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Biomechanics and Clinical Interactions in Podiatry Assessment

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Authors' contributions

This work was carried out in collaboration among all authors. Author JM conceived and designed the study, conducted the literature searches, did the clinical assessment and drafted the manuscript. Author IR was responsible for data collection and processing in the lab. Author GL reviewed the clinical assessment and discussion. Author JA conceived and designed the study, as well as reviewing the lab methodology and the biomechanics outputs. All authors read and approved the final manuscript.

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ABSTRACT

Background: Most foot joints have three degrees of freedom. Kinematics is important to understand gait cycle feet joint interactions. Daily clinical practice doesn't allow immediate access to specialized laboratories where specific developments contribute to progress of podiatry knowledge. The aim of this study is to contribute to the knowledge of the interactions between biomechanical and clinical assessments.
Methods: Five healthy subjects underwent two types of assessment. Clinical: Anamnesis; passive joint by goniometry; plantar pressure features and Centre of Pressure (COP) displacement (RsScan®). Biomechanical: In the Laboratory, subjects walked 7 metres (3 trials); the data/percentage stance phase graphics were displayed. Ankle and Forefoot/Hallux dorsi/plantarflexion; Hindfoot/Tibia and Hindfoot/Forefoot eversion/inversion, angles were measured. Ground reaction force (Fz) (AMTI® at 1250 Hz) was used to determine 5 stance phase

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events (initial contact, loading response, Midstance, Terminal stance, Preswing) collected with 10 Mx1.3 Vicon® (250Hz) and 3D Oxford Foot Model.

Results: Clinical assessments have shown that joint angles are in accordance with literature. The data/percentage stance phase graphics show similar patterns to the literature. Every 5 subject's angle data show the personalized quantification demonstrated in the text tables.

Conclusion: Despite the absence of statistical reasoning due to the reduced sample size, the obtained data are consistent with the literature's references. The clinical and biomechanical assessments show different information, although they complement each other. The biomechanical information knowledge gathered is an added value to the clinician and to the evidence-based practice.

Keywords: Biomechanics; foot model; clinical interactions; podiatry assessment.

1. INTRODUCTION

The analysis and study of plantar support and foot actions, during the walking cycle, seem quite difficult, due to the high complexity of the foot's anatomy. This is due to the number of small joints that interact with each other [1–3].

Consequently, mere qualitative analysis during clinical evaluation is insufficient for the correct diagnosis of the different pathologies that affect the locomotor system [3,4]. Therefore the use of quantitative evaluation methods becomes important, either in sedestation or during walking.

In a clinical environment the goniometric measurement of passive joint range allows the qualification of amplitude and also passive joint symmetry. These data allow us not only to make inferences about the relation between the analyzed joint and the adjacent joints, but to detect eventual alterations to its normal functioning, which can increase the appearance of pathologies [5].

Additionally, the analysis of plantar pressures allows us to obtain important information about the structure and function of the foot. This is possible not only in subjects without any types of pathology but also [6] in some systemic pathologies like rheumatoid arthritis, diabetes and cerebrovascular accident, which contribute to the alteration of the distribution of foot pressure in an important way [6–9].

The change of the normal distribution of plantar pressures is responsible for the appearance of pain, plantar ulceration and stress fractures of the metatarsus. Therefore, the understanding of these distributions and their repercussions enables, in a more effective way, the establishment of an appropriate treatment [10].

As plantar pressure provides information about the structure and function of the foot, the Centre of Pressure (CoP) allows us to notice the transversal (medium-lateral) and longitudinal (posterior-anterior) displacement. The variation of these displacements is acutely influenced by the foot structure as well as the speed of walk, type of shoe and support surface [11].

On the other hand, the traditional complementary methods of diagnosis, like X-ray, computerized axial tomography (CAT) or even magnetic resonance imaging (MRI) amongst others, provide pertinent information about the analyzed structure. However, the relation that exists between the information obtained through the latter methods and that obtained through the analysis of movement is reduced [12].

Due to these facts, the use of complementary methods that simultaneously represent the biological structure considered as the subject of study and allow the examination of its functionality becomes fundamental. In the present case, the subject of the study is the foot during the support phase of the walking cycle.

Traditionally, during the walking cycle, the initial contact of the foot with the support surface occurs through the heel (heel contact), followed by the midstance support (midstance). In this phase, the forefoot support (foot-flat) follows the heel contact. The propulsive phase (terminal stance) occurs with the support of the forefoot and toes. Finally, the take-off (pre-swing) is described as the last contact between the toes and the contact surface [13].

