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Correlations between the Gait Profile Score and standard clinical outcome measures in children with idiopathic clubfoot

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ABSTRACT

Background: Measures of overall gait deviations such as the Gait Profile Score (GPS) and the Gait Variable Score (GVS) are used to evaluate gait in clinical practice and for research purposes. In the clinical setting, gait deviations are often visually assessed and classified using structured protocols such as the Clubfoot Assessment Protocol (CAP).

Research question: Determine the relationship between measures of overall gait deviations and clinical assessments.

Methods: This cross-sectional study evaluated the usability of GPS and GVS in children with idiopathic clubfoot. Twenty consecutively born children with idiopathic clubfoot participated in this study. At 7 years of age, the children were referred for three-dimensional gait analysis and, on the same day, they also underwent a clinical examination according to the CAP.

Results: The overall gait deviations, expressed as the GPS (overall and affected side) and the GVS for nine key variables were calculated. The correlations between the GPS and values from CAP, its domains, and a single item called walking and between the item walking and the GVS values were analyzed using the Spearman's rank correlation coefficient (r_s). The item walking correlated significantly with the GPS (r_s = –0.62), and the GVS for foot progression (r_s = –0.61) and foot dorsiflexion/plantarflexion (r_s = –0.50). The domain "morphology" correlated with the GPS (r_s = 0.64).

Significance: These findings indicate that the GPS index along with the GVS reflects gait deviations observed clinically in children with clubfoot.

1. Introduction

Clubfoot is a complex foot deformity that affects the child's entire gait pattern [1–5] and requires long-term follow-up [6–9]. The initial correction is mainly nonsurgical at present, and good results have been reported [1–5,7]. However, relapses can occur even after successful initial correction, often before the age of 5 but sometimes after that age [7–9]. Early relapse detection may prevent the need for future surgical corrections [7–9] and follow-up even after the age of 7 years is recommended [9]. For this purpose, objective, sensitive, and easy-to-use assessment instruments during follow-up are needed.

Most clubfoot follow-up instruments are designed primarily for classification purposes and focus on body function and structure such as the Pirani and Dimeglio scores and the outcome score of the International Clubfoot Study Group [10–12]. Other instruments are designed as patient-reported outcome measures, such as the disease-specific questionnaire of Roye et al. [13]. The Clubfoot Assessment Protocol (CAP) is a valid and reliable instrument that can be used to assess a child's overall physical function longitudinally [14]. The CAP is a multilevel observer-administered test that includes assessments of body structure, function, and activity level [14–16].

Three-dimensional gait analysis (3DGA) provides detailed information about normal and pathological gait. Data generated from 3DGA are often presented as single values, such as minima, maxima, or ranges of motion, and include a significant number of variables. Overall measures have been proposed to evaluate gait deviations as a single score. The Gait Profile Score (GPS) is a frequently used measure of overall gait quality [17]. The GPS is a generic index that can summarize the overall deviation of kinematic gait data relative to reference data [17]. The GPS can be decomposed into Gait Variable Scores (GVSs) that

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represent each of the nine kinematic variables included in the GPS [17].

The GPS and GVS have previously been validated in children with various disorders, mainly cerebral palsy [18–21]. In adults, the GPS has been used for evaluating overall gait deviations in individuals with various diseases such as Parkinson's disease [22], Ehlers–Danlos syndrome [23], and stroke [24]. One study [20] found that the GPS and foot-related GVS were significantly deviant in children with clubfoot compared with control data, which indicates the sensitivity of the GPS in children with clubfeet. However, to our knowledge, no previous study has aimed to correlate the GPS and GVS with the clinical status in children with clubfoot.

This study aimed to evaluate whether and how overall gait deviations, as measured with the GPS and GVS, correlate with visually assessed gait deviations and with the different aspects of clinical status in children with clubfoot.

2. Methods

2.1. Participants

A cohort of 22 consecutive children born between 2001 and 2005 with idiopathic clubfoot were invited to participate in this cross-sectional study. All children were treated and followed prospectively at our department according to a standardized follow-up program. Informed consent was obtained from the children's parents. Two children did not respond to the study invitation, yielding a cohort of 20 children (three girls and 17 boys). Ten children had unilateral and 10 had bilateral clubfoot, yielding a total of 30 feet diagnosed with idiopathic clubfoot. Of the 10 children with unilateral involvement 5 were affected on the right side and 5 on the left side. From the 10 children with bilateral clubfoot only one side was included in the analysis in order to avoid the effects of dependency between sides. The right side was chosen for every second patient based on their inclusion number in the study. The mean age at the time of the study was 7 years (SD 3.4 months).

