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Published in:
Clinical biomechanics (Bristol, Avon)

DOI:
10.1016/j.clinbiomech.2019.11.013

Published: 01/02/2020

Document Version
Publisher's PDF, also known as Version of record

Citation for pulished version (APA):
Sanders, F. R. K., Peters, J. J., Schallig, W., Mittlmeier, T., & Schepers, T. (2020). What is the added value of pedobarography for assessing functional outcome of displaced intra-articular calcaneal fractures? A systematic review of existing literature. *Clinical biomechanics (Bristol, Avon)*, *72*, 8-15. https://doi.org/10.1016/j.clinbiomech.2019.11.013

Clinical Biomechanics 72 (2020) 8–15

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Review

What is the added value of pedobarography for assessing functional outcome of displaced intra-articular calcaneal fractures? A systematic review of existing literature

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ARTICLE INFO

Keywords:
Intra-articular calcaneal fractures
Pedobarography
Plantar pressure
Functional outcome

ABSTRACT

Background: Displaced intra-articular calcaneal fractures often result in permanent disability, reduced quality of life and high socio-economic costs. Since they often result in a change in geometry of the foot, pedobarography may be useful in predicting outcome at an early stage. The aim of this study was to examine whether a correlation exists between pedobarography and functional outcomes in patients with a displaced intra-articular fracture.
Methods: In this systematic review, studies were included when they investigated the correlation between pedobarography and functional outcome in displaced intra-articular calcaneal fractures. Excluded were studies on < 10 patients or on animals/cadavers. Collected were baseline patient/treatment characteristics, pedobarographic data (peak pressures, maximum force and centre of pressure) and functional outcome scores.
Findings: Out of 153 abstracts, 40 remained for full text screening and 9 were included. Pedobarographic measurements (pressure plate or insoles) showed a lateralization of centre of pressure, decreased pressures underneath the hindfoot, first and second toe and increased pressure underneath the midfoot and forefoot. Correlations with functional outcome were found in some combined pedobarographic results (entire foot/multiple measurements), but hardly in pressures underneath specific foot areas.
Interpretation: Even though increased or decreased pressures in specific areas of the foot may not be directly related to functional outcome, combined scores often did. For pedobarography to serve as a prediction tool, it should be more standardised. However, assessing centre of pressure and altered peak pressures underneath the foot, may be useful in developing customized aids such as insoles, aiming for a more individualized improvement.

1. Introduction

Overall, calcaneal fractures comprise 1.2% of the total amount of fractures seen in inpatient or outpatient clinics (Court-Brown and Caesar, 2006), with an annual incidence of 9.6–10.5 per 100,000 for men and 3.8–3.9 per 100,000 for women (Haapasalo et al., 2017; Humphrey et al., 2019), of which more than half are displaced intra-articular calcaneal fractures (DIACFs) (Epstein et al., 2012; Griffin et al., 2014). DIACFs often result in permanent disability and reduction of quality of life, due to persistent pain, stiffness and gait abnormalities (Besch et al., 2008; Bozkurt et al., 2004; Hirschmüller et al., 2011; Öçgüder et al., 2012). Moreover, DIACFs are most often diagnosed in adults and adolescents, the most economically active population (Contreras et al., 2004). Therefore, these fractures and the accompanying difficulty to return to work are associated with high socio-economic costs (Albin et al., 2015). An unfavourable long-term outcome is strongly associated with malalignment of the hindfoot (Catani et al., 1999). In case of malalignment, collapse of the heel bone and restrictions in joint movement can result in changes in the plantar pressure and shortening of the extremity (Genc et al., 2016).

Traditionally, the evaluation of calcaneal fractures and determination of effect of treatment relies on three pillars, consisting of

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https://doi.org/10.1016/j.clinbiomech.2019.11.013
Received 24 June 2019; Accepted 19 November 2019

standardised questionnaires, physical examination and the use of radiographs in various projections. To predict long-term functional outcome at an early stage, an objective assessment of functional outcome, such as pedobarography, may be a valuable addition. Pedobarography is a measure that determines the loading pattern under the sole of the foot. It provides the distribution of the vertical component of the ground reaction force over the plantar surface of the foot (Giacomozzi et al., 2016). It is a relatively easy to use measure that does not require expensive equipment and a dedicated laboratory with a skilled staff as needed with a complete gait analysis, hence it is becoming a popular choice to asses dynamic foot function (Stebbins, 2016). The plantar pressure can be measured by using either in-shoe sensors or a pressure platform that is embedded in the floor (Abdul Razak et al., 2012). Pedobarography is used primarily in the management of diabetic feet (Gurney et al., 2017) and to evaluate surgical treatments in cerebral palsy and hallux valgus patients (Brodsky et al., 2006; Chang et al., 2002). It might also be a useful objective measure of functioning after DIACFs, since DIACFs often result in a change in plantar geometry of the foot (Besch et al., 2008).

To measure the subjective outcome of fractures of the lower extremity, multiple patient reported outcome measures (PROMs) have been described in literature. Often used for foot and ankle conditions are the Lower Extremity Functional Scale (LEFS) (Binkley et al., 1999) and the American Orthopaedic Foot & Ankle Society score (AOFAS) (Kitaoka et al., 1994), but many others exist. To analyse the value of pedobarography in predicting long term functional outcome, it is important to know whether or not it corresponds to PROMs. If known which outcomes of the pedobarography lead to a certain functional outcome score, patients could be provided early on with an individualized training program to improve functional outcome (Follak and Merk, 2003). Therefore, the aim of this study was to examine whether a correlation exists between pedobarography and functional outcomes in patients with DIACFs.