The high number of joints present in the foot [32] as well as the shape of their joint faces originate inter-segmentar movements in more than one plane of displacement, limiting the movement of the adjacent joints [4,13–15].

The use of multisegmentar biomechanical models was developed by various authors [15-18]. In this study, the application of the Oxford Foot Model (OFM) was developed and adapted according to the Motion Builder and Nexus software of Vicon®, and applied in MovLab. The OFM was published for the first time in 2001 [19] and is being applied in clinical environments in the kinematic study of children with cerebral palsy. In terms of podiatry, we could only find one published article, using the OFM to compare the kinematics of the foot with different height of the internal longitudinal arch [20].

The OFM simplifies the complex anatomic structure of the foot and reduces that complexity to 3 rigid segments (tibia, hindfoot and forefoot) and 1 vector (hallux). The medial part of the foot is considered as a rigid body that supports the displacements between the hindfoot and forefoot. All of the displacements in the 3 rigid segments are considered free of angular displacement influence [16]. This model is based on the application of reflective marks on the skin (anatomical bony prominences previously defined).

The goal of this study is to contribute to the understanding of the interactions between the biomechanical results and the clinical assessment and therefore develop a new paradigm and a better framework for the evidence based on the clinic supported by the laboratorial biomechanics knowledge.

For such purpose we hypothesize that the angular displacement the Oxford Foot Model (OFM) and the measurement of the vertical component of the ground reactive force during the stance phase of the gait cycle in same patients can be necessary to complement the passive joint range of the joints and the Plantar pressures and displacement of the CoP.

2. METHODS

The present study describes how the laboratorial biomechanics resource can be used as a specific powerful complementary diagnostic method (OFM) as a specific complementary diagnostic method (OFM) as a powerful method to interact with the podiatry examination executed in specialized clinical environments. The absence of published papers regarding the subject of the interaction between biomechanics and clinical interactions in podiatry assessment led to the need to develop methodological data procedures. This fact justifies the presentation of 5 subjects and the particularity of each one of those subjects (Table 1).

Table 1. Subjects gender, age and body mass

	Male			Female	
	S1	**S2**	**S3**	**S4**	**S5**
Age (years)	23	23	24	21	23
Body mass (Kg)	70	74	75	70	56

(Abbreviations: S1: Subject 1; S2: Subject 2; Subject 3; Subject 4; Subject 5.)

In the clinical assessment the following records are executed:

1.1) Passive joint range of the joints that correspond to the segments of the biomechanical model, through the goniometric measurement (described in the material and methods of clinical evaluation);
1.2) Plantar pressures and displacement of the CoP during the stance phase of the gait cycle (described in the material and methods of the clinical evaluation) (Fig. 1).

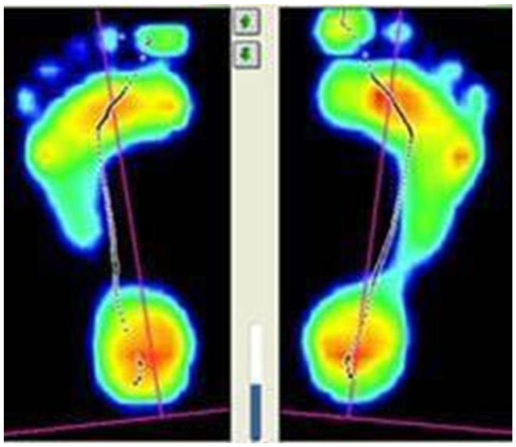


Fig. 1. Plantar pressure distribution. The CoP displacement is represented by the dashed line

In the biomechanical assessment the following records are executed:

2.1) Angular displacement of the ankle, hindfoot/tibia, hindfoot/forefoot and forefoot/hallux through the Oxford Foot Model (OFM);
2.2) Measurement of the vertical component of the ground reactive force during the stance phase of the gait cycle;

The subjects of the sample were included according to the following inclusion criteria: 1) No physical incapacity; 2) No musculoskeletal pathologies; 3) No musculoskeletal surgery of the locomotors system; 4) Agreement to participate in the study with signed consent.

The study had ethical approval by the Ethics Committee of Sevilla University (Comité Ético de Experimentación de la Universidad de Sevilla").

2.1 Clinical and Biomechanical Assessment

The clinical and biomechanical assessments were performed at the Mov Lab facilities.

