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Research Article

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Clubfoot Twin Study with Wearable GaitUp Sensors and Footscan V9

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Abstract

Purpose: *To control the therapeutic results in manual-dynamic physiotherapy for clubfeet we analyzed the gait pattern in children with clubfeet and their healthy twin siblings, aged between 3 and 13 years for GaitUp and 4 to 14 years for the footplate V9.*

Methods: *With the inertial GaitUp sensors and the footscan V9 pedobarographic plate the 11 twin-pairs were tested and statistically assessed. For the GaitUp sensors 22 parameters were considered and 10 parameters for the footplate V9. We analyzed the gait pattern for each child separately for both feet and in a second evaluation compared the affected feet with the ipsilateral feet of the healthy twins. The statistical comparisons were made with nonparametric methods. An additional twin girl treated with various therapies and her sister are included as a contrast.*

Results: *Especially in younger children, the gait pattern is not stabilized yet. Therefore, sometimes the healthy twins have inferior values in gait patterns than the affected siblings. Over the whole study there are only minor statistical differences between the affected group and the healthy group suggesting that with the manual-dynamic therapy the clubfeet children show a gait pattern statistically similar to the healthy group. Noteworthy are the less convincing results of the contrast twins.*

Conclusion: *Manual-dynamic physiotherapy can lead to a gait pattern equal to the one of unaffected children the same age. Our results do not support the statement that in one-sided clubfoot the other foot cannot be considered normal.*

Keywords: Clubfoot, Gait Analysis, Twin Comparison, Inertial Sensor, Footscan, Manual-Dynamic Physiotherapy, Derotation

1. Introduction

Clubfoot is the most common congenital deformity of the lower extremity with a number of permutations and combinations and already described by Hippocrates 400 BC [1]. The foot deformities interfere severely with locomotion ability and gait pattern and can lead to lifelong disability if not treated adequately. Human gait is an aspect with extraordinary complexity. Individual movements occurring simultaneously in the three planes of space make analysis difficult [2]. Quite a few publications stress the importance of computerized gait analysis in clubfeet for quality control [3-6].

Just visual observation of the walking pattern is too subjective [7]. Gait analysis in specialized laboratories has the disadvantage of being a foreign surrounding for the children and therefore influences the way of walking [8]. Computerized, wearable sensors and corresponding algorithms enable three dimensional spatio-temporal gait analysis and allow precise measurements in a doctor's office with minimal effort [9]. Another aspect of the evaluation of gait patterns is the plantar pressure assessment of human walking. Modern pedobarographic plates and adequate software make quantitative interpretation of loading of the foot available for doctor's offices [10].

In our practice with the footscan V9 (kinetics) and the wearable inertial GaitUp sensors (kinematics) we control the therapeutic results of the clubfoot treatment. Digital-quantitative methods are the only way to describe subtle deviations from normal, indicating a pending relapse even after 5 years of age [11]. In the literature it is described that in one-sided clubfoot, the contralateral foot cannot consider to be comparable to a normal foot [12,13]. To test this statement, we selected for this study eleven twin pairs from our patient collective where one sibling is affected, the other one is healthy.

2. Material and Methods

2.1. Ethics

This study has been approved by the Ethics committee of Zurich, Switzerland, Number 2023-00290. ClinicalTrials.gov ID: NCT05913934.

2.2. Patients

The parents of 11 pairs of twins and the contrast pair gave written informed consent for the participation for these control visits with inertial sensors and the footscan. All children involved gave their oral consent. The patients (15 clubfeet) of our group have been treated to date with manual-dynamic physiotherapy (Manuelles Zürcher Klumpfuss Konzept) by IU [14]. For comparison the analyses of a twin pair were one girl has double sided clubfeet treated elsewhere is included.