2.2. Treatment

The children's affected feet had been treated with serial casting according to the Ponseti method [7], followed by a percutaneous Achilles tenotomy when required (14 feet; 8 unilateral, 6 bilateral). Two children, one with unilateral and one with bilateral clubfoot underwent posteromedial release. After the initial correction, a custom-made dynamic knee–ankle–foot orthosis (KAFO) was prescribed and used for 18 h/day during the first 2 months [4]. Over the next 6 months, the use of the orthosis was gradually reduced to 12 h/day from the age of 8 months (10 h at night and 2 h during the day). From the time the child's walking had stabilized (around the age of 2 years), a custom-made dynamic ankle–foot orthosis (AFO) was used for a minimum of 10 h every night until the age of four years. Although the use of this dynamic type of orthoses differs from the standard treatment as recommended by Ponseti, a previous study has shown good results and low relapse rate comparable to that of children treated with the standard boot and bar orthosis [4]. After the age of four years, the children were followed up in a standardized way twice a year. At each visit a thorough assessment of joint range of motion, muscle function and motion quality was performed according to the CAP follow-up protocol [14] (Fig. 1).

2.3. Gait analysis

3DGA was performed using the Vicon plug-in gait lower-body marker set (Vicon, Oxford, UK). The marker placement was carried out by two physiotherapists specialized in gait analysis. Marker data were collected with six MX40 cameras capturing at 100 fps. The child walked on a 10-m walkway at a self-selected speed. Kinematic modeling was performed using the Vicon plug-in gait model. Three valid and representative gait cycles from each affected foot were selected and included in the analysis. The selection criteria for including the data in the analyses were trials that were midsession and of similar speed with valid data.

The GPS was calculated separately for each affected leg ($GPS_{affected\ side}$) and as an overall score ($GPS_{overall}$). The GVS from the nine key kinematic components were calculated for each affected side. The key components were pelvic tilt, pelvic obliquity, pelvic rotation, hip flexion/extension, hip abduction/adduction, hip rotation, knee flexion/extension, ankle dorsiflexion/plantarflexion, and foot progression. The spreadsheet provided by the original authors [25] was used for the calculations. However, the original reference data in the spreadsheet was discarded and reference data collected in the same gait laboratory as the research data was used instead. Reference data were from 16 typically developing children aged 6.1–12.0 years (median 8.5).

The GPS and GVS represent raw scores and are reported in the same units (degrees) as the kinematic variables [17]. These scores represent the root mean square differences between the patient's data and reference data. The higher the GPS, the more deviated the gait [17]. The GVSs are helpful for identifying which gait deviations contribute to the deviant GPS [17].

2.4. Clubfoot assessment protocol

The CAP is a multilevel observer-administered test that includes 19 items divided into four domains [14] (Fig. 1). It evaluates multiple aspects of a child's clinical status, such as joint mobility, muscle function, morphology, and functional activity [14]. The left and right sides are assessed separately. The domains included in CAP are mobility (mobility I and II, seven items), muscle function (two items), morphology (four items), and motion quality (motion quality I and II, six items) (Fig. 1) [14]. The scoring for each item is from 0 (severe reduction/no capacity) to 4 (within normal). Cutoff points have been established previously [15] for each item, domain, and total score. Scores below these points are considered as poor clinical outcomes [15]. The CAP has been shown to have moderate to good reliability and validity in previous studies [14,16].

The examination took place in a child-friendly environment, and the time for completion was 10–15 min depending on the child's cooperation. Both left and right side were assessed regardless of uni- or bilateral involvement (Fig. 1). The CAP scores for each domain on the affected side and the total score for each affected side (CAP total) were calculated and are reported in this study. From the domain Motion quality I, the item walking was selected and analyzed in the correlations analyses.

2.5. Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics (ver. 22; IBM Corp., Armonk, NY, USA). Demographic and disease characteristics are described using the mean and standard deviation (SD) or the median and range.