2. Methods

2.1. Screening and selection

In order to identify studies on pedobarography in patients with DIACFs a search was performed in MedLine (PubMed), EMBASE (Ovid) and the Cochrane Library on October 5th, 2018. A clinical librarian was consulted on the search strategy. The full search is presented in the Appendix, but included the following keywords: calcaneus, intra-

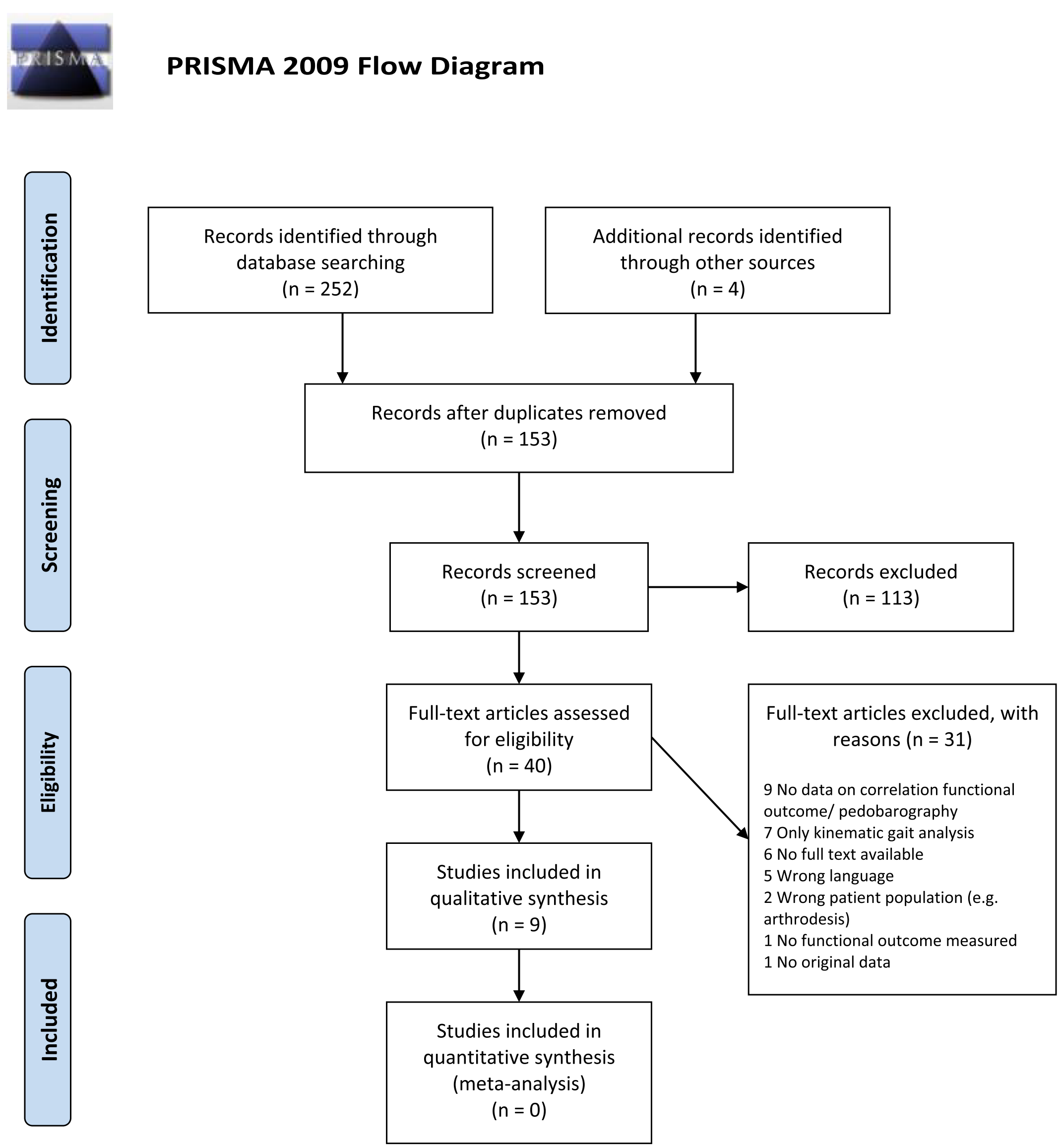

Fig. 1. PRISMA flow diagram.

Table 1
Baseline criteria of included studies.

Author	N	Subjects	Gender, N males (%)	Mean age (SD) [range][a]	Pedobarographic measurements	Foot areas	Mean FU time (SD) [range]	Control group	Functional outcome
Colak (2018)	36	Surgically treated (ORIF) DIACFs	34 (94.4%)	41.8 (10.3) [18–58]	Pressure plate: - Peak pressure - Maximum force	Hindfoot Midfoot Forefoot Toes	38 [13–82] months	Contralateral foot	AOFAS SF-36
Davies (2003)	12	Surgically treated (ORIF) DIACFs	9 (75%)	45.7 [18–60]	Pressure plate: - Peak pressure - COP	Heel Metatarsal head I Metatarsal head II Metatarsal head III Metatarsal head IV Metatarsal head V Hallux	45 [16–73] months	Contralateral foot	Score by Kerr et al. (1996)
Dudkiewicz (2002)	22	Surgically treated (ORIF) DIACFs	20 (90.9%)	35 [14–51]	Insole: - Footprint	Whole foot	[3–6] months	Contralateral foot + known normal control	AOFAS
Durr (2018)	65	Surgically treated (ORIF) DIACFs	50 (76.9%)	53.4 [23–77]	Pressure plate: - Peak pressure	Whole foot Hindfoot Midfoot Metatarsal head I Metatarsal head II Metatarsal head III-V First toe Second toe Lesser toes	97 [69–122] months	Contralateral foot	AOFAS SF-36 PCS Zwipp score
Hirschmuller (2011)	60	Surgically treated (ORIF) DIACFs	43 (71.7%)	46.4 (13.8)	Pressure plate: - Peak pressure - COP	Heel Midfoot Lateral forefoot Central forefoot Medial forefoot Great toe Second toe Other toes	49 (25) months	Contralateral foot	AOFAS SF-36 PCS SF-36 MCS
Kinner (2002)	20	Surgically treated (ORIF) DIACFs	18 (90%)	53 [26–71]	Insole: Combination score based on impact, contact, width, COP	Heel Forefoot	24 [12–36] months	Contralateral foot	MFS
Mittlmeier (1993)	45	Surgically treated (ORIF) DIACFs	62 (82.7%)[b]	36.1 [13–69][b]	Pressure plate: Performance score based on contact time, impulse, maximum pressure, COP	Hindfoot Midfoot Forefoot Toes	[18–50] months	Contralateral foot	Modified 18-points Merle d'Aubigne score
Rosenbaum (1995)	14	Conservative (5)/surgically (9) treated DIACFs	ND	47.1 (13.8)	Pressure plate: - Peak pressure	Central heel Medial heel Lateral heel Midfoot Metatarsal head I Metatarsal head II-III Metatarsal head V Hallux	52 [23–78] months	Contralateral foot +10 matched healthy subjects	Modified after Zwipp et al.
Schepers (2008)	21	Surgically treated (percutaneous distraction) DIACFs	14 (67%)	51, IQR: 46–55	Pressure plate: - Peak pressure - COP	Medial heel Lateral heel Metatarsal head I-V Hallux	18, IQR: 16–26 months	Contralateral foot	AOFAS MFS CN VAS

