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Original Article

Accuracy and repeatability of a semi-quantitative barefoot pressure measurement method for clinical use: The Derks Calculation Method

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ABSTRACT

Background: This study was designed to assess the accuracy and repeatability of the Derks Calculation Method in the normal foot during walking.
Methods: Measurements were taken from 25 healthy subjects (age 32.0 ± 12.4), 23 females and 2 males, on five separate occasions at seven days, three weeks, three months, and nine months apart by means of a mid-gait method. Values were calculated for internal rotation (IR) and external rotation of the heel (ER), heel valgus/varus (HV), heel length (HL), heel width (HW), width of the midfoot (WM) and the forefoot (WF), and the length of the foot (LF).
Results: For all five separate occasions and in 87.5% of the parameters investigated, the coefficient of repeatability (CR, expressed as a percentage of the mean) was less than 5%. One parameter showed a high CR - heel valgus/varus (HV) was extremely high (> 800%). The maximum 95% Confidence Interval (CI) for the five different occasions was no higher than 0.2 cm for IR, ER and HV with a standard error (SE) of 0.01 and > 0.01 respectively. The maximum 95% CI for WF was 0.4 cm (SE 0.1), and for HW, WM and LF the maximum 95% CI was 0.7 cm (SE 0.1 or 0.2). HL showed the highest 95% CI (0.9 cm) with an SE of 0.2.
Conclusion: The Derks Calculation Method was found to be accurate and repeatable if HV was excluded, which renders this method a viable clinical tool in settings where sophisticated computerised systems are still unavailable.

1. Background

Many attempts have been made to develop a suitable technique for measuring the distribution of pressure underneath the plantar surface of the foot. The range of techniques and equipment that have been devised have been extensive, varying from inexpensive and simple to expensive and extremely complex devices [1]. The first dynamic pressure studies during walking were performed using a rubber mat [2]. The earliest technique developed to accurately capture plantar foot pressure distribution can be attributed to Elftman [3] and Morton [4]. Their deformable rubber mat was adapted to facilitate calibration and popularised by Harris and Beath [5]. As modern technology has advanced, many researchers and particularly industry have turned their attention to the development of quantitative high-resolution pressure mats, matrix arrays of force or pressure transducers, thus providing a powerful tool for conducting a full objective foot pressure investigation. However, while repeatability is generally found to be good for quantitative systems [6,7], there is a relatively high cost to pay. Cheaply available semi-quantitative plantar pressure measurement devices like ink mats and paper pedographs are able to detect high pressure areas [8] but not exact pressure values. In addition, calculation of foot geometry based on plantar pressure measurements has been shown to be reliable [9–12] as long as the measurements were collected with the same measurement system [13]. Thus, semi-quantitative plantar pressure measurement systems may provide valuable information on foot geometry for foot diagnostics and treatment.

The aim of this current study is to investigate the accuracy and repeatability of a clinical tool based on a manual calculation method as described by Derks-Roskam and Derks [14] for simple rubber mat foot prints. In this method a set of pre-defined lines, points and angles are used to define foot geometry and calcaneal position. Two tangential lines are drawn, one to the medial side of the foot print and one to the lateral side. From these two lines a midline is calculated to define the length of the foot (LF) from the heel to the forefoot. On the LF line three

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orthogonal lines are determined: one at ½ LF for measurement of the width of the midfoot (WM), one at ¼ LF from the heel to measure calcaneal internal (IR) and external rotation (ER), and one at 3/8 LF from the heel. Where this line crosses the medial tangential line a diagonal line is drawn to the point ¼ LF from the heel. This line is used to define heel valgus/varus (HV). Heel length (HL) is measured as the distance from the rear of the heel to the point where the medial border of the footprint crosses the midline LF. The width of the foot (WF) is measured from the lateral to the medial tangential point of the forefoot.

These measures help to define the position of high pressure areas under the foot. From these measures corrective or sensorimotor insoles may be produced to unload high pressure areas under the foot and normalise foot function.

2. Materials and methods

Twenty-five healthy volunteers were recruited for the study. Subjects were excluded if they had previously experienced musculoskeletal pain or gait abnormalities. The mean age of the group was 32.0 years (± 12.4 years). Of the 25 subjects, 23 were female and two were male. Three measurements were taken from each foot on four occasions: on the first day (T1), at seven-day (T2), at six-week (T3) and at three-month interval (T4). An additional set of three measurements was taken six months later (T5) from 20 of the 25 originally recruited subjects (age 32.9 ± 11.1; 19 female and 1 male).