Patient	Age years	Gender	Clubfoot	Score Dimeglio*	WOP	Start of Treatment	Tenotomy	Embryo-genesis	Sibling	Gender
EIR	14	F	L	unknown	38 2/7	Day 60**	-	D	LIR	F
VOH	13	F	L R	11 12	33 5/7	Day1	-	D	BOH	F
DCH	12	M	R	11	33 5/7	Day 1	+	D	SCH	F
JLE	12	F	L R	17 18	32 6/7	Day 2	+	D	LLE	F
FBN	10	M	L	13	36 6/7	Day 3	-	D	JBN	F
IIN	10	F	R	14	35 6/7	Day1	+	M	CIN	F
AAR	9	M	L R	9 11	31 6/7	Day3	-	D	MAR	M
HIN	8	F	R	11	37 3/7	Day3	-	D	OIN	M
LOD	8	M	R	15	37 5/7	Day4	-	D	IOD	F
DEL	5	M	L	14	37 4/7	Day2	+	D	JEL	F
KOL	4	M	L R	18 17	33 5/7	Day 19	+	D	DOL	M
ECH ***	6	F	L R	14 14	33 2/7	Surgery,Ponseti	+	D	MCH	F

Gender: F = Female, M = Male, WOP: Week of Pregnancy
Embryogenesis: D= Dizygous, M= Monozygous
*) All diagnoses made by orthopedists from university hospitals
**) Initial Therapy: Ponseti Method
***) Contrast pair. ECH had different therapies elsewhere
The age is indicated for the foot scan V9 measurements. The GaitUp determinations were done 1 year earlier

Table 1: Anthropometric Details

2.3. Gait Analysis Systems

Figure 1: GaitUp Sensors

GaitUp sensors are wireless, inertial sensors (11g, self-calibrating) with a 3D accelerometer and a 3D gyroscope with 10D sensing capabilities (GaitUp, EPFL Innovation Park Bâtiment C, CH-1015 Lausanne, Switzerland). The sensors can yield 22 kinematic gait parameters. The sensors are attached to each foot with Velcro bands and are automatically synchronized. They are well accepted by children two years of age or older. GaitUp sensors have been validated with a motion capture system with 7 cameras (Vicon, UK) [15]. Most applications of GaitUp sensors until now were in adults. In children cerebral palsy was assessed [16].

In our study the test for each child comprises a walk of 25m in a gymnasium, repeated 3 times on a flat, even surface at a self-selected speed. First test series with shoes, second test series barefoot.

Parameters	Dimension	Interpretation
Essentials		
11 Speed	m/s	The speed of 3 to 6-year-old children is 1.00 to 1.40 m/s
Variability	%	Difference of the step duration during the run in %. In children 6 to 10%
Asymmetry	%	Comparison of the time the left and right foot is in the air. In children 1 to 5%
Swing, Stance	%	During swing no part of the foot touches the ground. Normal 35 to 45%
		Part of the step when a section of the foot touches ground. Extended stance means increased stability
		Unequal swing/stance phases indicate limping
Stride		The values for the left and the right foot should be equal
General		
2 Cycle Duration	s	Time should be equal for both feet. Otherwise it points to scuffle
3 Cadence	steps/min	Number of steps per minute. Children have a higher cadence
10 Stride Length	m	Distance between two footprints. Should be equal for both legs
1 Stride Velocity	s	Forward speed of a step
14 Turning Angle	º	Angle between the right and the left foot during a step
Temporal		
4 Stance	% of cycle duration	Part of the step when a section of the foot touches ground. Extended stance means increased stability
5 Swing	% of gait cycle	Portion of the gait cycle with the foot in the air
6 Loading	% of stance	Percentage of the time the foot touches ground until the foot lies flat
7 Foot Flat	% of stance	Portion of the stance phase with foot flat
8 Pushing	% of stance	Proportion of the step from foot flat until the toes leave the ground
9 Double support	% of cycle duration	Both feet touch the ground. Higher values point to insecurity
Spatial		
12 Peak Angle Velocity	º/s	Peak angle velocity during swing. Important indication of asymmetry
13 Swing Speed	m/s	Maximum velocity of the forward movement of the foot in the air
15 Strike Angle	º	Angle of the foot when touching ground. Low values point to "Foot Drop Syndrome"
16 Lift-Off Angle	º	Angle when the toes still touch the ground
17 Swing Width	m	Lateral deviation of the foot during a step
18 3D Path Length	% of stride length	Higher values are found in neuromotor disruption
Clearance		
19 Maximal Heel	m	Maximum height of the heel from the ground
20 Maximal Toe 1	m	Maximum height of the toes from the ground at the beginning of the swing phase
21 Minimal Toe	m	Smallest distance of the toes above ground during swing phase
22 Maximal Toe 2	m	Maximum height of the toes directly before the heel touches ground

Table 2: Measurement Values of the Gaitup Sensors and their Interpretation

Figure 2: Footscan V9

Plantar pressure plate: 4096 sensors; scanning rate 300 measurements per second. (RSscan Lab Ltd.10-15 Pegasus, Orion Court, Great Blakenham Suffolk, England).