Abbreviations: AOFAS: American Orthopaedic Foot & Ankle Society score, CN: Creighton-Nebraska score, COP: centre of pressure line, FU: follow-up, DIACFs: displaced intra-articular calcaneal fractures, IQR: inter quartile range, MCS: Mental Component Score, MFS: Maryland Foot Score, N: number of included patients, ND: not described, ORIF: open reduction internal fixation, PCS: Physical Component Score, SD: standard deviation.

[a] At time of injury.
[b] Of total group (also excluded patients).

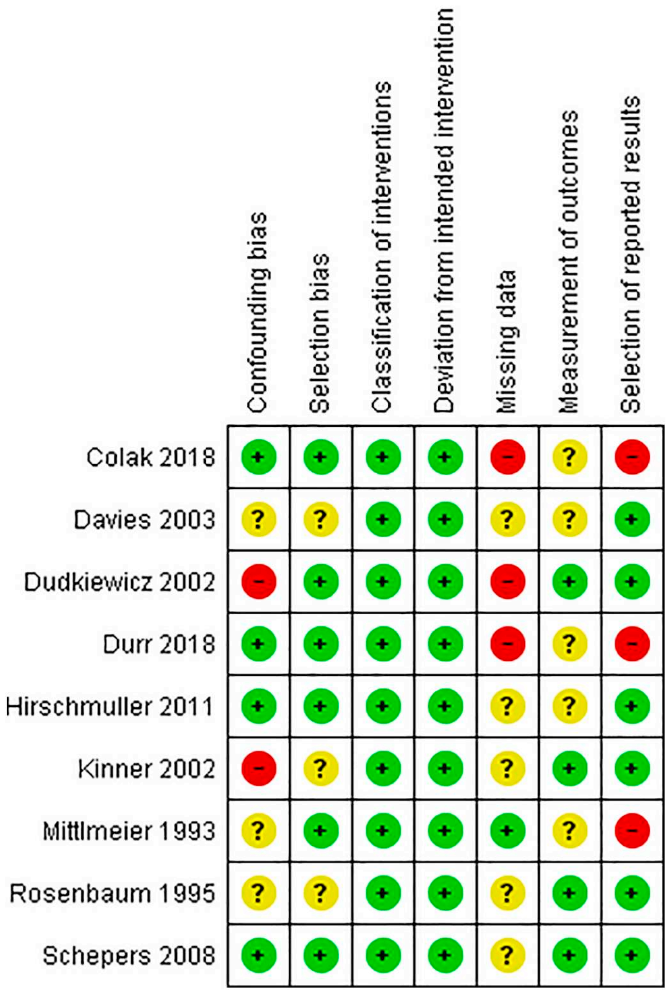

Fig. 2. Risk of bias assessment based on ROBINS-I tool.

articular, fracture, and pedobarography or gait analysis. In addition to the databases, reference lists were checked for additional articles. Two reviewers (FS and JP) independently screened the title and abstract of the articles found through the search mentioned above. Articles were considered potentially useful when they assessed pedobarography and functional outcomes in patients with DIACFs.

Eligible articles were then screened for inclusion based on full text by the same reviewers. Articles describing < 10 patients, not involving humans, not addressing the relationship between pedobarography and functional outcome, written in another language than English, Dutch, French or German or only consisting of an abstract, were excluded. No restrictions were posed on publication date. An overview of excluded studies is presented in the Appendix.

2.2. Data extraction

Data was extracted using a customized extraction sheet (based on the Cochrane data extraction template). One reviewer (JP) extracted the data and the other reviewer (FS) verified it. Duplicate publications were filtered out by juxtaposing author names and carefully reviewing study designs and treatment combinations. In case of multiple publications on one trial, all published information was combined to ensure comprehensiveness of data. We obtained the following patient, fracture and treatment characteristics: author, year of publication, number of patients, treatment, pedobarographic methods and performed measurements, controls, clinical scoring systems the correlation between clinical outcome and pedobarography. Pedobarographic measurements of our interest were peak pressure, maximum force and centre of pressure trajectory (COP). The peak pressure (N/cm^2) is the highest pressure measured underneath a predetermined foot area of interest during gait. Maximum force (N) is independent of area size and can also be expressed per foot area. The centre of pressure trajectory shows the movement over time of the point of application of the ground reaction force during gait.