The $GPS_{overall}$, $GPS_{affected\ side}$, and GVSs were averaged over three gait cycles for each child and then used in the statistical analyses. CAP scores on the affected sides were also used in the statistical analysis. Correlations between the $GPS_{overall}$, $GPS_{affected\ side}$, CAP total, CAP domains, and the CAP item walking, and between the item walking and each of the nine GVS were analyzed. Negative correlations were expected because higher CAP scores indicate better clinical status, and lower GPS/GVS values indicate less gait deviation.

Because CAP values are ordinal variables, the Spearman correlation coefficient was used to assess correlations between clinical assessments and gait analysis. Correlations were interpreted according to Cohen's method as low (0 to ± 0.29), moderate (± 0.30 to ± 0.49), and strong (± 0.5 to ± 1.0) [26]. Significance was accepted at $p \leq 0.05$.

Clinical examination and motion quality assessment (CAP version 1.2)

Name: Date of birth:

Date of assessment: Assessment number:

Side: O Left O Right

Rating	0	1	2	3	4
Passive mobility					
I.					
1. Dorsiflexion	< -10°	-10°-< 0°	0°- < +10°	+10°- +20°	>+20°
2. Plantar flexion	0°- < 10°	10°- < 20°	20°-< 30°	30°- 40°	>40°
3. Varus/valgus	>20°var	20°- > 10°var	10°- > 0°var	0°- neutral	>0°vlg
4. Derotation	>20°inv	20°- > 10°inv	10°- > 0°inv	0°- 10°evr	>10°evr
5. Add/abd, ff	>20°add	20°- > 10°add	10°- > 0°add	0°- neutral	>0°abd
II.					
6. Flx.dig.long.	+ reduced		reduced		normal
7. Flx.dig.hall.	+ reduced		reduced		normal
Muscle function					
8. M. peroneus	absent/poor		reduced		normal
9.M. ext.dig.long	absent/poor		reduced		normal
Morphology					
10. Tib.rotation	+ inward		inward		normal
11. Calcaneus pos.	> 10° varus		10°- >0°varus		neutral/ vlg
12. Forefoot pos.	> 20°add		20°- 10°add		<10° add
13. Foot arch	+ cavus/planus		cavus/planus		normal
Motion quality					
I					
14. Running 2y	cannot	+deviant	deviant	± deviant	normal
15. Walking 2y	cannot	+deviant	deviant	±.deviant	normal
16. Toe walking 3y	cannot	+deviant	deviant	± deviant	normal
17. Heel walking 3y	cannot	+deviant	deviant	± deviant	normal
II					
18. 1- leg stand 4y	cannot	+deviant	deviant	± deviant	normal
19. Hop 1 leg 4y	cannot	+deviant	deviant	± deviant	normal

Standard Questions

Pain with activities: Never ☐ Sometimes ☐ Regular ☐ Always ☐

Stiffness: Never ☐ Sometimes ☐ Regular ☐ Always ☐

Activity level of the child: Low ☐ Normal ☐ High ☐

Shoe problems: None ☐ Regular ☐ Always ☐ Orthopaedics shoes ☐

Leisure- time activities:

Does your child experience specific problems in daily life activities such as in sports, cycling, playing and keeping up with peers:

Never ☐ Sometimes ☐ Regular ☐ Always ☐

Specify problem(s):

Specification motion quality

☐ Intoeing

☐ Lateral loading

☐ No IC

☐ Deviant knee motion

☐ Limp

☐ Decreased propulsion power

☐ Co-ordination problems

+ = pronounced / very, ± = slightly, var= varus, vlg= valgus, inver= inversion, evr= eversion, add= adduction, abd=abduction, inw= inward rotation, outw= outward rotation, flx= flexor, dig= digitorum, long= longus, hall= hallucis, ext= extensor, tib= tibial, calc= calcaneus, pos= position, y = years

Fig. 1. Clubfoot Assessment Protocol.

A priori and based on the CAP construction, the following correlations were hypothesized. Low to moderate correlations were expected between the CAP total, CAP domains, and CAP item walking with $GPS_{overall}$ and $GPS_{affected\ side}$. The CAP item walking was expected to correlate moderately with the GVS for ankle kinematics. The CAP total and CAP domains were not expected to correlate significantly with the GVS.

The study was approved by the local ethics committee.

3. Results

Children with idiopathic clubfoot showed higher $GPS_{overall}$ scores

Table 1
Gait Profile Score (GPS) and Gait Variable Score (GVS) results.