This pressure plate is widely accepted and reliable [17]. We used a top-layer of ethylene-vinyl acetate copolymer (EVA) material (hardness: ShoreA 70, 2mm) on the plate and on the path. This layer hides the position of the pressure plate and circumvents the children trying to strike the plate with their feet which will result in an unnatural gait. The walk is inspected on the computer screen and the trial is terminated when sufficient steps in good quality have been acquired.

To assess the differences between the clubfoot patients and the healthy sibling we selected for our study the following footscan V9 parameters: Exorotation, Minimum Subtalar Joint Angle, Maximum Subtalar Joint Angle, Subtalar Joint Flexibility, Foot Length and Foot Width, Initial Contact Phase, Forefoot Contact Phase, Foot Flat Phase and Forefoot Push off Phase. For the comparisons with ECH and MCH we analyzed the forces curves of M2, M3, MH and LH.

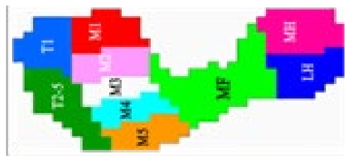


Figure 3: Foot Zones for Footscan v9. Our Measurements for the Comparison (m2, m3, mh and lh) are Based on the Work of Xu et al [18].

Parameter	Dimension	Interpretation
Exorotation	°	Midline axis of the hindfoot and the forefoot. Deviation from 0°
Minimum Subtalar Joint Angle	°	Describes supination or pronation
Maximum Subtalar Joint Angle	°	Describes supination or pronation
Subtalar Joint Flexibility	°	normal 39° to 49° (range: 36°- 61°)
Foot Length	cm	Both feet should have the same length
Foot Width	cm	Both feet should have the same width
Initial Contact Phase	ms / %	First 3% of the gait cycle. Heel touches ground until first metatarsal contact
Forefoot Contact Phase	ms / %	14% of the gait cycle. From first metatarsal contact to when all metatarsal zones make contact
Foot Flat Phase	ms / %	30% of the gait cycle. Heel and forefoot on the ground
Forefoot Push Off Phase	ms / %	53% of the gait cycle. Heel off the ground, foot off plate

Table 3: Measurement Values of the Footscan V9 and their Interpretation

2.4. Statistics

2.4.1. Working Hypothesis

With the digital-quantitative computer data obtained with the GaitUp sensors and the footscan V9 it will be possible to analyze the differences in the gait parameters between the group of healthy twins versus the group of the affected and identically treated siblings. Any significant disparity will be an indication to intensify or improve the therapy for the corresponding parameters. A second comparison was performed between the affected foot and the ipsilateral foot of the healthy twin siblings. In this study we deal with a limited sample, therefore nonparametric statistical tools were used. For comparisons we worked with Wilcoxon signed rank test with Tukey's post hoc procedure. Significance level alpha is 5%.

The concept of the effect size helps in the interpretation of the results. Due to the limited data we used Hedge's g as a measure of the effect size. The effect size represents the shift of the two Gaussian curves compared in standard deviation units. A Hedge's g of 0.2 is considered a small effect, 0.5 is a medium effect and 0.8 is a large effect. Hedge's g can also be negative when the shift is in the opposite direction. To illustrate the disparity of the differently treated double-sided clubfoot twin we compared her results with her sister's and with twins of a similar age and double-sided clubfeet of our patient group. Parameters are the footscan V9 forces curves of M2, M3, MH and LH. Statistical calculations were done with Analyse-it (Analyse-it Software, Ltd., The Tannery, 91 Kirkstall Road, Leeds, LS3 1HS, United Kingdom).