2.2 Clinical Assessment – Material and Methods

a) Anamnesis was used to verify whether the subjects fulfilled the inclusion criteria;
b) The passive joint ranges were measured using a two-branch goniometer (ref: PRESTIGIO – System doctor®) on the joints of the ankle (flexion/extension), the midtarsal joint (inversion/eversion) and the first metatarsal phalangeal joint (dorsiflexion/plantarflexion). The Helbing line was also quantified, which allows us to obtain the orientation of the hindfoot in load with the subject in "quasi static" position. The leaning of the Helbing line registers, in degrees, the valgo or varo position of the heel in relation to the ground. (This measurement was obtained through a Perthes ruler (ref: PRESTIGIO – System doctor®).
c) To register the plantar pressures and CoP displacement an RsScan (USB Footscan 7.97 – 0.5x0.4x0.008) pressure plate was used. This allowed the registration of the plantar pressures and the CoP during the stance phase of the gait cycle. The assessment of the plantar pressures was intended to characterize the distribution of pressures in the plantar surface. On the other hand, the CoP shows the transverse and longitudinal displacement that the foot suffers throughout the support phase.

2.3 Biomechanical Assessment – Material and Methods

Biomechanical evaluation through the capture of movement is supported by the Vicon® Motion Capture MX system, based on 10 Vicon® MX 1.3 cameras that are connected to MXUltranet hardware. In this study, the system was previously calibrated. The volume of capture was also defined and the kinematic data collected at 250 Hz.

Inside the capture volume, placed on the floor, there is a force platform (AMTI BP400600-2000) that collects the reactive force kinetic data at 1250 Hz. The force platform is connected to a Strain Gage amplifier (AMTI MSA-6 MiniAmp) to the Vicon® MXControl so that the system is synchronized through the amplifier with the Vicon® Motion Capture. The data collected are executed in the computer, where the Vicon's® Nexus 1.7 and Polygon 3.5 software process the data.

The weight and diameter of the different body segments were obtained through a SECA 764 scale and by using anthropometric measurement Siber Hegner tools.

The podiatry and the walking analysis that were used in the present study were based on the association between the "Lower Body" and "OFM" models of Vicon®. The model that was used includes 17 markers (9.5mm diameter) placed in specific anatomical bony prominences of the hip, thighs, legs and feet of both lower limbs.

The segments are composed of the following markers: (Tibia –(1) KNEE, (2) HFB, (3)TTB, (4)SHN, (5)TIB, (6)ANK e (7)MMA; Hindfoot– (8) CPG, (9)HEE, (10)PCA, (11)LCA, (12)STL; Forefoot–(13) P1M, (14)D1M, (15)P5M, (16) TOE and hallux – HLX). They can be seen in Figs. 2A-D.

The marker material reflects the MX camera's light that registers the position coordinates for each defined interval. The Nexus software receives the data from all cameras and reconstructs the 3D position of the set of markers.

This method is based on the principle that the movement of the markers that were placed on the skin translates the relative displacement of the segments that form the OFM and the three-dimensional displacements of these segments around the respective joint centers (Fig. 3).

The experimental procedure included the execution of a "static" trial and various "dynamic" trials for each subject.

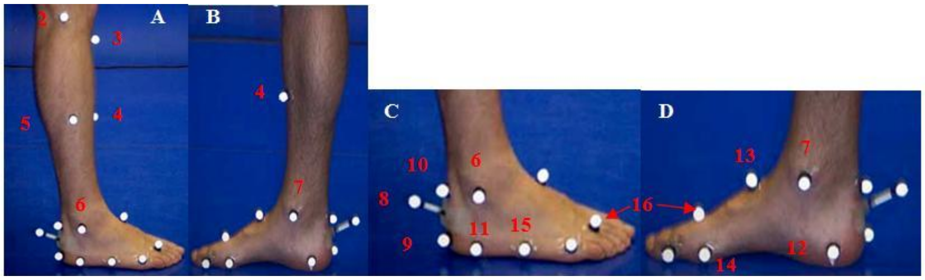


Fig. 2. Phase 2 of the experimental setup: Markers' placement. A – Markers outside of leg; B – Markers inside of leg; C – Markers outside of foot; D – Markers inside of foot