2.3. Analysis of findings

We determined the most important results and conclusions of the studies regarding pedobarography and functional outcome and used this data to assess whether or not there was a correlation between these outcome measures. When possible, raw data was extracted from individual patients, in order to calculate possible correlations ourselves. In articles describing this correlation but not the underlying data, the methods used, correlation coefficient and p values were collected. When the correlation was only described but could not be quantified in any way, studies were excluded. Statistical tests used to calculate

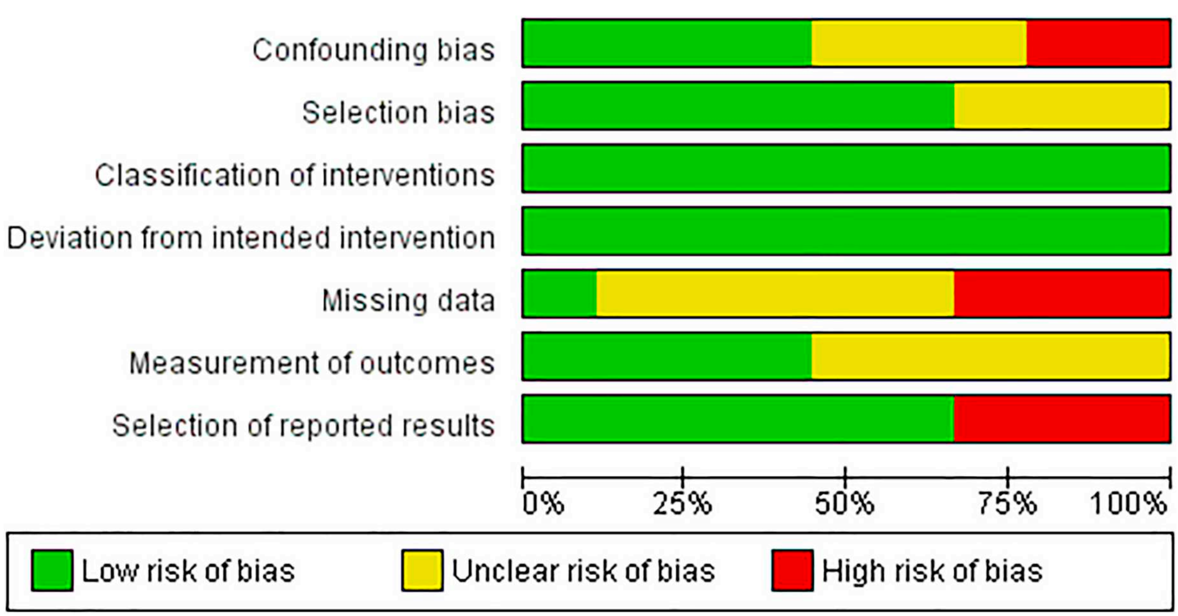

Fig. 3. Review authors' judgements about each risk of bias item presented as percentages across all included studies.

Table 2
Peak pressures per foot area and COP.

Foot area	Colak (2018)	Davies (2003)	Dudkiewicz (2002)[a]	Durr (2018)	Hirschmuller (2011)	Kinner (2002)	Mittlmeier (1993)[a]	Rosenbaum (1995)	Schepers (2008)
Whole foot	+		–	+				**-***	**-***
Hindfoot:	–	+		**-***	**-***	–			
								-[b]	=
- Medial								-[b]	
- Central								=	-
- Lateral									
Midfoot	**+***			**+***	**+***			**+***	
Forefoot:	**+***								
		+		-	+			**-***	**+***
- Medial		-		-	-			-[b]	+
- Central		+		**+***	**+***			**+***	+
- Lateral									
Toes:	–				=				
		+		**-***				-	-
- Hallux				**-***					
- 2nd toe				-					
- 3–5									
COP[c]		L			L	L		L	L

Peak pressures of the affected foot, compared to contralateral foot, where a + indicates higher pressure, a - lower pressure, a = comparable pressures and bold symbols with an * indicates a variable significantly differing from the contralateral foot.
Abbreviations: COP: centre of pressure trajectory, L: lateral.
[a] Individual parameters of performance score not described.
[b] Not significant compared to contralateral foot, but significantly lower compared to healthy controls.
[c] Not tested for statistical significance.

correlations were, depending on normality of the outcome, either a Pearson correlation (normal distribution) or a Spearman's rank correlation (non-normally distributed continuous or categorical data).

2.4. Risk of bias

All studies included were assessed for risk of bias with the ROBINS-I tool for non-randomized cohort studies of interventions (Appendix 3). Using this tool, bias was assessed on 7 domains, rating each one as “high”, “low” or “unknown” risk of bias. The 7 domains are bias based on: confounding, selection, classification of interventions, deviation of intended intervention, missing data, measurement of outcomes and selection of reported results. Potentially important confounders for this review that were used in this assessment were: previous foot injury, treatment of calcaneal fracture with arthrodesis or amputation, contralateral injury and comorbidity affecting gait or functional outcome. Studies excluding patients with these characteristics and comparing results to the contralateral (healthy) foot automatically received a low risk of bias on the first domain.

3. Results

3.1. General information

A total of 153 articles were screened for eligibility based on title and abstract, 40 remained for full text screening after which nine studies complied with the criteria and were therefore included for final analysis (Çolak et al., 2018; Davies et al., 2003; Dudkiewicz et al., 2002; Dürr et al., 2018; Hirschmüller et al., 2011; Kinner et al., 2002; Mittlmeier et al., 1993; Rosenbaum et al., 1995; Schepers et al., 2008) (Fig. 1). All were cohort studies including adult patients with surgically treated DIACFs and excluding patients with concomitant injuries that might affect pedobarography and/or functional outcome measurements. As shown in Table 1, varying functional outcome scores were used and pedobarographic measurements were performed using either a pressure plate or insoles, comparing results to those of the contralateral foot between 3 and 122 months after fracture treatment. A summary of the risk of bias analysis is shown in Figs. 2 and 3, complete results including author's justifications are featured in the Appendix. The most common causes of potential bias were insufficient characterisation of missing data and not reporting of or not correcting for confounders, and selection of reported data.