3. Results

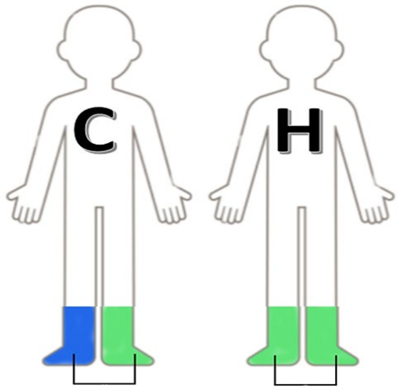


Figure 4

Shoes			
Parameters		**Clubfoot Twins**	**Healthy Twins**
Strike Velocity	p= Hedge's g	0.365 0.26	0.102 0.4
Cycle Duration	p= Hedge's g	0.922 0.05	0.846 0.04
Cadence	p= Hedge's g	0.695 -0.17	1.000 -0.2
Stance	p= Hedge's g	0.695 -0.06	0.922 0.03
Swing	p= Hedge's g	0.695 0.06	0.922 -0.04
Loading	p= Hedge's g	0.106 -0.65	0.432 -0.3
Foot Flat	p= Hedge's g	0.432 0.29	0.492 0.02
Pushing	p= Hedge's g	0.625 0.05	0.846 0.12
Stride Length	p= Hedge's g	0.002 1.18	0.02 0.96
Speed	p= Hedge's g	0.006 1.07	0.02 0.84
Peak Angle Velocity	p= Hedge's g	0.322 -0.31	0.625 0.14
Swing Speed	p= Hedge's g	0.846 0.21	0.002 1.13
Turning Angle	p= Hedge's g	0.131 -0.58	0.695 -0.16

Barefoot			
Clubfoot Twins		**Clubfoot Twins**	**Healthy Twins**
Strike Velocity	p= Hedge's g	0.482 -0.04	0.193 -0.39
Cycle Duration	p= Hedge's g	0.25 -0.33	0.652 -0.15
Cadence	p= Hedge's g	0.82 0.25	0.695 0.16
Stance	p= Hedge's g	0.77 -0.12	0.77 0.14
Swing	p= Hedge's g	0.770 -0.12	0.770 0.14
Loading	p= Hedge's g	0.922 -0.15	0.275 -0.32
Foot Flat	p= Hedge's g	0.322 0.29	0.275 0.41
Pushing	p= Hedge's g	0.275 0.33	0.557 0.3
Stride Length	p= Hedge's g	0.131 0.47	0.106 0.58
Speed	p= Hedge's g	0.131 0.53	0.010 0.95
Peak Angle Velocity	p= Hedge's g	0.922 -0.23	0.846 0.23
Swing Speed	p= Hedge's g	0.203 -0.36	0.106 0.58
Turning Angle	p= Hedge's g	0.131 -0.44	0.432 0.22

Strike Angle	p= Hedge's g	0.77 -0.01	1.000 -0.06	Strike Angle	p= Hedge's g	0.77 -0.05	0.557 0.22
Lift Off Angle	p= Hedge's g	0.922 0.09	0.77 -0.14	Lift Off Angle	p= Hedge's g	0.432 0.15	1.000 0.01
Swing Width	p= Hedge's g	0.004 -1.14	0.002 -2.24	Swing Width	p= Hedge's g	0.004 -1.39	0.002 -2.16
3D Path Length	p= Hedge's g	0.375 -0.35	0.922 0.18	3D Path Length	p= Hedge's g	0.770 -0.2	0.275 0.37
Maximum Toe	p= Hedge's g	0.922 -0.16	1.000 0.04	Maximum Toe	p= Hedge's g	0.250 -0.42	0.375 -0.29
Maximum Toe 1	p= Hedge's g	0.557 0.01	0.322 0.32	Maximum Toe 1	p= Hedge's g	0.652 -0.32	0.625 -0.12
Minimum Toe	p= Hedge's g	0.846 0.17	0.106 0.48	Minimum Toe	p= Hedge's g	0.652 -0.1	0.084 0.62
Maximum Toe 2	p= Hedge's g	0.496 0.24	1.000 -0.12	Maximum Toe 2	p= Hedge's g	0.734 0.15	0.014 0.98

Table 4: Comparison of the GaitUp Parameters for both Feet of the One-Sided Affected Children (C) and the Healthy Twins (H)

In Table 4 Single parameters quantified by the GaitUp sensors are statistically analyzed for the runs with shoes and barefoot. The comparison of both feet of the one-sided affected siblings and their healthy twins are assessed by the Wilcoxon signed rank test and the statistical Hedge's g effect size. Wilcoxon p values below 0.05 point to a marked difference between left and right foot. Hedge's g in excess of ±0.3 indicate a dissimilarity effect. The corresponding values are printed in red. Double support is not included because it is identical for both feet. (Interpretation of the parameters see Table 2).

