muscle forces as further boundary conditions, the foot FEM simulation results were improved even more on a healthy subject [3]. The aim of this study was twofold: first to evaluate the possibility of improving the performances of a foot FEM applied to a cohort of neuropathic subjects by including lower limb muscle forces computed in Opensim, and second to verify the impact of the novel approach on the internal stresses estimation.

METHODS: Eight neuropathic foot FEMs and 10 healthy subjects were developed as in [2] by applying subjects specific boundary conditions acquired during gait to two, previously developed, foot FEMs respectively of a healthy and of a neuropathic subjects [2]. Three gait trials per subjects were acquired through 2 force plates (Bertec FP4060), a motion capture system (BTS S.r.l), 2 plantar pressure plates (Imago Ortesi), an 8 channels electromyographic system (BTS) [2, 4]. Hence subjects specific muscle forces were determined as in [4] in Opensim for both healthy and diabetic subjects and compared through T-Test ($p<0.05$). FEM simulations were run by considering only the kinematics and the ground reaction forces as boundary conditions [2] or by including the muscles forces generated with the Gait 2392 model in Opensim. Plantar pressure data obtained through the FEMs were compared with the experimentally measured ones in both conditions for validation purposes.

RESULTS: Results showed that a better approximation of the experimentally measured plantar pressure was obtained when adopting the FEM driven with the muscle forces as boundary conditions together with the ground reaction forces and the kinematics (Figure 1). Furthermore these models leaded to lower Von Mises stresses, thus confirming that the important role of muscle forces in foot biomechanics shouldn't be neglected when developing foot FEMs.

DISCUSSION: The adoption of foot FEMs driven with lower limb muscles forces showed the possibility to improve prediction of both internal stresses and strain not only on healthy subjects [3] but also on diabetics.

SIGNIFICANCE/CLINICAL RELEVANCE: This methodology can be adopted to optimize the preventive management by providing a early detection of subjects at risk and in order to develop specific insoles that can improve gait biomechanics and foot function aiming to reduce foot internal and external stresses.

REFERENCES:
1. Armstrong DG, N Engl J Med. **2017**, 376(24):2367-2375 PMID: 28614678
2. Guiotto, J Biomech, 2014, 47:3064–3071. PMID: 25113808
3. Scarton A, Gait Posture, 2017 Sep 1. PMID: 28965863
4. Scarton A,, Gait Posture, 2017, 58:194-200.. PMID: 28802220

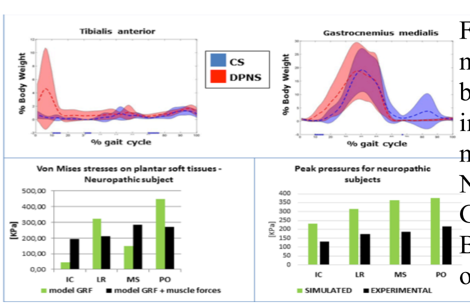

Figure 1: Top: OpenSim Static Optimization results: comparison between mean muscles forces (dashed lines) plus and minus 1 standard deviation of both CS (in blue) and of DPNS (in red). Results of T-Test have been reported in term of the instants of the gait cycle where significant differences were found (blue asterisk means $p < 0.05$). Bottom left: Von Mises stresses on plantar soft tissues for one Neuropathic subject: simulations with the GRF FEM model and the one with GRF and muscle forces.
Bottom right: comparison between simulated and experimental plantar pressures on the 8 neuropathic subjects.

Plantar System and Dysproprioception. Clinical evaluation of participation.

Janin Marc,

PhD, Podiatry office; Applied Podiatry College, Poitiers, France; Laboratory of Physiology, University of Toulouse, France.