3.2. Pedobarography

Most studies measured peak pressure, COP and maximum force in different foot areas (Table 1). Table 2 shows the difference in peak pressures underneath the inflicted foot compared to the contralateral foot for each study. In general, pressures seemed to be lower under the inflicted foot (Rosenbaum et al., 1995; Schepers et al., 2008), although non-significantly higher pressures have also been described (Çolak et al., 2018; Dürr et al., 2018). When comparing specific areas of the foot, pressures underneath the hindfoot seemed to be decreased (Dürr et al., 2018; Hirschmüller et al., 2011), as well as underneath the first and second toe (Dürr et al., 2018). Increased peak pressures were found mainly underneath the midfoot (Çolak et al., 2018; Dürr et al., 2018; Hirschmüller et al., 2011; Rosenbaum et al., 1995) and forefoot (Çolak et al., 2018; Dürr et al., 2018; Hirschmüller et al., 2011; Rosenbaum et al., 1995; Schepers et al., 2008). Studies dividing the forefoot in medial, central and lateral areas all found that specifically the lateral side showed increased pressures (Dürr et al., 2018; Hirschmüller et al., 2011; Rosenbaum et al., 1995), while on the medial side both increased and decreased pressures have been described (Rosenbaum et al., 1995; Schepers et al., 2008).

Studies measuring the COP all described a shift of the COP to the lateral side of the inflicted foot (Davies et al., 2003; Hirschmüller et al., 2011; Kinner et al., 2002; Rosenbaum et al., 1995; Schepers et al., 2008).

Two studies have also measured the maximum force (Çolak et al., 2018; Kinner et al., 2002) and found a significantly higher maximum force underneath the midfoot (Çolak et al., 2018), forefoot (Çolak et al., 2018; Kinner et al., 2002) and toes (Çolak et al., 2018) in the injured foot and a non-significantly decreased maximum force underneath the total foot (Çolak et al., 2018) and hindfoot (Çolak et al., 2018; Kinner et al., 2002) compared to the healthy side.

3.3. Functional outcome & pedobarography

Four studies described a significant correlation between pedobarography and functional outcome scores as measured by PROMs

Table 3
Summary of findings (significant correlations in italic).

Author	Foot areas	Pedobarographic measurements	Functional outcome	Correlation	Statistical test	Correlation coefficient	p-Value
Colak (2018)	Hindfoot, midfoot, forefoot, toes	Maximum force Peak pressure	AOFAS SF-36 score	No	ND	ND	ND
Davies (2003)	MT5	Peak pressure	Kerr et al.	No	Pearson	ND	0.660
		COP		No			.28
Dudkiewicz (2002)[a]	*Whole foot*	*Footprint analysis*	*AOFAS*	*Yes*	Spearman's rank	*−0.551*	*0.005*
Durr (2018)	*Overall*[*]	*Plantar pressure*	*AOFAS*	*Yes*	Kruskal-Wallis	-	*0.003*
			SF-36 PCS	*Yes*		-	*0.015*
			FFI	*Yes*		-	*0.018*
			Zwipp	*Yes*		- –	*0.007*
	Midfoot	*Max. pressure*	*SF-36 pcs*	*Yes*	Spearman's rank	*0.269 –*	*< 0.05*
			Zwipp	*Yes*		*0.387*	*0.001*
	Hallux		*SF-36 pcs*	*Yes*		*0.291*	*< 0.05*
Hirschmuller (2011)	Hindfoot, midfoot, forefoot (L/C/M), toes	Pressure distribution	AOFAS SF-36 pcs SF-36 mcs	No	Spearman's rank	ND	ND
Kinner (2002)[a]	*Heel, sole*[**]	*Pedobarographic score*[**]	*MFS*	*Yes*	Spearman's rank	*−0.62*	*0.04*
Mittlmeier (1993)[a]	*Hindfoot, midfoot, forefoot, toes*	*Performance score*[†]	*Clinical score*[***]	*Yes*	Spearman's rank	*0.607*	*< 0.001*
Rosenbaum (1995)	Central heel	Peak pressure	Modified Zwipp[‡]	No	ND[¥]	0.21	> 0.05
	Medial heel			No		0.22	> 0.05
	Lateral heel			No		−0.38	> 0.05
	Midfoot			No		−0.08	> 0.05
	MT1			No		0.37	> 0.05
	MT2			*Yes*		*0.54*	*< 0.05*
	MT5			No		0.32	> 0.05
	Hallux			No		−0.38	> 0.05
Schepers (2008)	Medial heel	Peak pressure	AOFAS I MFS I CN I	No	Spearman's rank	0.05 I −0.04 I 0.00 I	> 0.05
	Lateral heel		VAS	No		−0.24	> 0.05
	MT1			No		0.06 I 0.05 I 0.15 I 0.19	> 0.05
	MT2			No		−0.16 I 0.01 I 0.06 I	> 0.05
	MT3			No		−0.23	> 0.05
	MT4			No		0.09 I 0.20 I 0.18 I	> 0.05
	MT5			No		−0.14	> 0.05
	Hallux			No		0.17 I 0.27 I 0.29 I 0.14	> 0.05
						0.42 I 0.28 I 0.41 I 0.49	
						0.11 I −0.06 I 0.14 I	
						0.25	
						0.41 I 0.38 I 0.52 I 0.35	

Abbreviations: AOFAS: American Orthopaedic Foot & Ankle Society score, CN: Creighton-Nebraska score, COP: centre of pressure line, DIACFs: displaced intra-articular calcaneal fractures, IQR: inter quartile range, MCS: Mental Component Score, MFS: Maryland Foot Score, N: number of included patients, ND: not described, PCS: Physical Component Score, SD: standard deviation.

[a] No correlation coefficient given, calculated with Spearman's rank based on given data.

[*] Functional outcome was compared between 3 groups based on a combined score (sum of the difference of all plantar pressure parameters between feet), comparing patients with a large, medium and small difference between injured and contralateral foot.