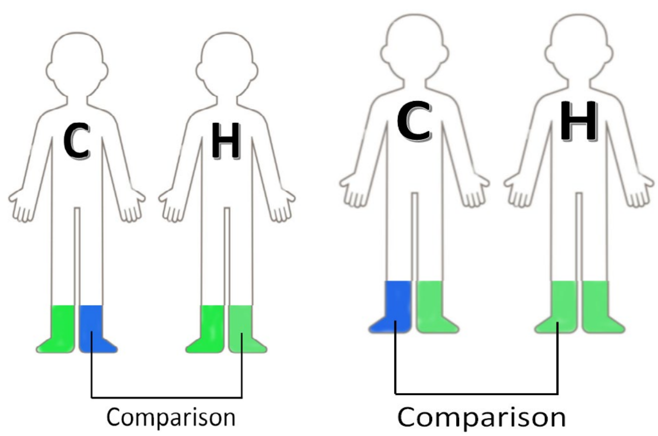


Figure 5

Clubfeet vs Ipsilateral Feet of the Healthy Twins (Shoes)			
Parameters		**Left foot comparisons**	**Right foot comparisons**
Strike Velocity	p= Hedge's g	0.922 0.03	0.770 0.06
Cycle Duration	p= Hedge's g	0.846 0.06	0.846 0.05
Cadence	p= Hedge's g	0.625 0.09	0.695 0.08
Stance	p= Hedge's g	0.625 0.19	0.232 0.37
Swing	p= Hedge's g	0.625 -0.19	0.232 -0.38
Loading	p= Hedge's g	0.922 0.20	0.557 0.17
Foot Flat	p= Hedge's g	0.275 0.37	0.432 0.25
Double Support	p= Hedge's g	0.490 0.28	0.492 0.28
Pushing	p= Hedge's g	0.232 -0.37	0.275 -0.42
Stride Length	p= Hedge's g	1.000 -0.10	0.557 -0.22
Speed	p= Hedge's g	0.846 0.01	0.922 -0.08
Peak Angle Velocity	p= Hedge's g	0.922 0.08	0.695 0.00
Swing Speed	p= Hedge's g	0.625 -0.11	0.846 -0.02
Turning Angle	p= Hedge's g	0.770 -0.06	0.106 0.59
Strike Angle HSP	p= Hedge's g	0.077 -0.10	1.000 0.09
Lift Off Angle	p= Hedge's g	0.110 0.46	0.492 0.19
Swing Width	p= Hedge's g	0.770 0.13	0.492 0.04
3D Path Length	p= Hedge's g	0.275 -0.44	0.770 0.02
Maximum Toe	p= Hedge's g	0.625 -0.11	0.232 0.38
Maximum Toe 1	p= Hedge's g	1.000 0.10	0.322 0.12
Minimum Toe	p= Hedge's g	0.625 -0.15	0.193 -0.04

Clubfeet vs Ipsilateral Feet of the Healthy Twins (Barefoot)			
Parameters		**Left foot comparisons**	**Right foot comparisons**
Strike Velocity	p= Hedge's g	0.910 0.02	0.900 0.00
Cycle Duration	p= Hedge's g	1.000 0.07	0.900 -0.10
Cadence	p= Hedge's g	1.000 0.10	1.000 0.08
Stance	p= Hedge's g	1.000 -0.02	0.800 0.08
Swing	p= Hedge's g	1.000 0.02	0.820 -0.08
Loading	p= Hedge's g	0.164 0.36	0.230 0.38
Foot Flat	p= Hedge's g	0.496 -0.25	0.734 0.01
Double Support	p= Hedge's g	0.820 0.03	0.820 0.03
Pushing	p= Hedge's g	1.000 -0.06	0.500 -0.20
Stride Length	p= Hedge's g	0.557 0.29	0.203 0.36
Speed	p= Hedge's g	0.734 0.12	0.359 0.27
Peak Angle Velocity	p= Hedge's g	0.570 -0.27	1.000 0.03
Swing Speed	p= Hedge's g	0.910 0.10	0.945 0.04
Turning Angle	p= Hedge's g	0.820 0.10	0.100 0.61
Strike Angle	p= Hedge's g	0.820 0.10	0.426 0.29
Lift Off Angle	p= Hedge's g	0-359 0.31	1.000 0.02
Swing Width	p= Hedge's g	1.000 0.20	0.800 0.01
3D Path Length	p= Hedge's g	0.570 -0.03	0.910 -0.01
Maximum Toe	p= Hedge's g	0.301 0.29	0.023 0.88
Maximum Toe 1	p= Hedge's g	1.000 -0.07	0.313 0.39
Minimum Toe	p= Hedge's g	0.652 -0.09	0.055 0.62

