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Normal pressure values and repeatability of the Emed® ST2 system

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ABSTRACT

Objectives: This study was designed to assess the repeatability of the Emed® ST2 system and identify the range of pressure values observed in the normal foot.
Methods: Measurements were taken from twenty-three healthy subjects, 14 females and 9 males, on two occasions 7 days apart. Begin of contact (BC), end of contact (EC), contact time (CT), peak pressure (PP), instant of peak pressure (IPP), contact area (CA) and pressure–time integral (PTI) were recorded.
Results: The coefficient of repeatability (CR) was less than 16.0% for all 63 parameters considered. In 87.3% of the parameters investigated (55 of 63) the CR (expressed as a percentage of the mean) was less than 10%. The highest areas of PP were found under the great toe and second metatarsal heads, with mean (S.D.) equal to 435 kPa (202) and 407 kPa (146), respectively, followed by the third metatarsal head 345 kPa (96) and the hindfoot 332 kPa (93). The CT (% ROP (range of pressure)) was in the range 74–85% under the metatarsal heads, and 71% under the great toe. CA was highest under the heel at 33.8 cm^2.
Conclusion: Emed® ST2 system was found to be repeatable. The presented range of parameters compared very well to the results presented in the literature for the Emed® ST4 system.

1. Introduction

In modern gait analysis pressure distribution measurement technology is the furthest developed and the easiest to use [1]. Ideally, a foot pressure system should meet certain requirements; it must be supported by reliable software, hardware and sensors (transducers) and should take into account: hygiene, comfort, repeatability, linearity of transducers, reproducibility of data in different formats, presence of reliable technical support, ease of use, and cost. The Emed® systems are among the most commonly used clinical tools for barefoot pressure measurement in humans worldwide. There are several different Emed® systems available [2]. Putti et al. [3] have studied the repeatability of the Emed® ST4 system. No previous publications have addressed the repeatability of the Emed® ST2 system, nor have ranges of values been identified for normal foot function during barefoot walking using the mid-gait method. In this study the repeatability of the Emed® ST2 system (model-ST2; Novel GmbH, Germany) was examined and ranges for pressure distribution and contact times were determined for reference in clinical examination of the normal and pathological foot.

2. Materials and methods

Twenty-three healthy volunteers were recruited for the study. Approval was obtained by the local Research Ethic Committee. All subjects gave written informed consent. Subjects were excluded if they had experienced musculoskeletal pain or gait abnormalities. The mean age of the group was 36.0 years (±11.6 years) with a mean BMI of 24.5 kg/m^2 (±3.95 kg/m^2). Of the 23 subjects, 14 (61%) were female and 9 (39%) were male. Measurements were taken on two occasions with a 7-day interval. The Emed® ST2 system used in the current study enabled both static and dynamic measurement with a maximum speed of 150,000 sensors per second. The signal, produced from a maximum of 4000 calibrated Nicole capacitance pressure sensors (2 sensors/cm^2), was displayed as a uniform colour picture. An applied force altered the capacitance across the two perpendicular strips, which the system sensed and relayed to a computer. The platform was mounted in the centre of a flat 10 m walkway to allow mid-gait analysis. A mask was produced to divide the foot into 9 regions: heel, midfoot, first, second, third, fourth and fifth metatarsal heads, hallux and second to fifth toes (Fig. 1). Six of the clinically most relevant parameters were selected for analysis: begin of contact (BC, %ROP), end of contact (EC, %ROP), contact area (CA, cm^2), contact time (CT, %ROP), instant of peak pressure (IPP, %ROP), peak pressure (PP, kPa) and pressure–time integral (PTI, kPa s). In total, 63 parameters were assessed: seven parameters, under 9 mask areas.