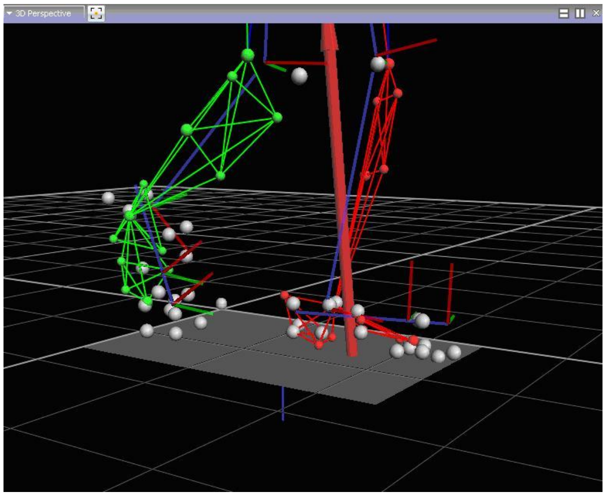


Fig. 3. MovLab adaptation of Nexus Lower Body Model + Oxford Foot Model and GRF vector representation

During the 'static' trial the subject was at the center of the capture volume of the Vicon® system with the elbows in extension and shoulder-width apart. The legs were also shoulder-width apart and the head aligned according to the Frankfurt plane. This trial has an approximate duration of 5 seconds depending on the easiness demonstrated by the subject in keeping the standing position.

In the “dynamic” trial, the subject moved in a corridor with a length of 7 meters and a width of 1.5 meters. There were 3 meters from the beginning of the corridor to the center of the force platform and 4 meters from the force platform to the end of the route (Fig. 4).

The sample of gait data was based on the 3-step protocol [21] and the subjects of the sample were asked to walk at a self-selected speed.

Three trials were performed with the left leg and three with the right leg, a total of six valid trials per subject, a valid trial being a trial in which the contact between the foot and the platform was completely made.

The outputs of the collected biomechanical data are divided into:

a) Kinematics – tibia/foot angles (Sagittal plane); tibia/hindfoot (Frontal plane); hindfoot/forefoot (Frontal plane) and forefoot/hallux (Sagittal plane)
b) Kinetics – vertical component of the reactive force

2.4 Data Collection and Processing

2.4.1 Clinical assessment

a) Anamnesis: A questionnaire about the physical condition of the subjects was compiled. A qualitative analysis of the passive joint range of the foot concerned was also made with the subject lying on a table.

b) Passive joint range: after the qualitative analysis and with the subject in the same position, the degrees of freedom of each joint were measured. This was executed with a two-branch goniometer. For the Helbing line quantification, the subject was in "quasi static" position. The degrees relative to the inclination of the heel bisection in standing position were obtained using a Perthes ruler.
c) Plantar pressure and CoP displacement: the route used was the same as the route defined for the "dynamic trial" described in Biomechanical evaluation – material and methods. In the same sample the plantar distribution and the CoP displacement data were obtained.

2.4.2 Biomechanical assessment

Initially the anthropometric data of the subjects were collected. Afterwards the 17 markers were put on each leg.

The subject placed himself in the middle of the force platform (AMTI – OR640 x 600) for the performance of the static trial. Afterwards, the three dynamic trials were carried out for each leg, as described in Biomechanical assessment – material and methods.

The biomechanical data presented in "results" concern the values registered in specific instant for each performer during the single-support phases in the gait cycle, namely: (Fig. 5)

1) Initial contact of the heel (I.C.) – first contact of the foot with the force platform;
2) Loading response (L.R.) – acceptance of the body weight that corresponds to the first peak of maximum reactive force during the heel contact;
3) Midstance (M.S.) – minimum value of the reactive support force during the midstance phase;
4) Terminal stance (T.S.) – second peak of the reactive support force in the propulsion phase;
5) Preswing (P.Sw.) – last contact of the foot with the force platform.

Afterwards, the temporal normalization of the single support that is underlined to each gait cycle was done through the conversion of the temporal data into percentages. The initial contact (IC) corresponds now to the instant 0% and the final instant (Preswing) corresponds to 100% of the single-support phase. The swing phase wasn't analyzed.

The vertical lines on the graphics represent the instant in which the selected events occurred.

No statistical analysis of the data was conducted after processing. The aim was to treat each subject as unique and with their individual variability.