Email of Presenting Author: marcjanin@cegetel.net

INTRODUCTION: Regulation of the balance function is organized in hierarchical patterns and chronologically requires the central sensory integration of information on vestibular, visual, cutaneous and proprioceptive inputs, as well as the motor command and component (1; 2). The plantar system (PS) provides cues and feedback coming from tactile and proprioceptive information (3). Their sensory integration contributes to the balance function control. Sensory integration can be affected by syndromes such as: the Proprioceptive Dysfunction Syndrome (PSD; 4), the Oral Dysperception Syndrome (ODS, 4), the Postural Deficiency Syndrome (5-7) or the Sensory Processing Disorders (8; 9), In the aforesaid syndromes, PS participation is usually assessed by clinical evaluation such as delays in crawling, standing, walking or running (8; 9) or more recently by Vertical Heterophoria (VH; 4; 10). To evaluate the sensory processing disorder, called “dysesthesiology” in patients presenting PDS and ODS (4), clinicians and podiatrists usually use VH, separated into 7 conditions: 5 in sitting positions without plantar contact and 2 in natural standing position with and without foam (4). The last 2 conditions require some PS participation but do not provide podiatrist with enough information on disruptor and/or regulator factors.
In order to improve clinical practice, we propose a new framework, adding 14 conditions to allow the evaluation PS participation with the MP, on foam thickness: 1) 3 mm, reduction of exteroceptive and nociceptive cues, 2) 5 mm, reduction of exteroceptive cues and recruitment of plantar surface, 3) 8 mm, recruitment of proprioceptive cues, 4) 10 mm, induction of proprioceptive instability; 5) with stimulation (11-13) to maximize plantar cutaneous sensory awareness and increase feedback from cutaneous receptors; 6) with the patient’s current shoes; 7) with therapeutic foot orthoses/insoles; in standing and sitting position to compare results with the control conditions (standing and sitting in spontaneous position, 4).
DISCUSSION: The hereby proposed clinical score aims to follow the scoring defined by Quercia *et al.*(10), e.g. the sum of the number of conditions giving the Vertical Orthophoria (VO) and changing MP Index of Lability (IL; 10): a number between 0 and 14 for VO and IL for sitting and standing. Higher numbers would expose a significant relevance of implication of the PS in regulation for VO, while it could suggest perturbation or neutral for IL. The efficient sensory integration would be obtained with a higher VO and lower LI score. Low numbers would expose poor sensory integration. Consequently the VO and LI score variations could first indicate where the sensory processing disorder is, and then the level of participation of the PS in terms of perturbators and/or regulators.
This new clinical score could be used to improve the podiatry therapeutic proposition, help communication between clinicians of different domains, and help follow patients’ foot health in clinical routine. However, this framework of the PS participation still needs to be validated in clinical trials.

SIGNIFICANCE/CLINICAL RELEVANCE: Improvement of the clinical practice to evaluate the PS participation in PDS, ODS and Sensory Processing Disorders. High score of vertical orthophoria show good sensory integration. Creation of a clinical score to evaluate the efficiency/inefficiency of the sensory integration of the PS cues in sensory processing disorders.

REFERENCES:

1. Horack et al. 2009 May;89(5):484-98. PMID: 19329772.
2. Paillard T. 2017. Jan;72:129-152. PMID: 27894829.
3. Paillard T. 2012. Jan;36(1):162-76. PMID: 21645543.
4. Quercia P, Marino A. 2017. Juil ISBN : 979-10-699-0945-8.
5. da Cunha, HM. 1979. Syndrome de déficience posturale. Actual. Réeducation Fonct. Rèadaptation" 4e :27–31.
6. da Cunha HM, da Silva OA. 1986 Jan;27(1):63-7. PMID: 3717512.
7. da Cunha HM. 1987 Oct;28(9):941-3. PMID: 3445900.
8. Ayres, AJ. 1972. ISBN 0-87424-303-3. OCLC 590960.
9. Ayres AJ. 1972. Am J Occup Ther. 26 (1): 13–8. PMID: 5008164.
10. Quercia et al. 2015 Sep 25;9:1785-97. PMID: 26445526.
11. Waddington G, Adams R. 2000. DOI: 10.1054/ptsp.2000.0020.
12. Kalron et al. 2015. 7:17-25. doi: 10.1016/j.pmrj.2014.08.942.
13. Hatton et al. 2009 19:957-64. PMID: 25153447.

Key-words: learning disorder, foot insoles, sensory processing disorders, Proprioceptive Dysfunction Syndrome, podiatry.

Coupling angle mapping to assess multi-segment foot coordination and coordination variability during gait

Robert A. Needham, Roozbeh Naemi, Aoife Healy, Nachiappan Chockalingam
Staffordshire University, School of Life Science & Education, Stoke-on-Trent, UK
Email of Presenting Author: r.needham@staffs.ac.uk

Disclosures: Robert A. Needham (N), Roozbeh Naemi (N), Aoife Healy (N), Nachiappan Chockalingam (N)

INTRODUCTION: Vector coding (VC) provides a quantitative measure of movement coordination and coordination variability (CAV). Traditional time-series reporting of VC data can be difficult to interpret when multiple trials are overlapped. Coupling angle mapping (CAM) is a reporting approach that uses color to depict movement coordination and CAV across multiple participants and trials (Needham et al., 2017). This study is the first of its kind to apply this technique on the multi-segmented foot to report on novel insights into the coordination pattern (CP).