Measurements were taken by means of the PedoPrint® (Bauerfeind GmbH, Germany) semi-quantitative pressure measurement system. The PedoPrint® rubber mat was covered with blue ink on the underside and placed on top of a sheet of blank paper such that a subject walking over the rubber mat would leave a footprint on the paper. The PedoPrint® system was mounted level into a carpet walkway as shown in Fig. 1. Firstly, one left and one right foot print were taken. Subsequently, three foot prints were taken from each side. Subjects were allowed sufficient time to adapt themselves to the walkway. A mid-gait analysis (third step) was used to resemble normal walking.

The footprints obtained from the different measurements were manually analysed by an independent researcher according to the guidelines of the Derks Calculation Method [8]. The data was normally distributed. Values were calculated for internal (IR) and external rotation (ER) of the heel, heel valgus/varus (HV; positive values resemble heel valgus, negative values resemble heel varus), heel length (HL), heel width (HW), width of the midfoot (WM) and the forefoot (WF), and the length of the foot (LF) as shown in Fig. 2.

The collected data was analysed using SPSS® 13.0 (SPSS Inc., Chicago) program. Plausibly normal data was summarised and presented in the format mean (SD (standard deviation)). The SD reflects the within-subject and between-subject variations as well as trial-to-trial differences and variation of the calculation method. Repeated

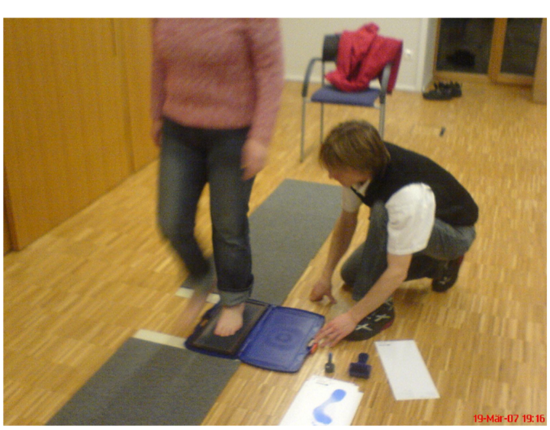

Fig. 1. PedoPrint® system mounted along carpet walkway.

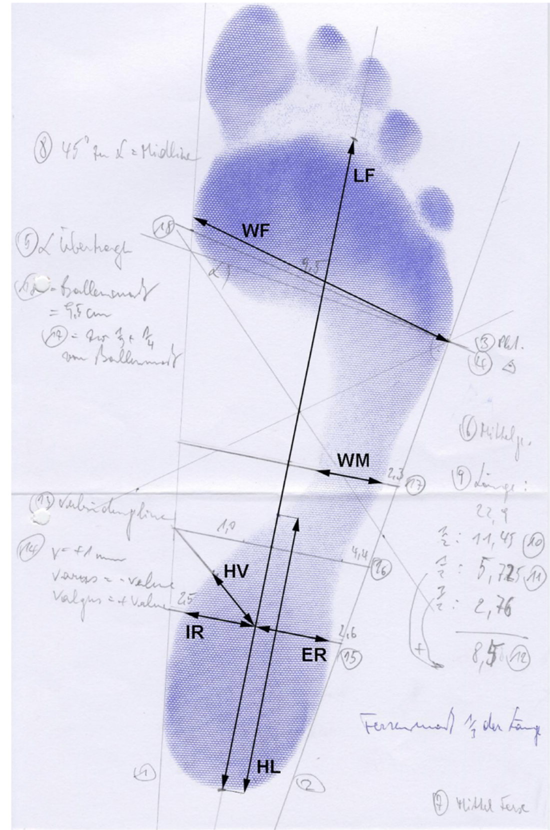

Fig. 2. Calculation of variables for foot geometry: length of the foot (LF), forefoot width (WF), width of the midfoot (WM), heel length (HL), heel width (HW), heel varus/valgus (HV), and internal (IR) and external rotation of the heel (ER).

measures analysis of variance (ANOVA) was used to investigate the variability of pressures measured during 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 [15]. The CR was expressed as a percentage of the mean by using the formula [(coefficient of repeatability)/mean] × 100 [15], i.e., the lower the CR the stronger the repeatability. Plantar pressure measurements during able-bodied gait analysis showed differences between the two lower limbs. These dynamic asymmetries were the result of a natural functional organisation of the supports differentiating a loading foot and a propulsive foot [16]. Therefore, repeatability was investigated for the left and right foot separately and the mean CR determined.

3. Results

For all five different occasions in 87.5% of the parameters investigated (seven of eight parameters on each occasion or 35 of 40 parameters on five different occasions) the CR (expressed as a percentage of the mean) was less than 5%. One parameter showed a higher CR: heel valgus/varus was extremely high for T1-T2 (812.8), T2-T2 (737.4), T2-T3 (120.8), T2-T4 (120.1), and T2-T5 (510.3). Table 1 shows the mean values and standard deviation for the different parameters and the different measurement days.