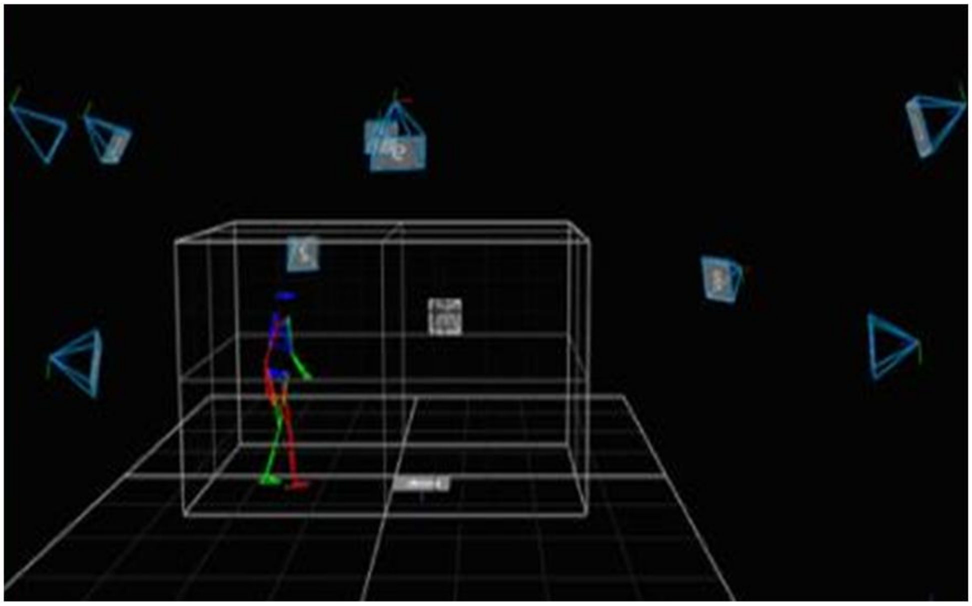


Fig. 4. Cameras' disposition, trial and capture volume

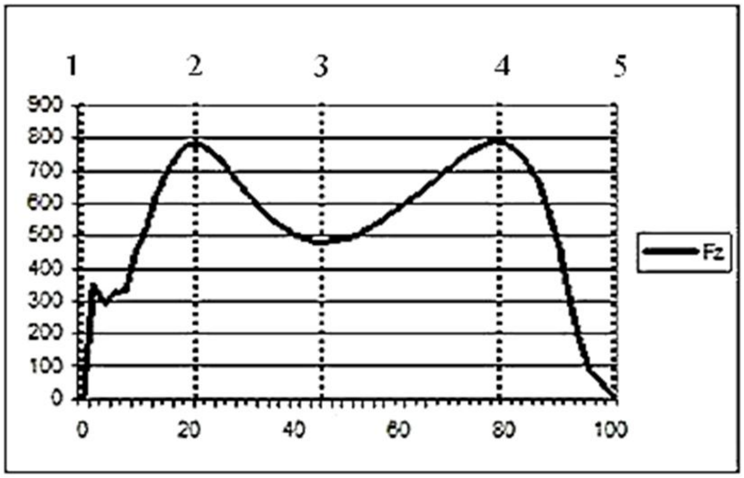


Fig. 5. Ground reaction force vertical component (Fz) during stance phase and instants of selected events (dash lines)

3. RESULTS

3.1 Clinical Assessment

Table 2 shows the differences intra and inter subject of the passive joint ranges and the Helbing line.

Although there are differences in the obtained values, these are found to be within standards defined as normal according to the consulted bibliography [22-24].

In subject 2, it's worth highlighting the values of 18° in the right foot and 10° in the left foot of the dorsiflexion of the ankle. The same occurs in the plantarflexion: the right foot with 60° and the left with 50°. This means the total passive joint range is bigger in the right foot than the left.

In subject 4, a difference of over 10° was also detected in the dorsiflexion of the 1st metatarsal-phalangeal joint of the right foot in relation to the left.

Only subjects 1 and 4 presented similar values of plantarflexion of the 1st metatarsal-phalangeal joint. In all the other results, the degrees obtained are equal to or greater than 10°.

In subject 2, besides the difference in the dorsiflexion of the ankle, the inversion of the midtarsal joint is also bigger in the right foot at approximately 8°.

Regarding the values of bisection of the heel, subject 3 presents 2° more valgo in the left foot (4°) than in the right foot (2°).

The Table 3 summarize the values to the plantar pressures, these are presented individually for each subject in the tables. Though the maximum pressure always occurs at heel level, in the right foot of subject 2 the value of the maximum pressure is equal when comparing the heel with the 3rd metatarsus (Mtt).