Repeated measures analysis of variance (ANOVA) was used to investigate the variability of pressures measured in walks conducted on different days. The Bonferonni correction for multiple comparisons was applied to means *post hoc* and the Huynh–Feldt correction was applied for non-sphericity. The standard deviations of the between-day differences identified in the ANOVA were used to determine the coefficient of repeatability (CR) of each parameter [4]. The CR was expressed as a percentage of the mean by using the formula [(coefficient of repeatability)/mean] × 100 [4], i.e., the lower the CR the stronger the repeatability. Plantar pressure measurements during able-bodied gait showed differences between the two lower limbs. These dynamic asymmetries were the results of a

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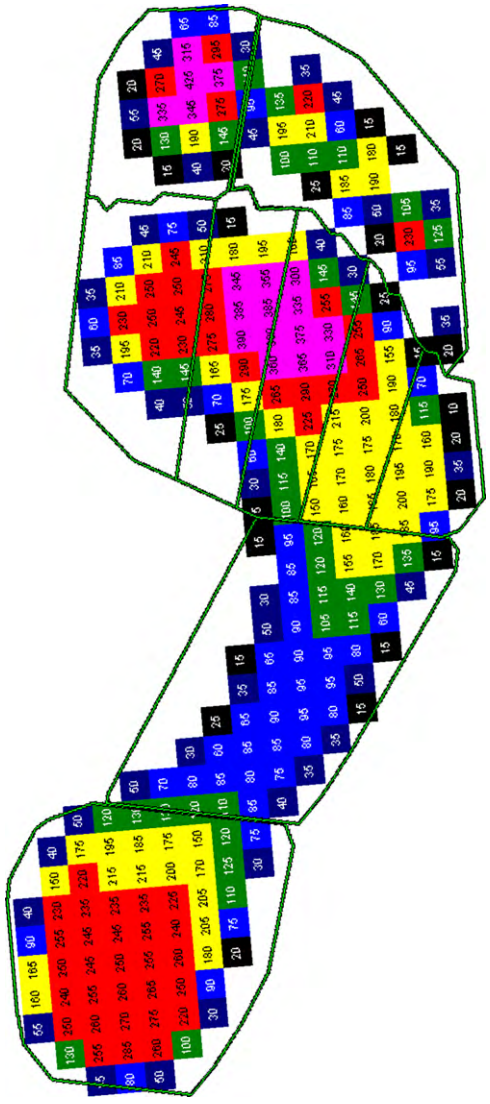

Fig. 1. Mask areas.

natural functional organisation of the supports differentiating a loading foot and a propulsive foot [5]. Therefore, repeatability was investigated for the left and right foot separately and the mean CR determined.

3. Results

In 87.3% of the parameters investigated (55 of 63), the CR (expressed as a percentage of the mean) was less than 10%. Five mask areas showed parameters with a higher CR: the great toe and the first metatarsal head (both 1 of 8 parameters), the fifth metatarsal head, the midfoot and the hindfoot (all 2 of 8 parameters). These parameters included BC under the great toe (CR = 10.3%) and the midfoot (CR = 12.8%). The coefficients of repeatability for IPP measured under the midfoot and hindfoot were 13.6% and 10.2%, respectively. PP had CR values of 12.0% under the hindfoot, 13.2% under the first metatarsal head and 12.0% under the second metatarsal head, respectively. The highest CR value (16%) was found for PTI under the fifth metatarsal head. Table 1 also shows mean values for PP of the normal foot. The highest PP was found under the great toe (435 kPa (202)), followed by the second metatarsal head (407 kPa (146)), the third metatarsal head (345 kPa (96)), the hindfoot (332 kPa (93)) and the first metatarsal head (275 kPa (98)). Table 2 shows the minimum and maximum values for PP recorded in the different mask areas.