	Clubfeet (n = 20)		Reference feet (n = 32)	
	Mean	SD	Mean	SD
$GPS_{overall}$	7.0	1.4	5.6	1.6
$GPS_{affected\ side}$, ($GPS_{ls\ or\ rs}$)	6.9	1.6	5.3	1.6
GVS pelvis anterior/posterior	4.7	3.2	3.3	2.1
GVS pelvis internal/external rotation	4.4	1.8	4.1	1.8
GVS pelvis up/down	2.7	1.4	1.9	0.8
GVS hip flexion/extension	6.3	3.6	5.7	2.7
GVS hip adduction/abduction	3.6	1.4	3.0	1.2
GVS hip internal/external rotation	7.0	2.8	5.1	1.9
GVS knee flexion/extension	6.3	1.5	6.0	2.6
GVS ankle dorsal/plantar flexion	6.5	3.2	4.1	1.9
GVS foot internal/external rotation	11.5	4.7	8.0	5.4

n, number of feet; ls, left side; rs, right side; as, affected side; SD, standard deviation.

(mean: 7, SD: 1.3) and $GPS_{affected\ side}$ scores (mean: 6.9, SD: 1.6) compared with reference data (Table 1). The most deviant GVS variables were: ankle dorsi/plantar flexion (mean: 6.5, SD: 3.2) and foot progression (mean: 11.5, SD: 4.7) (Table 1).

The median CAP total scores and median scores of all CAP domains and the item walking were all over the cutoff points previously established [15] (except for the domain of motion quality II), which indicated good clinical outcome and little variation in the CAP results (Table 2). Specifically, the median CAP for each affected side was 63 (max, 76) with a range from 52 to 76 and cutoff point of 57. The median of the CAP item walking was 3 (max, 4) with a range from 2 to 4 and cutoff point of 2. All CAP results are shown in Table 2.

As hypothesized a priori, the $GPS_{overall}$ and $GPS_{affected\ side}$ showed low to moderate correlations with most of the different aspects of CAP (Table 2). The $GPS_{overall}$ showed a significant strong negative correlation with CAP morphology but low or non-significant correlations with the remaining CAP domains and CAP total. By contrast, the item walking showed a significant strong negative correlation with $GPS_{affected\ side}$. All correlations between the CAP scores and $GPS_{overall}$ and $GPS_{affected\ side}$ are shown in Table 2. The relationship between $GPS_{overall}$ and the domain morphology is illustrated in Fig. 2.

Furthermore, the CAP item walking showed significant negative moderate/strong correlations with the GVS of ankle dorsiflexion and foot progression. Low or non-significant correlations were found for the remaining GVS. All correlations between the item walking and GVS are shown in Table 3.

The relationship between the item walking and the GPS affected side as well as the most affected GVS variables in clubfoot are illustrated graphically in Fig. 3.

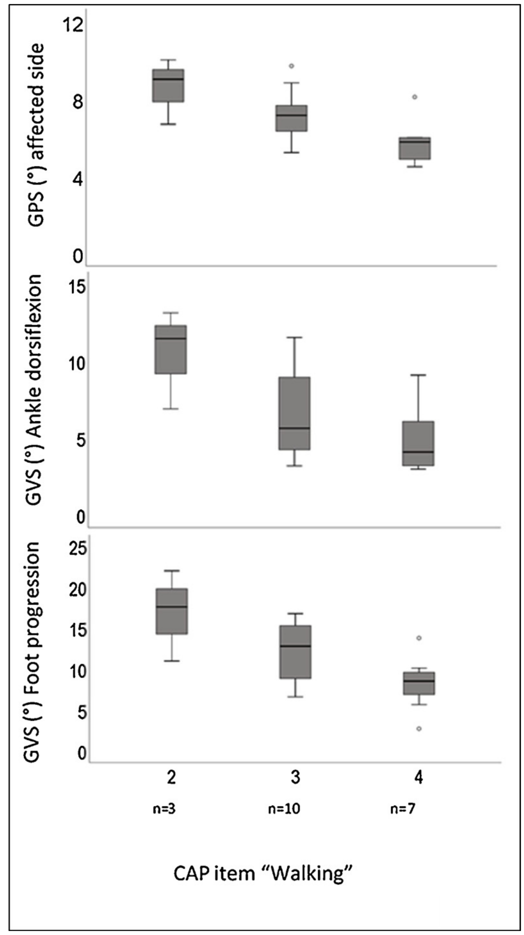

Fig. 2. Boxplots showing the distribution of GPS and GVS scores categorized according to CAP item walking score for 20 feet with clubfoot.
GVS, Gait Variable Score. GPS, Gait Profile Score. CAP, Clubfoot Assessment Protocol. n, number.