METHODS: Data were obtained from ten male participants ((mean ± standard deviation) age: 22.4 ± 2.46 years, height: 180.3 ± 7.18 cm, mass: 74.97 ± 11.02 kg). Ethical approval was sought and granted by the University Research Ethics Committee. Rearfoot and medial-forefoot kinematic data was collected (100Hz) using an 8-camera motion capture system (VICON, Oxford, UK). Procedures and data processing for VC in addition to CAM are reported elsewhere (Needham et al. 2017). At each instant in time, the coupling angle (CA) is assigned to a CP classification (Figure 1c).

RESULTS: In figure 1, subtle differences in the CP were noted between trials (a), while the CP for several participants did not coincide with the group (b). CAV was higher and extended for the group (b) in comparison with participant 10 data (a).

DISCUSSION: Although CAM highlights the CP, this novel approach showcases the reporting of segmental dominancy that details the changes in the distribution of the CA within the CP classification. CAM noted differences in the CP between participants during early stance phase that questions the interpretation and clinical relevance of reporting group CAV data.

SIGNIFICANCE/CLINICAL RELEVANCE: This work presents CP, CAV and segmental dominancy data via illustrations that provides unique insights into segmental movements that may support the design of individualized clinical interventions.

FIGURES AND TABLES:

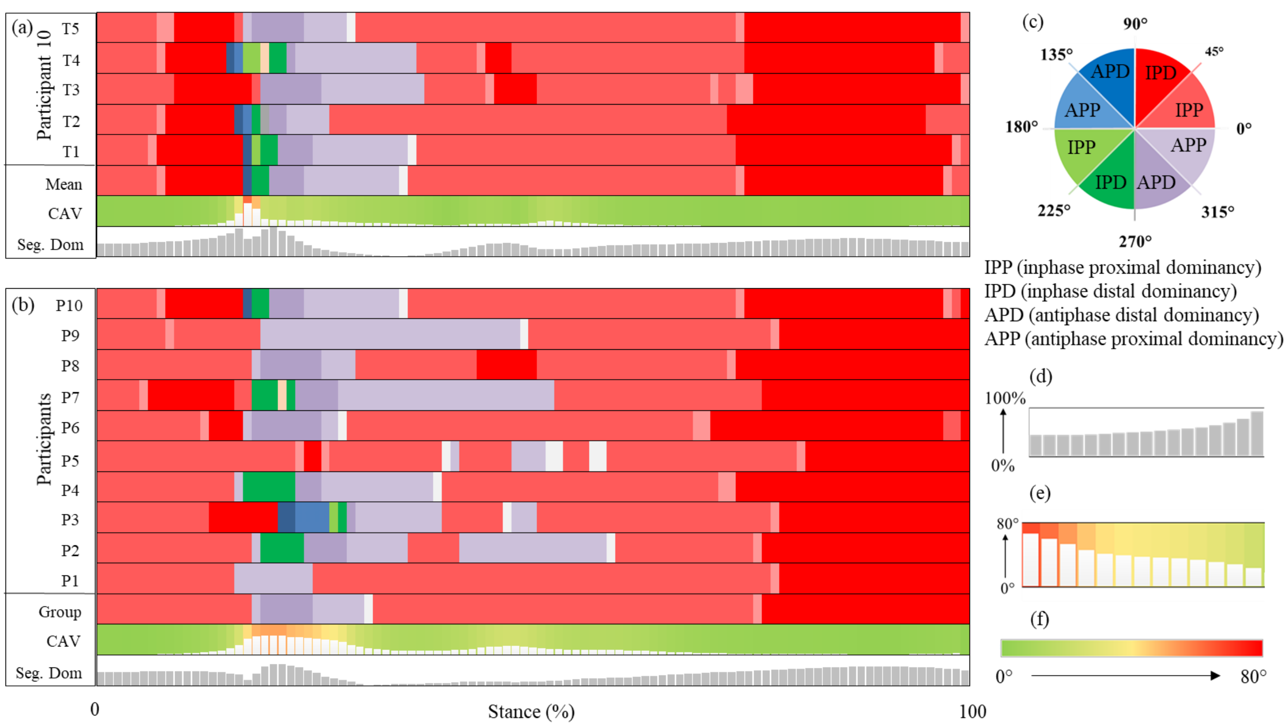

Figure 1. Coupling angle mapping during stance representing coupling angle data on forefoot-rearfoot coordination in the sagittal plane across five trials (T1-T5) for participant 10 (P10) (a); mean coupling angle data across 10 participants (P1-P10) (b). Coordination variability (CAV – legend 'e/f') and segmental dominancy (Seg. Dom. – legend 'd') are also presented.