Table 2. Goniometric measurements of the different joints of the five subjects in the study

Goniometry		**Right**					**Left**				
		Subject					**Subject**				
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Ankle	**DF.**	12°	18°	8°	12°	14°	10°	10°	8°	12°	14°
	PF.	44°	60°	52°	62°	58°	52°	50°	48°	64°	62°
1stMt.Ph	**DF.**	54°	60°	56°	54°	64°	60°	60°	56°	64°	64°
	PF.	70°	68°	80°	70°	76°	72°	50°	70°	66°	62°
MT	**Inv.**	30°	32°	38°	40°	40°	30°	24°	38°	42°	42°
	Eve.	28°	12°	20°	22°	26°	34°	18°	22°	26°	30°
Helbing		4° Valgo	2° Valgo	2° Valgo	3° Valgo	5° Valgo	5° Valgo	2° Valgo	4° Valgo	3° Valgo	5° Valgo

(Abbreviations.: 1st Mt. Ph – First Metarsophalange joint; MT – Midtarsal joint; DF – Dorsiflextion; PF – Plantarflextion; Inv. – Invertion; Eve. – Evertion)

Table 3. Characterization of the 10 areas of plantar pressure during the support phase for each foot and subject

		Left foot					Right foot				
		Start (ms)	**End (ms)**	**Contact (%)**	**Max P (N/cm²)**	**Time Max P (ms)**	**Start (ms)**	**End (ms)**	**Contact (%)**	**Max P (N/cm²)**	**Time Max P (ms)**
Subject 1	1 Toe	327.4	708.2	51	3.6	580.0	312.5	681.0	52	1.7	520.0
	2-5 Toes	464.6	715.9	34	1.1	626.7	437.0	677.4	34	0.7	603.3
	1 MTT	140.8	675.9	72	3.0	520.0	179.0	629.5	63	3.5	470.0
	2 MTT	127.8	686.7	75	8.1	586.7	139.3	645.8	71	7.1	516.7
	3 MTT	106.6	687.6	78	9.4	563.3	109.8	645.6	75	7.5	556.7
	4 MTT	97.0	680.6	79	5.7	553.3	96.1	637.9	76	4.7	403.3
	5 MTT	124.1	651.9	71	2.4	503.3	103.3	613.3	72	3.5	426.7
	Mid-foot	50.2	500.6	61	2.1	176.7	71.4	423.5	50	1.9	223.3
	Medial heel	0.2	409.3	55	10.0	150.0	0.0	343.6	48	9.6	150.0
	Lateral heel	0.0	385.9	52	7.6	96.7	0.0	347.5	49	9.1	116.7
Subject 2	1 Toe	374.8	848.5	56	16.3	756.7	464.8	822.6	43	3.5	720.0
	2-5 Toes	414.8	818.5	47	2.2	763.3	374.8	798.5	51	1.1	720.0
	1 MTT	258.2	782.6	61	4.2	536.7	118.2	782.6	81	8.1	666.7
	2 MTT	141.5	799.2	77	13.2	660.0	80.8	799.2	87	22.0	686.7
	3 MTT	94.8	798.5	82	21.8	663.3	67.4	799.2	89	23.3	683.3
	4 MTT	74.1	795.9	85	17.4	666.7	54.8	788.5	89	16.3	686.7
	5 MTT	58.2	751.8	81	5.7	623.3	261.5	725.2	56	2.4	623.3
	Mid-foot	128.2	545.9	49	2.0	360.0	68.2	621.8	67	3.7	406.7
	Medial heel	11.5	501.8	57	11.9	186.7	4.8	508.5	61	16.3	206.7
	Lateral heel	3.6	481.8	56	14.5	213.3	0.0	451.8	55	7.0	30.0
Subject 3	1 Toe	181.5	825.9	77	14.5	700.0	351.5	801.8	56	6.4	656.7
	2-5 Toes	544.8	771.8	27	1.1	650.0	284.8	785.2	62	4.6	636.7
	1 MTT	148.2	765.9	74	11.0	613.3	118.2	755.2	79	15.8	626.7
	2 MTT	141.5	775.9	76	9.2	610.0	98.2	762.6	82	18.3	706.7
	3 MTT	84.8	768.5	81	15.0	653.3	78.2	739.2	82	13.2	613.3
	4 MTT	68.2	729.2	79	5.9	606.7	64.8	675.9	76	3.3	543.3
	5 MTT	68.2	691.8	74	4.2	573.3	108.2	641.8	66	1.5	493.3
	Mid-foot	104.8	498.5	47	1.1	216.7	224.8	441.8	27	0.9	316.7
	Medial heel	11.5	435.2	50	11.0	163.3	7.2	411.8	50	24.0	170.0
	Lateral heel	0.8	431.8	51	14.7	93.3	8.2	368.5	45	12.5	133.3
Subject 4	1 Toe	338.2	748.5	54	7.7	706.7	504.8	849.2	40	6.2	796.7
	2-5 Toes	411.5	745.2	44	1.1	593.3	281.5	795.2	59	2.4	713.3
	1 MTT	224.8	698.5	63	4.8	540.0	294.8	785.2	57	7.9	650.0
	2 MTT	124.8	698.5	76	7.9	506.7	131.5	788.5	76	20.5	660.0
	3 MTT	94.8	678.5	77	9.5	493.3	108.2	788.5	78	18.7	636.7
	4 MTT	70.8	661.8	78	6.8	476.7	124.1	771.8	75	12.3	650.0
	5 MTT	64.8	621.8	74	4.4	393.3	91.5	718.5	72	12.1	530.0
	Mid-foot	3.3	750.0	99	0.0	0.0	204.8	458.5	29	1.5	346.7
	Medial heel	0.5	418.5	55	15.6	203.3	0.5	458.5	53	19.8	210.0