4. Discussion

This study evaluated the correlations between overall gait deviations, as measured by the GPS and GVS, and clinically assessed function in 20 children, aged 7 years, treated for idiopathic clubfoot. The CAP item walking showed a significant moderate to strong correlation with overall gait deviations and the gait variables most affected in clubfoot pathology: ankle dorsiflexion and foot progression. This implies that the GPS reflects the clinically assessed gait deviations commonly seen in children with clubfoot.

The item CAP walking is based on the visual observation of gait. The CAP manual describes specific gait deviations for each score (0–4), such

Table 2
Summary of Clubfoot Assessment Protocol (CAP) results and correlation coefficients between CAP domains/items and Gait Profile Score (GPS). (n = 20).

CAP score	Median (range)	Correlations	
		$GPS_{overall}$	$GPS_{affected\ side}$
Domain mobility I (max 20, cutoff ≤15)	16 (13–20)	−0.17	−0.27
Domain mobility II (max 8, cutoff ≤6)	8 (2–8)	−0.20	−0.20
Domain muscle function (max 8, cutoff ≤6)	8 (6–8)	−0.29	−0.12
Domain morphology (max 16, cutoff ≤12)	14 (10–16)	−0.63**	−0.36
Domain motion quality I (max 16, cutoff ≤12)	13 (10–16)	0.09	−0.30
Domain motion quality II (max 8, cutoff ≤6)	5 (2–8)	−0.33	−0.31
Item walking (max 4, cutoff ≤2)	3 (2–4)	−0.38	−0.62**
Total CAP (max 76, cutoff ≤57)	63.5 (54–76)	−0.25	−0.33

Cutoff points as previously established [16]. Values less than the cutoff indicate a poor outcome. n, number of feet. max, maximum. ** $p \leq 0.01$.

Table 3
Correlation coefficients between Gait Variable Scores (GVSs) and the Clubfoot Assessment Protocol (CAP) item walking. (n = 20).

	CAP item walking
GVS pelvis anterior/posterior	−0.32
GVS pelvis internal/external rotation	0.34
GVS pelvis up/down	−0.09
GVS hip flexion/extension	−0.36
GVS hip adduction/abduction	0.22
GVS hip internal/external rotation	0.07
GVS knee flexion/extension	−0.26
GVS ankle dorsal/plantar flexion	−0.50*
GVS foot internal/external rotation	−0.61**

n, number of feet. * $p \leq 0.05$; ** $p \leq 0.01$.

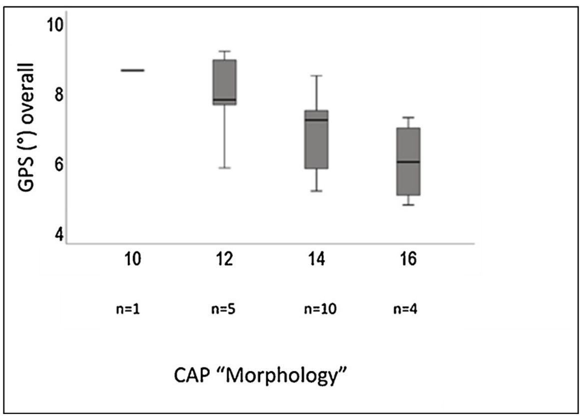

Fig. 3. Boxplots showing the distribution of GPS overall categorized according CAP domain morphology score for 20 feet with clubfoot.
GPS, Gait Profile Score. CAP, Clubfoot Assessment Protocol. n, number.

as walking straight, knee and hip movement, roll of the foot, step length, initial heel contact, and intoeing [14]. This item is more likely to relate to the GPS and several of the GVS items than the other CAP domains and items. This was confirmed by the significant moderate correlations found in this study between the CAP item walking and GPS, $GPS_{affected\ side}$, GVS for foot progression, and GVS for ankle dorsiflexion.