REFERENCES: Needham R.A. et a. J Biomech (under review).

What are the immediate effects of foot orthosis geometry on tibialis posterior EMG activity and foot biomechanics?

Joanna Reeves[1], Prof. Rich Jones[1], Dr. Anmin Liu[1], Dr. Leah Bent[2], Prof. Chris Nester[1]

[1]University of Salford, UK, [2]University of Guelph, Canada

j.e.reeves@edu.salford.ac.uk

INTRODUCTION: Foot orthoses used to treat conditions like tibial posterior tendon dysfunction can effectively reduce the external forces applied to the foot. However little is known about whether specific aspects of foot orthosis geometry can affect activation of the tibialis posterior. If an orthosis reduced the external eversion moment during stance, we might expect the force required from the tibialis posterior to resist eversion to be less and so a reduced EMG activation would be seen. Reduced activation could mean less force through the tendon which could facilitate healing in the case of tibialis posterior tendon dysfunction. The aim of this study was to establish if medial heel wedging and increased medial arch height have effects on EMG of tibialis posterior and other muscles of the lower limb, and foot and ankle moment/motion

METHODS: Ethical approval was obtained from the University of Salford (HSR1617-36). Healthy participants (n=10) performed walking trials in standardised shoes with five inserts in a random order: *i)* a flat inlay and *ii)* a standard Salfordinsole®, and a Salfordinsole® with *iii)* a 6 mm increase in arch height, *iv)* an 8 mm increase in medial heel wedging and *v)* both a 6 mm increase in arch height and an 8 mm increase in medial wedging. Recording of the tibialis posterior was performed with bipolar fine-wire electrodes (44 gauge × 100 mm paired-hook wires, Teflon-coated stainless-steel wire) using the posterior approach. Kinematic and kinetics data was collected concurrently. The root mean squared (RMS) EMG signal was normalised to the peak of the average of the six gait cycles in the flat inlay condition. A repeated measures ANOVA, or non-parametric equivalent, will be performed to compare peak EMG between conditions for early and mid-stance.

RESULTS: Preliminary results (n=10) show that tibialis posterior activity reduced in early stance in the wedge and combined arch and wedge conditions and also reduced slightly in the arch and arch and wedge conditions in late stance relative to the flat inlay (FIGURE). However there was typically a reduction in moment across stance for all orthotic conditions.

DISCUSSION: The findings of this study so far are similar to that of Murley et al. (1) who found a reduction in tibialis poster activity in early stance with customized and prefabricated orthoses relative to a shoe only. Large between trial variability exists in tibialis posterior activity, however there appears to be a trend towards phase specific reduction in tibialis posterior activity with orthoses. With a greater sample size the specific effects of heel wedging and arch height on tibialis poster activity may become more apparent.

SIGNIFICANCE/CLINICAL RELEVANCE: By relating change in tibialis posterior activation with foot orthoses to change in the forces and motion at the foot and ankle we can better understand the mechanism by which foot orthoses can benefit patients. If we can better understand how a foot orthosis can offload the tibialis posterior tendon we may be able to improve the prescription of treatments for tibialis posterior tendon dysfunction.

REFERENCES: Murley et al. Clinical Biomechanics. 2010; 25(7):728-36.

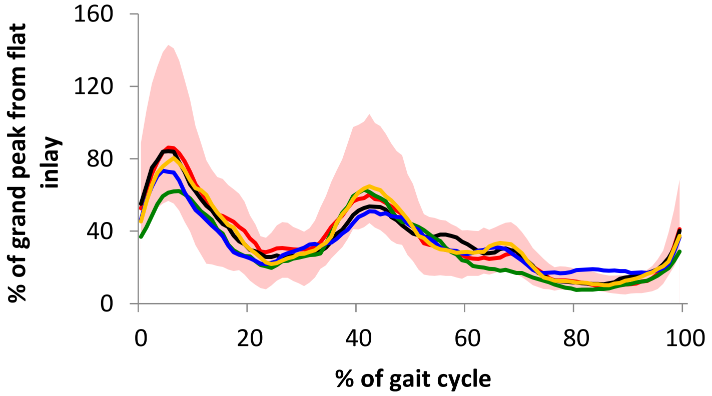

FIGURE: Average RMS amplitude of the tibialis posterior over the gait cycle expressed as a percentage of the grand peak of the flat inlay condition. Red line: flat inlay; yellow line: standard Salfordinsole®; black line: 6 mm increase in arch height; green line: 8 mm increase in medial wedging and blue line: both a 6 mm increase in arch height and an 8 mm increase in medial wedging. Shaded pink area represents average standard deviation of flat inlay condition.