Maximum Toe 2	p= Hedge's g	1.000 0.11	0.922 0.01

Maximum Toe 2	p= Hedge's g	0.496 0.27	0.313 0.44

Table 5: Comparison of the GaitUp parameters of the clubfoot of the affected twins (C) and the ipsilateral foot of the siblings (H) for the left feet there are 7 pairs, for the right feet 8 pairs

In Table 5, Comparison between all clubfeet with the ipsilateral feet of the healthy siblings in relation to the different parameters. (Interpretation of the parameters see Table 2).

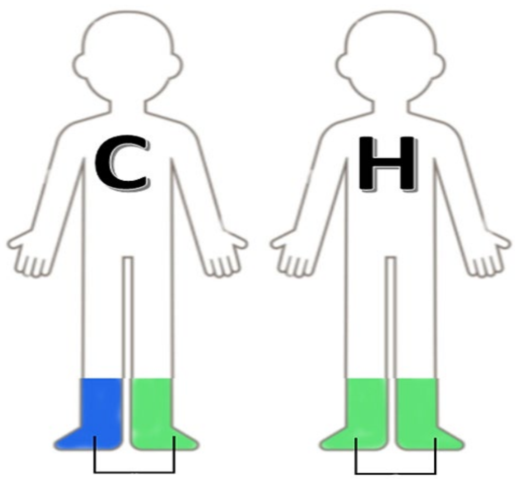
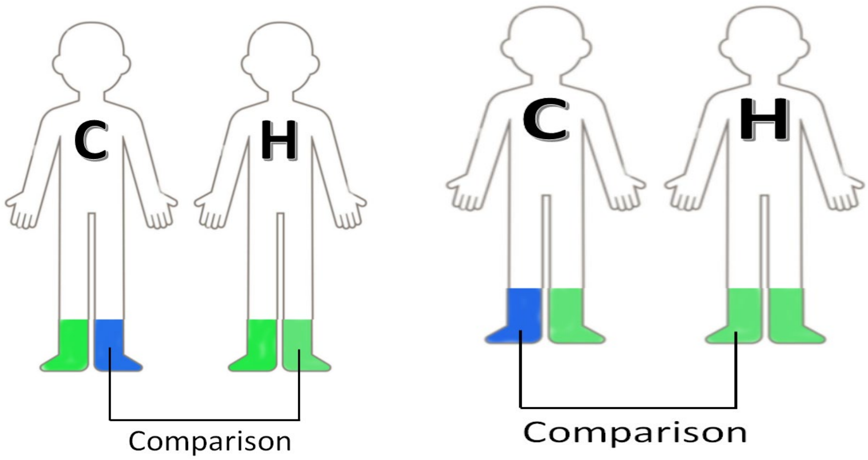


Figure 6: Footscan V9 Results

Parameters		Clubfoot Twins	Healthy Twins
Exorotation	p= Hedge's g	0.913 -0.14	0.413 -0.22
Minimum subtalar joint angle	p= Hedge's g	0.765 0.10	1.000 0.00
Maximum subtalar joint angle	p= Hedge's g	0.496 -0.10	0.375 -0.10
Subtalar joint flexibility	p= Hedge's g	0.625 -0.20	0.820 0.20
Foot Length	p= Hedge's g	0.250 -0.23	0.734 0.08
Foot Width	p= Hedge's g	0.922 0.04	0.922 0.03
Initial Contact Phase	p= Hedge's g	0.813 0.00	0.193 0.40
Forefoot Contact Phase	p= Hedge's g	0.570 -0.30	0.426 -0.30
Foot Flat Phase	p= Hedge's g	0.106 0.60	0.123 -0.40
Forefoot Push Off Phase	p= Hedge's g	0.193 -0.40	0.067 0.60

Table 6: Comparison of the footscan V9 parameters for both feet of the one-sided affected children (C) and the healthy twins (H)

In Table 6 the gait analysis of the footscan V9 parameters measured in the clubfeet children and their healthy siblings. Barefoot only. Wilcoxon p ≤ 0.05 describes a statistically significant difference for the respective parameter and are printed in red. Hedge's g is the statistical effect size. g = ±0.2 is considered a small effect size, ±0.5 is a medium effect size and ±0.8 a large effect size. Values in excess of ±0.3 are printed in red. (Interpretation of the parameters see Table 3).



