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Normal pressure values and repeatability of the Emed[®] ST2 systemM. Maetzler^a, T. Bochsansky^b, R.J. Abboud^{a,*}^a Institute of Motion Analysis and Research (IMAR), Orthopaedic & Trauma Surgery, University of Dundee, TORT Centre, Ninewells Hospital & Medical School, Dundee DD1 9SY, Scotland, UK^b LKH Rankweil, Valdunastraße 16, A-6830 Rankweil, Austria

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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 cm².**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.

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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/m² (± 3.95 kg/m²). 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/cm²), 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, cm²), 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 Bonferroni 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] $\times 100$ [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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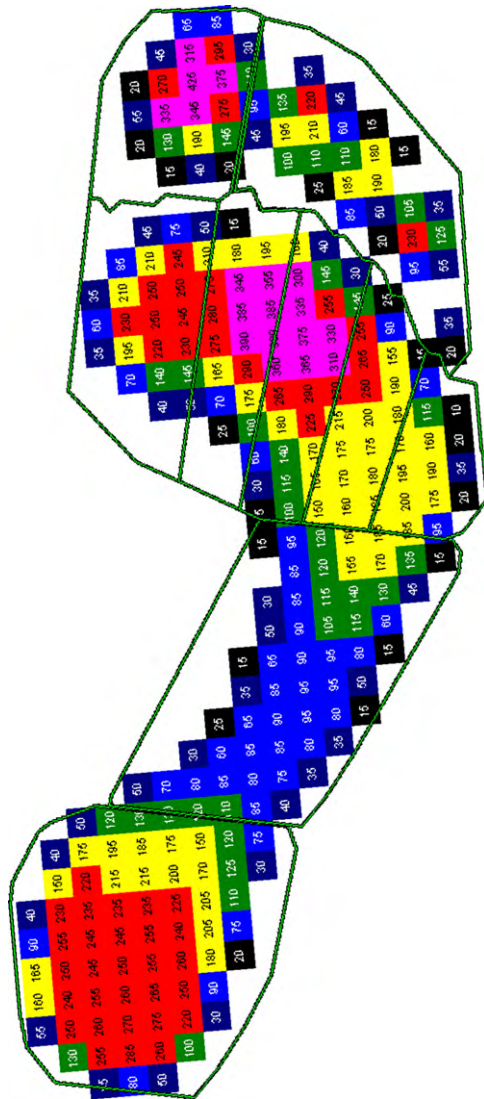


Fig. 1. Mask areas.

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

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.

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.

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 cm² (4.8)) followed by the midfoot region (19.2 cm² (8.8)), and then first metatarsal head (12.5 cm² (2.2)). The second to fifth region had the lowest CA (4.6 cm² (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

progression from the hindfoot to the midfoot, the lateral forefoot, the medial forefoot, the great toe and the second to fifth toe. Only the IPP of the second metatarsal head (80.3%ROP (4.4)) occurred slightly later than the IPP of the first metatarsal head (75.6%ROP (6.3)) and the great toe (79.5%ROP (4.3)).

4. Discussion

While Young [6] calls for standardisation of methodology in foot pressure measurements abbreviated gait protocols are often employed in plantar pressure studies [7]. One-step and two-step protocols are less time consuming [8] but produce longer contact times [7–9]. Young [6] reported that one-step measurements gave pressures which were 7–10% less than mid-gait measurements. Meyers-Rice et al. [10] summarised, that a two-step method, in comparison with a one-step protocol, provided more representative pressure data. Although other authors found that peak pressures measured with the different protocols are comparable [8–11] one-step and two-step protocols do not resemble normal walking [8] because of the changes in contact timing. In this study the mid-gait protocol was applied. Subjects were allowed extra time to accustom themselves to the mid-gait method to optimise the quality of measurement results. While van der Leeden et al. [8] stated that a minimum of three measurements were sufficient to obtain a consistent average, McPoil et al. [12] found that three to five walking trials are needed to obtain reliable regional peak pressure and pressure–time integral values. In this study five measurements were taken from each foot. The first aim of this study was to assess the repeatability of the Emed[®] ST2 system using the coefficient of repeatability. From the 63 parameters assessed, the highest CR was 16.0%, observed in PTI under the fifth metatarsal head. This compared to the findings of Putti et al. [3] who found the highest CR to be 16.9% for the Emed[®] ST4 system. Gurney [13] also reported satisfactory repeatability for the Emed[®] AT system. However, the intraclass correlation coefficients (ICC) as used by Gurney [13] were not appropriate in the analysis of measurement method comparison data [4]. In this study the majority of the parameters (55 of 63, 87.3%) had a CR less than 10%, whereas Putti et al. [3] reported that 91% of all parameters (111 of 122) had a CR less than 10%. Since no two foot steps are identical due to sway during gait in a normal subject [14] the highest CR achieved was clinically acceptable [3], which suggests that the Emed[®] ST2 system is repeatable.