		Left foot					**Right foot**				
		Start (ms)	**End (ms)**	**Contact (%)**	**Max P (N/cm²)**	**Time Max P (ms)**	**Start (ms)**	**End (ms)**	**Contact (%)**	**Max P (N/cm²)**	**Time Max P (ms)**
	Lateral heel	0.0	405.2	54	14.5	23.3	0.3	418.5	48	10.6	213.3
Subject 5	1 Toe	374.8	735.2	48	15.2	620.0	451.5	761.8	40	6.8	670.0
	2-5 Toes	328.2	718.5	52	3.5	623.3	3.3	763.3	99	0.0	0.0
	1 MTT	284.8	645.2	48	3.5	493.3	301.5	715.2	54	6.8	560.0
	2 MTT	181.5	658.5	64	8.8	503.3	248.2	729.2	63	24.6	650.0
	3 MTT	148.2	685.2	72	9.9	503.3	258.2	715.2	60	13.9	630.0
	4 MTT	124.8	668.5	72	5.7	500.0	311.5	695.2	50	2.0	586.7
	5 MTT	98.2	618.5	69	6.2	440.0	264.8	651.8	50	1.5	420.0
	Mid-foot	168.2	435.9	36	1.3	343.3	214.8	535.2	42	2.4	396.7
	Medial heel	1.5	388.5	52	20.0	56.7	21.5	478.5	60	15.0	203.3
	Lateral heel	1.5	388.5	52	18.9	116.7	31.5	438.5	53	10.8	173.3

(Abbreviations: ms – milisecond; % - percent; N/cm^2 – Newton per square centimeter; 1 Toe – First Toe; 2-5 Toes – Second to Fifth Toes; 1 MTT – First Metatarsal; 2 MTT- Second Metatarsal; 3 MTT – Third Metatarsal; 4 MTT – Fourth Metatarsal ; 5MTT – Fifth Metatarsal)

In subject 2, the third Mtt presents a value of maximum pressure of 21.8 N/cm^2 in the left foot and 23.3 N/cm^2 in the right foot. Also, the value of maximum pressure in the 2nd Mtt of the right foot in subjects 4 and 5 is underlined as the values are above 20 N/cm^2: 20.5 N/cm^2 and 24.6 N/cm^2 respectively.

The beginning of plantar pressure occurs mostly through the lateral heel, although in the right foot of subject 3, the beginning of the support occurs through the medial heel. It is also worth noting that in the right foot of subject 1 and in both feet of subject 5, the beginning of plantar pressure occurs through the central region of the heel.

The final stage of plantar pressure mostly occurs through the 1st toe, although in subjects 1 and 5 foot off is done by the small toes (left foot of subject 1 and right foot of subject 5).

On the other hand, the initial displacement of the CoP (graphics E of each subject) occurs on its lateral side, but after the heel support, suffering medial displacement throughout the stance phase of the gait cycle. The positive values of the graphics correspond to the varo or supination and the negative values correspond to the valgo or pronation.

The data concerning subjects 1 and 4 (Figs. 6E and 9E) underline the medial transition; it still occurs in the loading response. This is relevant the fact that subject 1 presents the medical displacement much earlier on the right foot than on the left one. In all the other subjects this situation only occurs during the midstance.