The third metatarsal head was the longest in contact with the platform (84.7%ROP (3.0)), closely followed by the second (82.9%ROP (3.7)), the fourth (82.5%ROP (3.6)) and the first metatarsal heads (80.0%ROP (4.6)). The heel had the shortest contact time (54.5%ROP (8.2)). PTI was highest in the second metatarsal head (122 kPa s (40)) followed by the third metatarsal head (113 kPa s (29)) and the great toe (103 kPa s (57)). The midfoot and second to fifth toes had the lowest PTI. CA was largest under the hindfoot (33.8 cm^2 (4.8)) followed by the midfoot region (19.2 cm^2 (8.8)), and then first metatarsal head (12.5 cm^2 (2.2)). The second to fifth region had the lowest CA (4.6 cm^2 (5.8)). Normal roll over of the foot can be described as successive BCs or progression of IPPs of the different mask areas. Analysis of BC succession showed a generally normal BC for the hindfoot followed by the lateral forefoot, the medial forefoot, the great toe and the second to fifth toe. However, BC of the midfoot was slightly delayed and occurred slightly after BC of the lateral forefoot. IPP progression analysis of the different mask areas showed normal

Table 2
Range for the peak pressure (PP) in the nine regions of the foot.

Emed® masks	Range (kPa)	
	Minimum	Maximum
Hindfoot	180	875
Midfoot	0	225
1MT[a] head	95	895
2 MT head	185	885
3 MT head	165	935
4 MT head	85	670
5 MT head	45	425
Great toe	60	910
Second to fifth toes	30	375

[a] Metatarsal.

Table 1
Mean, standard deviation (S.D.) and coefficient of repeatability (CR) for the begin of contact (BC), end of contact (EC), contact time (CT), instant of peak pressure (IPP) and pressure–time integral (PTI) for the 9 regions of the foot (left and right sides combined).

Emed® masks	BC (%ROP)		EC (%ROP)		CT (%ROP)		IPP (%ROP)		PP (kPa)		PTI (kPa s)		CA (cm^2)	
	Mean (S.D.)	CR[a]	Mean (S.D.)	CR[a]	Mean (S.D.)	CR[a]	Mean (S.D.)	CR[a]	Mean (S.D.)	CR[a]	Mean (S.D.)	CR[a]	Mean (S.D.)	CR[a]
Hindfoot	0 (0.0)	0.0	54.5 (8.2)	1.5	54.5 (8.2)	1.5	0 (0.0)	0.0	332 (93)	12.0	77 (33)	4.2	33.8 (4.8)	0.8
Midfoot	9.3 (4.9)	12.8	65.2 (9.4)	2.6	55.7 (11.8)	1.7	9.3 (4.9)	12.8	104 (43)	3.3	28 (15)	8.6	19.2 (8.8)	0.1
1MT[b] head	13.3 (4.0)	0.2	93.2 (1.7)	0.1	80.0 (4.6)	0.1	13.3 (4.0)	0.2	275 (98)	13.2	84 (31)	2.8	12.5 (2.2)	0.3
2 MT head	10.8 (3.2)	1.2	93.7 (1.6)	0.2	82.9 (3.7)	0.1	10.8 (3.2)	1.2	407 (146)	0.3	122 (40)	7.2	9.8 (1.6)	0.8
3 MT head	8.7 (2.5)	0.2	93.4 (1.6)	0.2	84.7 (3.0)	0.3	8.7 (2.5)	0.2	345 (96)	4.0	113 (29)	9.1	10.6 (1.7)	0.9
4 MT head	8.2 (2.4)	0.6	90.7 (2.6)	0.7	82.5 (3.6)	0.7	8.2 (2.4)	0.6	238 (87)	3.5	82 (28)	9.6	9.3 (1.4)	0.9
5 MT head	8.9 (2.8)	3.0	82.4 (5.5)	1.1	73.6 (6.3)	0.9	8.9 (2.8)	3.0	141 (66)	12.0	46 (20)	16.0	6.0 (1.1)	1.7
Great toe	28.1 (11.4)	10.3	99.7 (0.8)	0.2	71.3 (11.9)	5.3	28.1 (11.4)	10.3	435 (202)	4.6	103 (57)	1.1	11.2 (2.1)	0.4
Second to fifth toe	30.6 (12.1)	3.6	98.6 (2.1)	0.4	68.1 (12.4)	1.1	30.6 (12.1)	3.6	167 (77)	1.4	39 (19)	6.4	4.6 (5.8)	3.8

[a] CR: expressed as a percentage of the mean.
[b] MT: metatarsal.