[**] Combination score based on impact, contact, width of heel and sole, gait line (COP) and multistep (8–32 points).

[***] Clinical score is based on pain (0–6), gait (0–6), tiptoe gait (0–2), heel gait (0–2), footwear (0–2) and divided in 4 groups: excellent (17–18), good (13–16), moderate (9–12) or poor (0–8).

[†] Performance score is based on contact time (0–4), normalized impulse (0–4), percentile distribution of vertical impulse (0–4), normalized maximum pressure (0–4), centre of pressure (COP) (0–4) and divided into 4 groups: excellent (5–7), good (8–12), moderate (13–17) or poor (18–20).

[‡] Clinical score based on subjective, objective and radiological evaluation of foot function and restoration, ranging from −200 to +200 points with the following grades: excellent (150–200 points), good (100–149 points), fair (25–99 points), poor (< 25 points).

[¥] Unspecified correlation analysis method. Authors mention that for the given number of subjects (i.e. 12 degrees of freedom) a correlation coefficient r 3 0.53 is significant at the 5% level for two-tailed tests.

(Dudkiewicz et al., 2002; Dürr et al., 2018; Kinner et al., 2002; Mittlmeier et al., 1993) (Table 3). All of these studies combined the pedobarographic results of the entire foot or used a performance score incorporating multiple aspects of a kinetic gait analysis (e.g. contact time, vertical impulse, maximum pressure, maximum force, COP). Studies investigating the correlation of functional outcome with area specific peak pressures mostly did not identify a significant correlation (Çolak et al., 2018; Davies et al., 2003; Rosenbaum et al., 1995; Schepers et al., 2008) (Table 3). Rosenbaum et al. found that, of all measured areas, only peak pressures of MT2 had a correlation with functional outcome measured by a modified Zwipp score (Rosenbaum et al., 1995). Durr et al. found a relationship between the maximum pressure in the midfoot and hallux and the SF-36 and Zwipp score (Dürr et al., 2018).

The AOFAS was the most commonly used functional outcome score, followed by the SF-36. Only Dudkiewicz et al. and Durr et al. found correlations between these outcome scores and pedobarography (Dudkiewicz et al., 2002; Dürr et al., 2018), other studies did not (Çolak et al., 2018; Hirschmüller et al., 2011; Schepers et al., 2008). The type of functional outcome score did not seemed to be related to whether or not there was a correlation with pedobarographic results.

4. Discussion

4.1. Summary and comparison to previous literature

As this study confirms, the pressure distribution underneath the foot after a DIACF is markedly changed. This study showed that overall, after a DIACF, the COP shifts to lateral and that, compared to the healthy side, peak pressures were higher underneath the midfoot and forefoot and decreased underneath the hindfoot and toes. These results were largely comparable with previous studies on this subject (Besch et al., 2008; Hetsroni et al., 2014; Jansen et al., 2013). Moreover, this review showed that some performance scores combining pedobarographic results of the entire foot had a correlation with functional outcome, however peak pressures of individual foot areas were usually not related to functional outcome scores. Although previous evidence on the correlation between pedobarography and functional outcome is limited, some studies on other foot injuries have found similar results, where direct correlations between pedobarography and functional outcome could also not been identified. Schepers et al. previously performed pedobarographic measurements in 26 patients with a Lisfranc fracture dislocation and did not find a correlation with functional outcome or quality of life (AOFAS and SF-36) (Schepers et al., 2010). Also in patients operated on a hallux valgus (N = 32) peak pressures could not be correlated to functional outcome as measured by the AOFAS (Lorei et al., 2006). However, the number of included patients in both studies was small, potentially causing a lack of power. Van Hoeve et al. did find a correlation in calcaneal fractures between functional outcome and range of motion between hindfoot and tibia in the push off phase, measured with kinematic gait analysis (Van Hoeve et al., 2014). Rammelt et al. used pedobarography to evaluate results of subtalar arthrodesis after malunited calcaneal fractures and found that AOFAS score and pressure-time integral of the whole foot had a positive correlation (Rammelt et al., 2004).

4.2. Limitations

A few limitations can be pointed out for this review, mostly due to the large variation in methods between the included studies. First of all, pedobarographic measurements were performed using a pressure plate or in-shoe sensors in either patients' own shoes or in standardised shoes. Because each of these devices has a different way of measuring and reporting results, the variation between studies was large, making it difficult to compare pedobarographic outcome measures. Secondly, there is no standardised way of dividing the foot into areas of interest, making it hard to compare peak pressures of specific areas. Thirdly, measurements were performed at a wide range of time points (3–122 months after fracture treatment). Consequently, a confounding effect of fracture healing on the outcome measures is likely, since an improvement in functional outcome and walking pattern are still expected 3 months after surgery. Finally, since there is no specific functional outcome score for calcaneal fractures, many different scoring systems were used to assess functional outcome. Because of these variations pooling of the results was unfortunately not possible. Moreover, we had no control in how the original data was collected. We have tried to make the reliability of the results of the individual studies transparent by performing a risk of bias analysis. However, as this risk of bias assessment is partly subjective, it is subjective to a risk of bias on its own. By including support of judgement for each study on each ROBINS-1 item in the Appendix, we have tried to make these subjective items more insightful.

4.3. Conclusions and implications for clinical practice

Despite limitations this study is, to the best of our knowledge, the only systematic review on the correlation of pedobarography and functional outcome in the lower extremity. By providing an overview of performed studies on DIACFs, some valuable insights in the clinical relevance of pedobarography are given. The most important question might be how pedobarography can contribute to improving outcome and quality of life for these patients. Even though increased or decreased pressures in specific areas of the foot may not be directly related to functional outcome scores, this study showed that a combined score of pedobarographic results often did. To serve as a prediction tool, it should be more standardised to be of use. However, instead of using pedobarography for prediction of outcome, it may be applicable in early interventions such as the development of medical aids (Genc et al., 2016). Combining the COP and the different peak pressures underneath the foot, these results could be used for customized aids such as insoles, thereby aiming for a more individualized improvement.