Mean values for the different parameters were consistent for T1-T2, T2-T2, T2-T3, T2-T4, and T2-T5 with values of 2.1 and 2.2 cm for IR, 2.4 and 2.5 cm for ER, 0.0 and 0.1 cm for HV, 8.6 to −8.9 cm for HL, 3.1 and 3.3 cm for HW, 2.6 and 2.7 cm for WM, 8.8 and 9.0 cm for WF,

Table 1
Mean, standard deviation (SD) and coefficient of repeatability (CR) for internal (IR) and external rotation of the heel (ER), heel varus/valgus (HV), heel length (HL), heel width (HW), width of the midfoot (WM), forefoot width (WF), and the length of the foot (LF) for different measurement days: day one (T1), 7 days later (T2), 6 weeks later (T3), 3 months later (T4), and 9 months later (T5).

Para-meter	T1-T2		T2-T2		T2-T3		T2-T4		T2-T5	
(cm)	Mean (SD)	CR[a]	Mean (SD)	CR	Mean (SD)	CR	Mean (SD)	CR	Mean (SD)	CR
IR	2.1 (0.3)	1.1	2.1 (0.3)	1.9	2.2 (0.3)	1.9	2.1 (0.3)	0.5	2.1 (0.3)	0.9
ER	2.5 (0.3)	3.4	2.4 (0.3)	1.3	2.4 (0.3)	1.3	2.4 (0.3)	1.1	2.4 (0.3)	2.2
HV	0.0 (0.4)	812.8	0.0 (0.4)	737.4	0.1 (0.4)	120.8	0.0 (0.4)	120.1	0.0 (0.4)	510.3
HL	8.6 (1.3)	3.8	8.7 (1.4)	1.1	8.9 (1.4)	1.1	8.7 (1.4)	1.8	8.6 (1.3)	1.3
HW	3.1 (1.1)	1.8	3.1 (1.1)	4.7	3.3 (1.1)	4.4	3.1 (1.1)	1.3	3.1 (1.1)	2.5
WM	2.6 (1.4)	4.1	2.6 (1.0)	0.1	2.7 (1.0)	0.1	2.6 (1.0)	2.9	2.6 (1.0)	3.4
WF	9.0 (0.6)	0.8	9.0 (0.6)	0.3	9.0 (0.6)	0.3	9.0 (0.7)	0.2	8.8 (0.6)	1.0
LF	20.1 (1.1)	0.6	20.1 (1.1)	0.8	20.3 (1.1)	0.8	20.1 (1.1)	0.4	20.0 (1.1)	0.0

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

and 20.0–20.3 cm for LF.

Standard deviation values were also consistent for T1-T2, T2-T2, T2-T3, T2-T4, and T2-T5 and show high accuracy with values between 0.3 and 0.4 cm for IR, ER, and HV. SD values for WF were shown to be 0.6 or 0.7 cm, the mean SD for LF was 1.1 cm, values for WM were 1.0 cm apart from T1-T2 with a mean SD of 1.4 cm, and values for HL were 1.3 or 1.4 cm.

The maximum 95% Confidence Interval (CI) for the five different occasions was no higher than 0.2 cm for IR, ER and HV with a standard error (SE) of 0.01 and > 0.01 respectively. The maximum 95% CI for WF was 0.4 cm (SE 0.1), and for HW, WM and LF the maximum 95% CI was 0.7 cm (SE 0.1 or 0.2). HL showed the highest 95% CI (0.9 cm) with an SE of 0.2 as shown in Table 2.

4. Discussion

While Giacomozzi [17] called for standardisation of methodology in foot pressure measurements, abbreviated gait protocols are often employed in plantar pressure studies [18]. One-step and two-step protocols are less time consuming [19] but produce longer contact times [18–20]. Giacomozzi [17] reported that one-step measurements gave pressures which were 7–10% less than mid-gait measurements. Meyers-Rice et al. [21] summarised, that a two-step method, in comparison with a one-step protocol, provided closer representative pressure data. Although other authors found that peak pressures measured with different protocols are comparable [18–20,21] one-step and two-step protocols do not resemble normal walking [19] due to changes in contact timing. In this current study a mid-gait protocol was applied [22]. 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. [19] stated that a minimum of three measurements were sufficient to obtain a consistent average, McPoil et al. [23] found that three to five walking trials are needed to obtain reliable regional peak pressure and pressure-time integral values. Keijsers et al. [24] discussed the need for an average of 3.8 steps for an intra-class correlation coefficient of 0.85. As such, three measurements were taken from each foot in the present study.