A previous study [21] used an 11-point scale to analyze overall gait and all GVS variables to identify correlations between the GPS and GVS, and clinicians' rating of gait in 60 children. 37 of the 60 children had unilateral cerebral palsy (CP), while the remaining had other orthopedic or neurologic conditions. The authors observed a strong significant correlation between the clinicians' rating of gait and items in the GVS. The lower correlation observed in our study between the CAP-item walking and GPS and GVSs is explained by the difference in the construct of the two measures. While both are measures of gait deviation, the item walking in CAP evaluates deviations mainly at foot level while GPS/GVS is based on deviations measured at the foot, knee, hip and pelvic levels (Table 1) [14,17].

One study [19] found strong significant correlations between the Edinburgh Visual Gait Score and GPS in children with CP. That study tested more parameters and used a broader scale. The gait deviations in children with CP are often more prominent and involve multiple joints compared with clubfoot pathology in which the deviations are often milder and affecting mostly the distal part of the lower limb [1–5].

The $GPS_{overall}$, $GPS_{affected\ side}$, and GVS showed low to moderate correlations with most aspects of the disease-specific follow-up CAP instrument. Most of the low correlations found were as expected. The CAP assesses different clinical aspects of clubfoot pathology such as foot mobility, gross motor quality, and certain aspects of foot muscle function. The GPS is an index that contains only kinematic gait parameters, and strong correlations were not expected.

The domains CAP mobility I and II showed surprisingly low correlations with the GPS, possibly because the CAP mobility measures only passive ranges of motions. The items in this domain are assessed by passively correcting the foot maximally and thereby eliminating muscle and ligament tensions that normally influence foot position in activity. This can result in better outcomes, and less variation in outcomes, compared with the outcomes in the domain morphology. The morphology domain was strongly negatively correlated with $GPS_{overall}$. This is possible because the items included in foot morphology (tibia rotation, calcaneus and forefoot position and foot arch), which are assessed with the children standing, indirectly affect the gait pattern. Furthermore, the deviations observed at the domain morphology are more pronounced as they incorporate the effects of skeletal changes and the passive influences of muscle and ligament tensions.

The low correlations found between the GPS and CAP domain muscle function and motion quality in this study were expected. A recent study of patients with 46 different pathologies showed that muscle strength was related to GPS but mainly when muscle strength was altered [27]. The median muscle strength of the children in our study (Table 2) was above the cutoff point for the CAP and therefore the GPS was less likely to correlate with muscle strength.

An interesting finding in this study was that $GPS_{affected\ side}$ was less affected by clubfoot than the $GPS_{overall}$. This may reflect the compensation mechanisms on the contralateral side during walking, which is also included in the $GPS_{overall}$ [1]. This is likely to be a confounding factor when gait is visually assessed.

The GPS alone is difficult to use when evaluating gait because it is a summary measure of overall gait deviations. Complementing the GPS with GVS added information about which joints and planes contribute mainly to the overall gait deviation. However, the GVS is also a summary that indicates the deviation in gait without indicating the direction of that deviation. Previous studies [18–24] have shown that the GPS together with the GVS provides a useful measure of both individual and group outcomes over time or following an intervention in children with other pathologies. The next step in developing the usability of the GPS /GVS in clubfoot follow-up is to calculate the minimal clinically important difference (MCID) specific for this patient group. A previous study proposed a MCID for GPS [28], but this was evaluated for children with cerebral palsy, which should be carefully taken into consideration if applied to children with clubfoot. A specific gait index, such as the Foot Profile Score [29] derived from the Oxford foot model [30] might be more strongly correlated with clinical assessment protocols in children with clubfoot. However, the aim of this study was to analyze how the more general GPS/GVS correlates with the clinical status in children treated for clubfoot. Further studies are needed in order to evaluate the usability of specific gait indices derived from a multi-segment foot model in clubfoot follow-up, as these are likely to be more clinically meaningful for children with Clubfoot.

One limitation of this study was that most CAP scores were above the cutoff point, which resulted in only a small variation in outcome. Stronger correlations may have been observed in a study population with a wider variation in outcome (which would indicate inferior outcome results). This is a result of the construct of the instrument. The strengths of this study are the consecutive recruitment, that all children were examined at the same age and that CAP was administered by the same senior physiotherapist [14,16].

This study has shown significant negative correlations between some CAP scores and the GPS and GVS. These findings suggest that the GPS together with the GVS reflects the gait deviations clinically observed in children with clubfoot. This overall gait index may be useful for assessing and communicating gait deviations in children with clubfoot.

Conflict of interest statement

The authors declare that they have no competing interests.

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