Declaration of competing interest

The authors declare that they have no conflict of interest. None of the authors have been paid or sponsored in the process of writing this review.

Acknowledgements

The authors would like to thank Faridi S. van Etten – Jamaludin, clinical librarian for her assistance with the literature search.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clinbiomech.2019.11.013.

References

Abdul Razak, A.H., Zayegh, A., Begg, R.K., Wahab, Y., 2012. Foot plantar pressure measurement system: a review. Sensors (Switzerland) 12, 9884–9912. https://doi.org/10.3390/s120709884.

Albin, S.R., Cornwall, M.W., McPoil, T.G., Van Boerum, D.H., Morgan, J.M., 2015. Plantar pressure and gait symmetry in individuals with fractures versus tendon injuries to the hindfoot. J. Am. Podiatr. Med. Assoc. 105, 469–477. https://doi.org/10.7547/14-073.1.

Besch, L., Radke, B., Mueller, M., Daniels-Wredenhagen, M., Varoga, D., Hilgert, R.E., Mathiak, G., Oehlert, K., Seekamp, A., 2008. Dynamic and functional gait analysis of severely displaced intra-articular calcaneus fractures treated with a hinged external fixator or internal stabilization. J. Foot Ankle Surg. 47, 19–25. https://doi.org/10.1053/j.jfas.2007.10.013.

Binkley, J.M., Stratford, P.W., Lott, S. a, Riddle, D.L., 1999. The Lower Extremity Functional Scale (LEFS): scale development, measurement properties, and clinical application. Phys. Ther. 79, 371–383. https://doi.org/10.1097/00005650-198903001-00007.

Bozkurt, M., Kentel, B.B., Yavuzer, G., Öçgüder, A., Heycan, C., Tonuk, E., 2004. Functional evaluation of intraarticular severely comminuted fractures of the calcaneus with gait analysis. J. Foot Ankle Surg. 43, 374–379. https://doi.org/10.1053/j.jfas.2004.09.006.

Brodsky, J.W., Beischer, A.D., Robinson, A.H.N., Westra, S., Negrine, J.P., Shabat, S., 2006. Surgery for hallux valgus with proximal crescentic osteotomy causes variable postoperative pressure patterns. Clin. Orthop. Relat. Res. 280–286. https://doi.org/10.1097/01.blo.0000191269.50033.ec.

Catani, F., Benedetti, M.G., Simoncini, L., Leardini, A., Giannini, S., 1999. Analysis of function after intra-articular fracture of the os calcis. Foot Ankle Int 20, 417–421. https://doi.org/10.1177/107110079902000704.

Chang, C.H., Albarracin, J.P., Lipton, G.E., Miller, F., 2002. Long-term follow-up of surgery for equinovarus foot deformity in children with cerebral palsy. J. Pediatr. Orthop. 22, 792–799. https://doi.org/10.1097/00004694-200211000-00020.

Çolak, İ., Çolak, T.K., Polat, M.G., Timurtaş, E., Bulut, G., Gülabi, D., 2018. The results of physical, radiologic, pedabarographic, and quality-of-life assessments in patients with surgically treated intraarticular calcaneus fractures. J. Foot Ankle Surg. 57, 1172–1180. https://doi.org/10.1053/j.jfas.2018.06.009.

Contreras, M.E.K., De Souza Muniz, A.M., De Souza, J.B., Avila, A.O.V., Borges Junior, N.G., Barbosa, D.R.F., Kroth, L.M.M., Dos Reis Filho, M., 2004. Biomechanical evaluation of intra articular calcaneal fracture and clinical radiographic correlation. Acta Ortop. Bras. 12, 105–112.

Court-Brown, C.M., Caesar, B., 2006. Epidemiology of adult fractures: a review. Injury 37, 691–697. https://doi.org/10.1016/j.injury.2006.04.130.

Davies, M.B., Betts, R.P., Scott, I.R., 2003. Optical plantar pressure analysis following internal fixation for displaced intra-articular os calcis fractures. Foot ankle Int./Am. Orthop. Foot Ankle Soc. [and] Swiss Foot Ankle Soc. 24, 851–856.

Dudkiewicz, I., Levi, R., Blankstein, A., Chechick, A., Salai, M., 2002. Dynamic footprints: adjuvant method for postoperative assessment of patients after calcaneal fractures.

Isr. Med. Assoc. J. 4, 349–352.

Dürr, C., Apinun, J., Mittlmeier, T., Rammelt, S., 2018. Foot function after surgically treated intraarticular calcaneal fractures: correlation of clinical and pedobarographic results of 65 patients followed for 8 years. J. Orthop. Trauma 32, 593–600. https://doi.org/10.1097/BOT.0000000000001325.

Epstein, N., Chandran, S., Chou, L., 2012. Current concepts review: intra-articular fractures of the calcaneus. Foot Ankle Int 33, 79–86. https://doi.org/10.3113/FAI.2012.0079.

Follak, N., Merk, H., 2003. The benefit of gait analysis in functional diagnostics in the rehabilitation of patients after operative treatment of calcaneal fractures. Foot Ankle Surg 9, 209–214. https://doi.org/10.1016/S1268-7731(03)00092-4.

Genc, Y., Gultekin, A., Duymus, T.M., Mutlu, S., Mutlu, H., Komur, B., 2016. Pedobarography in the assessment of postoperative calcaneal fracture pressure with gait. J. Foot Ankle Surg. 55, 99–105. https://doi.org/10.1053/j.jfas.2015.07.018.

Giacomozzi, C., Caravaggi, P., Stebbins, J.A., Leardini, A., 2016. Integration of foot pressure and foot kinematics measurements for medical applications. In: Handbook of Human Motion, pp. 1–22. https://doi.org/10.1007/978-3-319-30808-1_186-1.