All feet measured in this study were found to show pronation/supination within a well acceptable range. Thirty-five feet (70%) showed relatively low longitudinal arch with an increased mean WM of 1 ± 0.69 cm which would be interpreted as a pronator foot (0 value represents a normal longitudinal arch, positive values define arch height reduction, negative values define increased arch height). Three feet (6%) showed normal WM (equals 1/3 of the distance between the tangential lines between forefoot and hindfoot) with a minor increased mean WM of 0.02 ± 0.01 cm. Twelve feet (24%) showed a reduced mean WM of −0.66 ± 0.54 cm which would be interpreted as relatively high instep or supinated foot. HV values for the same sample of feet showed a heel valgus position in 58.1%, varus position in 37.3%, and neutral position in 4.6% of feet.

The first aim of this study was to assess the repeatability of the Derks Calculation Method using the coefficient of repeatability. From the eight geometric parameters assessed on five different occasions, the highest CR was 812.8%, observed for HV. The majority of parameters (seven of eight, 87.5%) showed a CR less than 5%, whereas Putti et al. [6] reported that 91% of all parameters (111 of 122) had a CR less than 10% for an electronic foot pressure measurement system. Since no two foot steps are identical due to sway during gait in a normal subject [25] CR values as high as 20% are clinically acceptable [6], which suggests that the Derks Calculation Method is repeatable if the values for HV are

Table 2
95% Confidence Intervals (CI, Lower Bound (lower) and Upper Bound (upper)) and standard error (S.E.) for internal (IR) and external rotation of the heel (ER), heel varus/valgus (HV), heel length (HL), heel width (HW), width of the midfoot (WM) and the forefoot (WF), and the length of the foot (LF) for different measurement days: day one (T1), 7 days later (T2), 6 weeks later (T3), 3 months later (T4), and 9 months later (T5).

Para-meter	T1-T2			T2-T2			T2-T3			T2-T4			T2-T5		
(cm)	95% CI		S.E.	95% CI		S.E.	95% CI		S.E.	95% CI		S.E.	95% CI		S.E.
	lower	upper		lower	upper		lower	upper		lower	upper		lower	upper	
IR	2.0	2.2	> 0.1	2.0	2.2	> 0.1	2.1	2.2	> 0.1	2.0	2.2	> 0.1	2.0	2.1	> 0.1
ER	2.4	2.6	0.1	2.4	2.5	> 0.1	2.4	2.5	> 0.1	2.3	2.5	> 0.1	2.3	2.4	> 0.1
HV	−0.1	0.1	0.0	−0.1	0.1	> 0.1	0.0	0.2	> 0.1	−0.1	0.1	0.1	−0.1	0.1	> 0.1
HL	8.2	9.0	0.2	8.3	9.1	0.2	8.5	9.3	0.2	8.3	9.2	0.2	8.2	9.0	0.2
HW	2.8	3.4	0.2	2.8	3.4	0.2	2.9	3.6	0.2	2.8	3.5	0.2	2.8	3.4	0.1
WM	2.2	2.9	0.2	2.3	2.9	0.1	2.3	3.0	0.1	2.3	2.9	0.1	2.3	2.8	0.1
WF	8.8	9.2	0.1	8.8	9.2	0.1	8.8	9.2	0.1	8.8	9.2	0.1	8.7	9.0	0.1
LF	19.7	20.4	0.2	19.8	20.5	0.2	19.9	20.7	0.2	19.8	20.5	0.2	19.7	20.3	0.1

excluded.

The second aim of our study was to assess the accuracy of this calculation method. IR, ER and HV showed very small confidence intervals of 0.2 cm with a SE of 0.1 or less at a 95% level. The high confidence of a small SE for HV (> 0.01) was in direct contrast with the high CR values for all occasions, suggesting that HV values vary in a small range of 0.2 cm only (SD). However, variability of HV values seemed to be remarkable. This may well be due to pronatory adaptation of the subtalar joint during walking as part of the musculoskeletal suspension system and natural medial/lateral deviation of the body during gait.

Clinically, an SD of ± 0.4 cm is relevant while the maximum accuracy of a pencil and ruler calculation may be expected at approximately 0.1 cm. Therefore, the lack of repeatability of HV values must be considered during planning of an intervention procedure. Ninety-five percent CI of 0.4 cm with a SE of 0.1 were found for WF, and 0.7 cm for HW, WM and LF (SE 0.1 or 0.2). HL showed the highest CI with 0.9 cm (SE 0.2), which may be adaptive to walking speed and/or suspensory function of the foot. HL represents the contact length of the heel bone in the sagittal plane. A smaller angle between the heel bone and the ground produces a lower instep while the heel leaves a longer blueprint mark on the paper. With increased walking speed the longitudinal arch of the foot will adapt with increasing deformation as part of its suspensor function.

5. Conclusion

The Derks Calculation Method was found to be accurate and repeatable if HV was excluded, which renders this method a viable clinical tool in settings where sophisticated computerised systems are still unavailable.

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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