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Classification of forefoot plantar pressure distribution in patients with diabetes: a biomechanical approach based on relative regional impulses and non-hierachical clustering

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SUMMARY

This study aimed to identify groups of subjects with similar patterns of forefoot loading and verify if patients with diabetes (PwD) could be distinguished from non-diabetics. Kmeans cluster analysis on the relative regional impulses originating from 6 forefoot segments, led to the identification of three distinct groups when considering only non-diabetics and of four groups when taking into account diabetics only or both populations together. An 'exclusive' pattern of PwD only was identified. The relevance of the reported clusters was supported by differences observed between groups when considering other parameters.

INTRODUCTION

Objective evaluation of plantar pressure pattern (PPP) in PwD can be a starting point for the development of treatment algorithms, preventive strategies and early detection [1, 2]. Cross-sectional, comparative study designs are most commonly used and define populations on the basis of the presence or absence of diabetes, neuropathy, vasculopathy and history of ulceration (pathophysiological approach) [3]. Intrinsic flaws associated to this approach relate to: 1) the 'smoothing' of relevant PPP associated to the calculation of ensemble averages, 2) the assumption of a linear relationship between specific pathophysiological complications and PPP, 3) the assumption of low variability in PPP in the so-called healthy population.

Recently, an interesting alternative has been proposed, characterised by the stratification of PwD based on their PPP homogeneity (biomechanical approach) [4,5]. These studies illustrated the potential clinical relevance of a biomechanical approach, but they lack discriminative value for ulceration diagnosis [4], omitted to describe their study population, nor included a control group [5]. The aim of our study was to classify forefoot PPP in control subjects and PwD using a non-hierarchical clustering technique.

METHODS

Dynamic barefoot PPP of ninety-seven PwD and 33 control subjects (45-70 years) were recorded, at a self-selected speed, along a 10m walkway. Pressure measurements were recorded with a Footscan pressure plate (RSscan®) (dimensions 0.5m x 0.4m, 2.8 sensors/cm²) which was dynamically calibrated by a custom made AMTI® force plate. Data analysis consisted of semi-automatic total mapping (SATM), identifying ten regions of interest (RoI) on the peak pressure footprint of each trial (five trials per foot) (figure 1).

Following SATM, force-time curve of the peak force sensor was extracted for all RoI, except for the midfoot and toes two to five. Subsequently, relative regional impulses (RrI, as % of summed impulses) were calculated considering the remaining eight RoI. Average RrI were calculated based on all trials of each individual in order to obtain one profile for each person and each foot (left and right foot were kept separated).

Kmeans clustering was used to classify the RrI of the forefoot (the five metatarsals and the hallux). First, the RrI of the forefoot were converted into z-scores, subsequently, a Kmeans function (Matlab 2012a) was used and a standard Euclidean distance was selected for the partitioning into clusters. Classification construction was guided by the highest silhouette coefficient.

The clustering process, including the determination of the optimal number of clusters, was consecutively performed for the control group (CtrlOnly, N= 66 feet), the diabetic group (DbtOnly, N= 194 feet) and finally for both groups together (BothGr, N= 260 feet). Finally, one-way multivariate ANOVA (Matlab 2012a) was used to assess significant differences between the optimal classification resulting from Kmeans clustering of BothGr data. These analyses were performed on the peak force and the RrI of all eight RoI.

RESULTS AND DISCUSSION

Silhouette calculation indicated three clusters to be the most suitable when considering only RrI of CtrlOnly (SC=0.44). The preferred number of clusters was four (SC=0.43) for DbtOnly, which was also the case for BothGr (SC=0.43). Figure 1 (b,c,d) summarizes the PPP for each cluster.
RrI and Peak Force were significantly different between the four clusters (Table 1)

Table 1. Results of one-way multivariate ANOVA statistics performed on the four clusters of BothGr data

	RoI	Medial M1 pattern Cluster 1	Central Pattern Cluster 2	T1-M1 pattern Cluster 3	Lateral M4-M5 pattern Cluster 4	p value
% total regional impulse	HL	14.3 (4.1) *^{2,4}	11.8 (3.7) *^{1}	13.2 (3.0)	11.5 (4.3) *^{1}	$<$0.001
	HM	15.9 (5.0) *^{2,4}	13.8 (3.5) *^{1}	14.8 (3.1) *^{4}	12.3 (4.5) *^{1,3}	$<$0.001
	T1	5.7 (4.3) *^{3}	6.3 (4.2) *^{3,4}	19.6 (4.5) *^{1,2,4}	3.8 (4.4) *^{2,3}	$<$0.001
	M1	24.4 (6.6) *^{2,3,4}	10.4 (3.7) *^{1,3}	12.9 (4.4) *^{1,2}	11.1 (5.9) *^{1}	$<$0.001
	M2	13.9 (4.9) *^{2,4}	18.6 (4.5) *^{1,3,4}	12.5 (3.8) *^{2}	10.2 (4.5) *^{1,2}	$<$0.001
	M3	11.5 (3.7) *^{2}	17.5 (3.0) *^{1,3,4}	11.8 (2.5) *^{2}	11.9 (5.8) *^{2}	$<$0.001
	M4	7.8 (2.9) *^{2,4}	12.3 (3.4) *^{1,3,4}	8.9 (3.1) *^{2,4}	15.7 (12.8) *^{1,2,3}	$<$0.001
	M5	6.5 (4.1) *^{2,4}	9.2 (3.7) *^{1,3,4}	6.4 (3.5) *^{2,4}	23.5 (7.6) *^{1,2,3}	$<$0.001
Peak Force (Newton)	HL	17.1 (4.5)	16.5 (3.0)	16.8 (4.1)	15.8 (2.9)	n.s.
	HM	19.2 (5.4) *^{4}	17.8 (3.6)	18.5 (5.1)	16.0 (2.6) *^{1}	0.02
	T1	19.4 (12.0) *^{3}	19.0 (8.4) *^{3}	32.2 (12.8) *^{1,2,4}	18.4 (12.2) *^{3}	$<$0.001
	M1	29.7 (10.4) *^{2,3,4}	13.2 (5.7) *^{1}	16.8 (8.9) *^{1}	17.7 (10.0) *^{1}	$<$0.001
	M2	17.7 (7.7) *^{2}	22.1 (6.9) *^{1,3,4}	14.5 (5.8) *^{2}	16.0 (5.9) *^{2}	$<$0.001
	M3	14.1 (5.0) *^{2}	19.6 (5.8) *^{1,3,4}	12.8 (4.1) *^{2}	16.0 (5.9) *^{2}	$<$0.001
	M4	9.3 (3.3) *^{2,4}	13.0 (3.5) *^{1,3,4}	9.3 (3.2) *^{2,4}	15.9 (5.1) *^{1,2,3}	$<$0.001
	M5	8.7 (7.0) *^{4}	10.7 (5.5) *^{4}	7.1 (3.5) *^{4}	28.8 (12.2) *^{1,2,3}	$<$0.001