Griffin, D., Parsons, N., Shaw, E., Kulikov, Y., Hutchinson, C., Thorogood, M., Lamb, S.E., 2014. Operative versus non-operative treatment for closed, displaced, intra-articular fractures of the calcaneus: randomised controlled trial. BMJ 349, g4483. https://doi.org/10.1136/bmj.g4483.

Gurney, J.K., Kersting, U.G., Rosenbaum, D., Dissanayake, A., York, S., Grech, R., Ng, A., Milne, B., Stanley, J., Sarfati, D., 2017. Pedobarography as a clinical tool in the management of diabetic feet in New Zealand: a feasibility study. J. Foot Ankle Res. 10. https://doi.org/10.1186/s13047-017-0205-6.

Haapasalo, H., Laine, H.J., Mäenpää, H., Wretenberg, P., Kannus, P., Mattila, V.M., 2017. Epidemiology of calcaneal fractures in Finland. Foot Ankle Surg 23, 321–324. https://doi.org/10.1016/j.fas.2016.10.004.

Hetsroni, I., Ben-Sira, D., Nyska, M., Ayalon, M., 2014. Plantar pressure anomalies after open reduction with internal fixation of high-grade calcaneal fractures. Foot Ankle Int 35, 712–718. https://doi.org/10.1177/1071100714531226.

Hirschmüller, A., Konstantinidis, L., Baur, H., Müller, S., Mehlhorn, A., Kontermann, J., Grosse, U., Südkamp, N.P., Helwig, P., 2011. Do changes in dynamic plantar pressure distribution, strength capacity and postural control after intra-articular calcaneal fracture correlate with clinical and radiological outcome? Injury 42, 1135–1143. https://doi.org/10.1016/j.injury.2010.09.040.

Humphrey, J.A., Woods, A., Robinson, A.H.N., 2019. The epidemiology and trends in the surgical management of calcaneal fractures in England between 2000 and 2017. Bone Jt. J. 101B, 140–146. https://doi.org/10.1302/0301-620X.101B2.BJJ-2018-0289.

Jansen, H., Frey, S.P., Ziegler, C., Meffert, R.H., Doht, S., 2013. Results of dynamic pedobarography following surgically treated intra-articular calcaneal fractures. Arch. Orthop. Trauma Surg. 133, 259–265. https://doi.org/10.1007/s00402-012-1655-8.

Kerr, P.S., Prothero, D.L., Atkins, R.M., 1996. Assessing outcome following calcaneal fracture: a rational scoring system. Injury 27, 35–38. https://doi.org/10.1016/0020-1383(95)00165-4.

Kinner, B.J., Best, R., Falk, K., Thon, K.-P., 2002. Is there a reliable outcome measurement for displaced intra-articular calcaneal fractures? J. Trauma 53, 1094–1101. discussion 1102. https://doi.org/10.1097/01.TA.0000025790.13092.65.

Kitaoka, H.B., Alexander, I.J., Adelaar, R.S., Nunley, J.A., Myerson, M.S., Sanders, M., 1994. Clinical rating system for the ankle hindfoot midfoot hallux and lesser toes. Foot Ankle Int 15, 349–353. https://doi.org/10.1177/107110079701800315.

Lorei, T.J., Kinast, C., Klärner, H., Rosenbaum, D., 2006. Pedographic, clinical, and functional outcome after scarf osteotomy. Clin. Orthop. Relat. Res. 161–166. https://doi.org/10.1097/01.blo.0000229297.29345.09.

Mittlmeier, T., Morlock, M.M., Hertlein, H., Fässler, M., Mutschler, W., Bauer, G., Lob, G., 1993. Analysis of morphology and gait function after intraarticular calcaneal fracture. J. Orthop. Trauma 7, 303–310. https://doi.org/10.1097/00005131-199308000-00002.

Öçgüder, A., Gök, H., Heycan, C., Tecimel, O., Tönük, E., Bozkurt, M., 2012. Effects of custom-made insole on gait pattern of patients with unilateral displaced intra-articular calcaneal fracture: evaluation with computerized gait analysis. Acta Orthop. Traumatol. Turc. 46, 1–7. https://doi.org/10.3944/AOTT.2012.2401.

Rammelt, S., Grass, R., Zawadski, T., Biewener, A., Zwipp, H., 2004. Foot function after subtalar distraction boneblock arthrodesis. A prospective study. J. Bone Jt. Surg. - Ser. B 86, 659–668. https://doi.org/10.1302/0301-620X.86B5.14205.

Rosenbaum, D., Lübke, B., Bauer, G., Claes, L., 1995. Long-term effects of hindfoot fractures evaluated by means of plantar pressure analyses. Clin. Biomech. 10, 345–351. https://doi.org/10.1016/0268-0033(94)00004-Q.

Schepers, T., Van der Stoep, A., Van der Avert, H., Van Lieshout, E.M.M., Patka, P., 2008. Plantar pressure analysis after percutaneous repair of displaced intra-articular calcaneal fractures. Foot Ankle 29, 128–135 https: //doi.org/965223 [pii]\r10.3113/FAI. 2008.0128 [doi].

Schepers, T., Kieboom, B., Van Diggele, P., Patka, P., Van Lieshout, E.M.M., 2010. Pedobarographic analysis and quality of life after lisfranc fracture dislocation. Foot Ankle Int 31, 857–864. https://doi.org/10.3113/FAI.2010.0857.

Stebbins, J., 2016. Assessing clubfoot and cerebral palsy by Pedobarography. In: Handbook of Human Motion, pp. 1–13. https://doi.org/10.1007/978-3-319-30808-1_37-1.

Van Hoeve, S., De Vos, J., Verbruggen, J.P.A.M., Willems, P., Meijer, K., Poeze, M., 2014. Gait analysis and functional outcome after calcaneal fracture. J. Bone Jt. Surg. - Am 97, 1879–1888. https://doi.org/10.2106/JBJS.N.01279.