The second aim was to establish ranges for PP, CT, PTI, CA and IPP under the normal foot. The highest PP values were found under the second and third metatarsal heads, the great toe and heel. These findings compare to the findings of Bryant et al. [15] and Hughes et al. [16], and are very much in agreement with Putti et al. [3]. Comparison of PP values for the different mask areas showed 332 (93) kPa vs. 313 (77) kPa for the hindfoot, 104 (43) kPa vs. 113 (37) kPa for the midfoot, 275 (98) kPa vs. 277 (90) kPa for the first metatarsal head, 407 (146) kPa vs. 361 (104) kPa for the second metatarsal head, 345 (96) kPa vs. 330 (84) kPa for the third metatarsal head, 238 (87) kPa vs. 233 (67) kPa for the fourth metatarsal head, 141 (66) kPa vs. 151 (78) kPa for the fifth metatarsal head, 435 (202) kPa vs. 421 (141) kPa for the great toe, and 167(77) kPa vs. 158 (73) kPa for the second to fifth toe. CT was highest under the metatarsal heads followed by the great toe which compares to previously mentioned studies [3,16]. While Putti et al. [3] found that the metatarsal heads bear weight for 75–85% of the total foot contact time, the results of this study show CT values for the metatarsal mask areas of 74–85%ROP. The CT values for the great toe in this study were 71%ROP compared to 70%ROP reported by Putti et al. [3]. The latter also reported that PTI was highest in the second, third, first metatarsal heads and the hallux, supporting the findings of Bryant et al. [15]. The PTI values found in this study were highest in the same

mask areas. The high agreement between this study and the findings of Putti et al. [3] can once again be illustrated through direct comparison of the mean PTI values: 77 (33) kPa s vs. 73 (25) kPa s for the hindfoot, 28 (15) kPa s vs. 33 (15) kPa s for the midfoot, 84 (31) kPa s vs. 87 (37) kPa s for the first metatarsal head, 122 (40) kPa s vs. 107 (35) kPa s for the second metatarsal head, 113 (29) kPa s vs. 104 (30) kPa s for the third metatarsal head, 82 (28) kPa s vs. 80 (30) kPa s for the fourth metatarsal head, 46 (20) kPa s vs. 50 (30) kPa s for the fifth metatarsal head, 103 (57) kPa s vs. 81 (49) kPa s for the great toe, and 39 (19) kPa s vs. 37 (24) kPa s for the second to fifth toe. PTI provides information about the load distribution over time. The CA values in this study correlates highly with those published in Putti et al. [3]. It is particularly important for the differentiation between normal feet and feet with pathologies such as neuropathic diabetic feet [17], while PP values alone do not provide sufficient information to differentiate clearly. IPP demonstrates the time at which peak pressure occurs. For better comparability IPP values in this study were normalised to the total contact time of the foot with the ground. Since Putti et al. [3] have presented their IPP values non-normalised results cannot directly be compared. However, the IPP progression pattern is very similar and is important for the analysis of centre of pressure progression.

5. Conclusion

Clinically, peak pressure is the most relied upon parameter. The PP values as well as the values for CA, CT and PTI presented in this study for the Emed[®] ST2 system are very well comparable to the results of Putti et al. [3] who studied the repeatability of the Emed[®] ST4 system and presented reference data. The Emed[®] ST2 foot pressure system was found to be repeatable.

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Conflict of interest

All authors have no financial or personal relationships with other people or organisations that could inappropriately influence (bias) their work.

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