Parameters		Left foot comparisons	Right foot comparisons
Exorotation	p= Hedge's g	0.467 0.62	0.313 -0.50
Minimum subtalar joint angle	p= Hedge's g	0.844 0.10	1.000 -0.10
Maximum subtalar joint angle	p= Hedge's g	0.109 0.60	0.461 0.30
Subtalar joint flexibility	p= Hedge's g	0.438 0.40	0.469 0.30
Foot Length	p= Hedge's g	0.688 -0.17	0.547 0.22
Foot Width	p= Hedge's g	0.938 -0.21	0.578 0.03
Initial Contact Phase	p= Hedge's g	0.094 0.80	0.250 0.50
Forefoot Contact Phase	p= Hedge's g	0.563 -0.20	0.055 0.70
Foot Flat Phase	p= Hedge's g	0.313 0.40	0.813 0.00
Forefoot Push Off Phase	p= Hedge's g	0.219 -0.40	0.945 -0.10

Table 7: Comparison of the Affected Feet of the Siblings with the Ipsilateral Feet of the Healthy Twins

In Table 7 Comparison of Single Footscan v9 Parameters between the Affected Feet and the Ipsilateral Feet of the Healthy Twins. For the Left Feet there are 7 Pairs, for the Right Feet 8 Pairs.