Good resemblance was observed between BothGr and the DbtOnly clustering. Based on these observations, it was decided to use the optimal clustering based on the BothGr data. Following cluster names were introduced: cluster 1= Medial M1 pattern, cluster 2= Central pattern, cluster 3= T1-M1 pattern, cluster 4= Lateral M4-M5 pattern.
One hundred percent of the feet in cluster four of BothGr were from PwD (figure 1d).
All PwD with a history of a plantar foot ulcer at the fifth MTH (N=3) were stratified in the lateral M4-M5 pattern. Similarly, all plantar ulcers (N=3) observed in the T1-M1 pattern were located under the hallux.

CONCLUSIONS

A new era seems to emerge in DF medicine which encompasses the classification of PwD according to their biomechanical profile. The adoption of this alternative model has the potential to provide better management of the diabetic foot syndrome.

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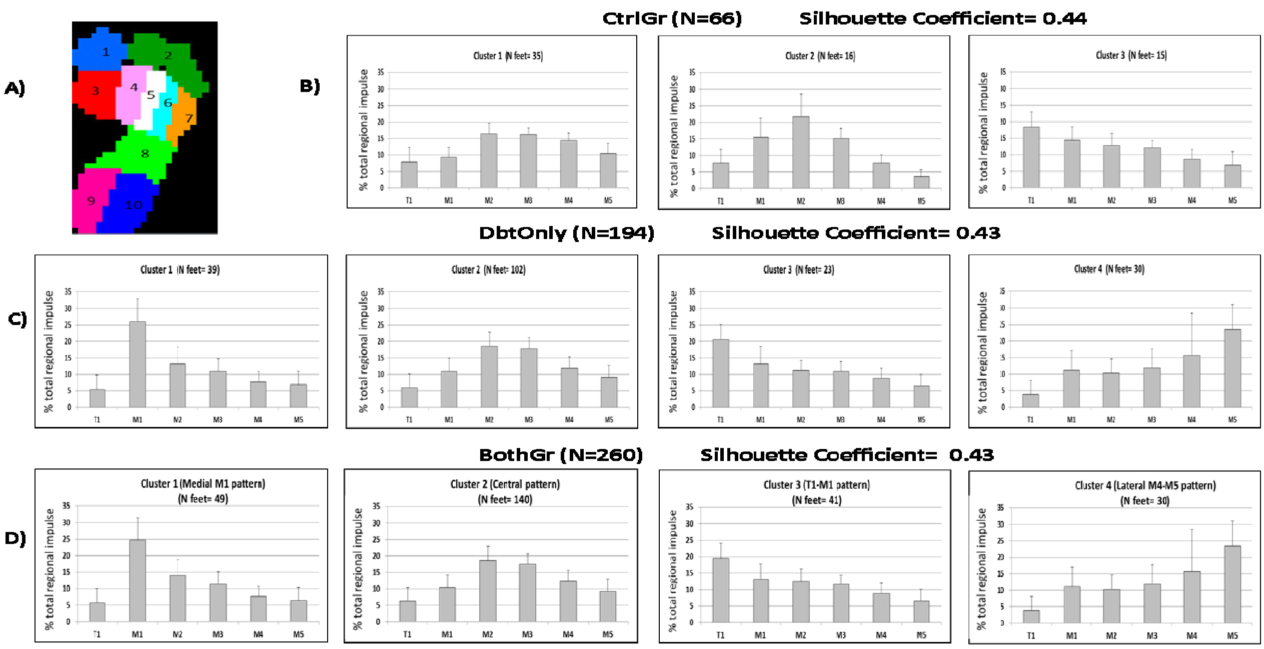
Figure 1. Illustration of the SATM method and summary of the PPP for clustering of both groups together



*F**igure 1.** A) SATM applied in the current study. The ten RoI where semi-automatically defined on the peak pressure footprint. The RoI were 1) hallux, 2) toes 2-5, 3) first metatarsal, 4) second metatarsal, 5) third metatarsal, 6) fourth metatarsal, 7) fifth metatarsal, 8) midfoot, 9) medial heel, 10) lateral heel. B) RrI for the forefoot segments of the three loading patterns considering only data of control group, C) RrI for the forefoot segments of the four loading patterns considering only data of diabetic group, D) RrI for the forefoot segments of the four loading patterns considering data from both groups.