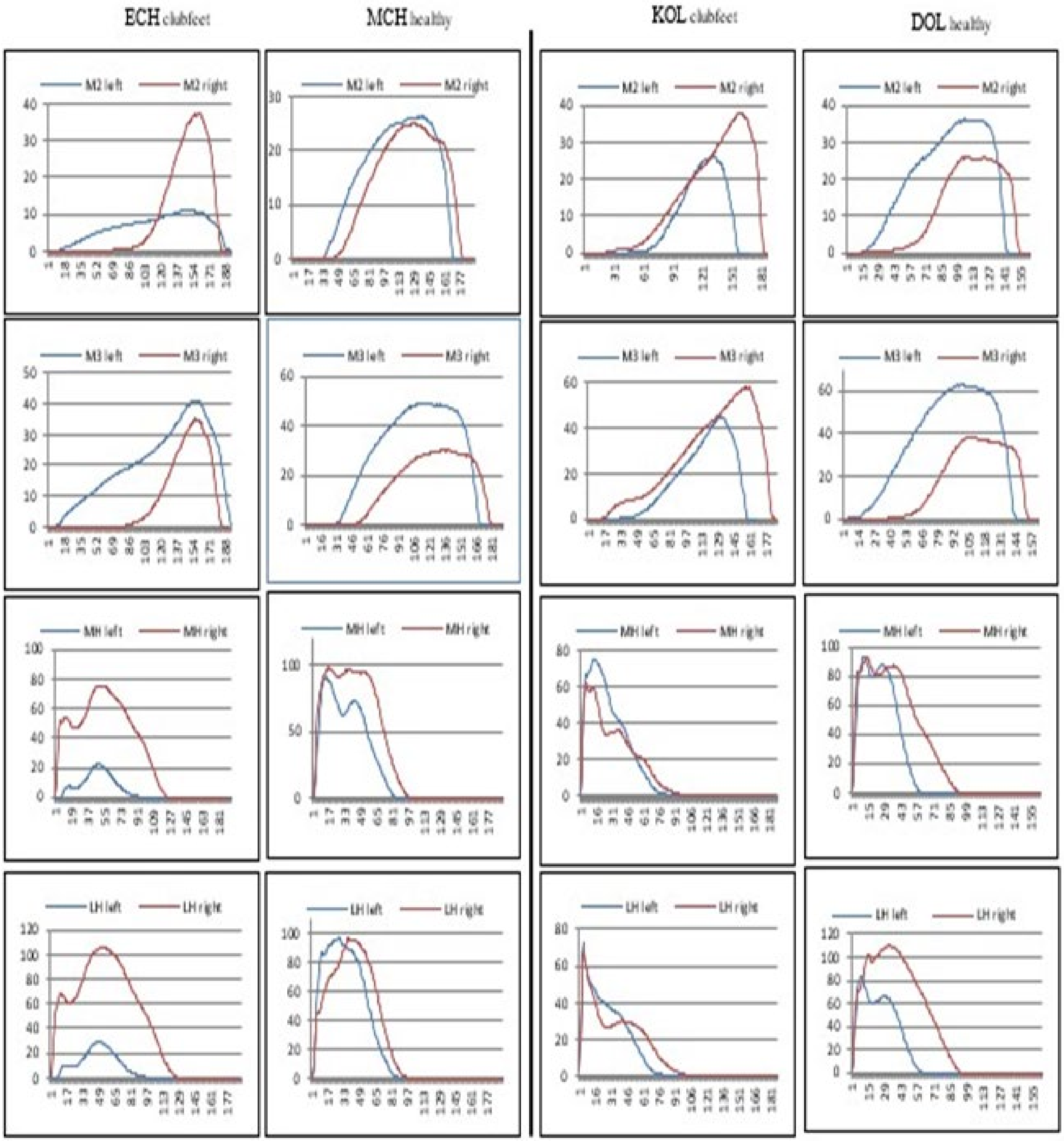


Figure 7: Comparison: Child with inadequate therapy (ECH), her sister (MCH) and a pair of our group (KOL; DOL)

In figure 7 from the footscan V9 data the forces values for M2, M3 MH and LH were extracted and depicted as curves for the left and the right foot. The double-sided clubfeet of (ECH) were not treated by UI with the manual-dynamic therapy. ECH is compared with her sister (MCH) and one of our pairs about the same age and double-sided.

Discussion

To our knowledge this is the first comparative study with a cohort of clubfoot twins considering gait analysis with two independent systems following identical treatment by a single person. Other twin publications concentrate on male to female ratio (2.5 to 1), twinning effects (2.9% versus 1.2% in the population) and discrepancy between monozygotic versus dizygotic twins (less clubfeet in dizygotic twins) [19].

Our working hypothesis for the gait analysis in clubfoot children was finding parameters not considered normal to adapt the treatment accordingly. However, we couldn't find consistent deviations between the clubfoot children and their healthy twins. The reason might be the limited sample. Among 300 clubfeet we had 11 twin-pairs for investigation. The few statistically significant gaits differences might also be due to the varying ages from 3 to 14 years. If in these instances, we split the youngest 5 pairs from the 6 older pairs, the statistical significance disappears (data not shown). The majority of the gait pattern parameters analyzed in our patient group show an equivalence between the clubfoot children treated with manual-dynamic physiotherapy and their healthy twins. One goal of clubfoot therapy is to reach the physiologic derotation as measured with the footscan V9 exorotation. This parameter shows no statistical difference between the affected and the healthy children.

The clubfeet of a girl treated with varying methods reveals a substantial difference to the manual-dynamic treated group. The deviations in this girl support the validity of the gait analyses with the pedobarometric plate.

Unfortunately, normal values for children in the field of gait patterns with similar methods are missing. Such data would be beneficial to further validate the presented data.

Today there are different accepted modalities to treat clubfeet. An important principle of the manual-dynamic method is to avoid thigh-casts and immobilizing (night-) braces [14]. We assume that this reduces negative effects on the child's perception and development. The early beginning of the therapy may reduce fibrosis of connective tissues due to impaired movement during pregnancy. The derotating lower leg orthosis used allow for the knee- and hip mobility [14]. The three-dimensional torsion of the clubfoot is multi-dimensionally well addressed with the manual-dynamic therapy in all levels and axes. Thus, the calcaneotalar angle in the transverse plane could be adjusted to normal values. Highly important is the inclusion of the functional movement chain in the treatment. Admittedly our study is a snapshot and permits no statement for a lifelong absence of symptoms, the ultimate goal of every therapy. There is a generally accepted need for further studies.

The key of our study design lays in the fact that the controls and patients share the exact same age, the same environment, genetics and treatment by the same person. This ensures statistical homogeneity. The drawbacks are the small sample size. Future studies are needed.

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