With regard to the ΔCoP (Table 4) subjects 2 and 3 are the ones in which a bigger variation occurs, 43.8 mm and 49.8 mm respectively, although subjects 3 and 4 are the ones who present a bigger difference between the right and the left foot.

Table 4. Med-lateral variation in stance phase (ΔxCoP)

	Right foot	**Left foot**
	Max. Δx (mm)	
Subject 1	24,5	16,7
Subject 2	43,8	37,3
Subject 3	35,1	49,8
Subject 4	29,9	39,3
Subject 5	23,1	33,1

(Abbreviation: Max. Δx (mm) – Maximum med-lateral variation)

3.2 Biomechanical Assessment

During the stance phase of the gait cycle, kinetic (ground reactive force – vertical component) and kinematic (angular displacement) variables were obtained. As happened with the clinical examination, differences between the left and right feet were quantified as well as differences between the sample's different subjects (Table 5) and (Figs. 6A, 6B, 6C, 6D to 10A, 10B, 10C, 10D).

In the present study, the vertical component of the reactive force served as reference for the five stances (I.C., L.R., M.S., T.S. and P. Sw.) described in the processing and collection of data. That way it is known that the vertical lines that appear on the graphics (Figs. 6A, 6B, 6C, 6D to 10A, 10B, 10C, 10D) correspond to instants of the vertical component of the reactive force in the stance phase. The dark line represents the right foot and the dashed line represents the left foot.

In Table 5 besides the previously mentioned instants, the time in percentage of the support phase was also quantified. The differences regarding subject 2 on his left and right feet are noteworthy in the L.R. and M.S. (Table 5 and Figs. 7A to D).

Table 5. Ankle, Tibia/hindfoot, hindfoot/forefoot and forefoot/hallux angles to the right foot at different instants of the stance phase

Subject 1					
Right foot	**I.C.(0%)**	**L.R.(18%)**	**M.S.(42%)**	**T.S.(80%)**	**P.Sw(100%)**
Ankle	8,7º DF	3,3º DF	9,0º DF	14,5º DF	-10,7º PF
HFTB	-6,9º EV	-15,9º EV	-8,7º EV	-0,1º EV	-5,4º EV
HFFF	22,6º IN	19,4º IN	17,9º IN	18,4º IN	27,3º IN
FFHX	-8,5º PF	-14,9º PF	-20,7º PF	-15,8º PF	-3,4º PF
Left foot					
Ankle	4,7º DF	3,0º DF	9,7º DF	14,1º DF	-12,8º PF
HFTB	-10,9º EV	-22,3º EV	-13,2º EV	-4,7º EV	-14,8º EV
HFFF	17,30º IN	17,0º IN	15,8º IN	15,0º IN	21,4º IN
FFHX	3,48º DF	5,3º FD	-6,2º PF	-3,3º PF	5,21º DF
	I.C.(0%)	**L.R.(20%)**	**M.S.(44%)**	**T.S.(78%)**	**P.Sw(100%)**
Subject 2					
Right foot	**I.C.(0%)**	**L.R.(16%)**	**M.S.(36%)**	**T.S.(80%)**	**P.Sw(100%)**
Ankle	6,8º DF	2,7º DF	12,0º DF	20,4º DF	-6,0º PF
HFTB	-25,7º EV	-40,3º EV	-34,7º EV	-26,7º EV	-25,7º EV
HFFF	-24,4º EV	-25,7º EV	-26,3º EV	-28,0º EV	-19,3EV
FFHX	-8,2 PF	-11,4º PF	-7,9º PF	-3,4º PF	4,8º DF
Left foot					
Ankle	2,5º DF	8,1º DF	8,9º DF	9,0º DF	
HFTB	-8,39º EV	-19,0º EV	-14,2º EV	-7,4º EV	-8,8º EV
HFFF	-10,2º EV	-8,6º EV	-11,5º EV	-10,4 EV	-3,2º EV
FFHX	-12,4º PF	-14,9 PF	-13,0º PF	-13,1 PF	7,5º DF
	I.C.(0%)	**L.R.(26%)**	**M.S.(56%)**	**T.S.(80%)**	**P.Sw(100%)**
Subject 3					
Right foot	**I.C.(0%)**	**L.R.(22%)**	**M.S.(50%)**	**T.S.(76%)**	**P.Sw.(100%)**
Ankle	3,7º DF	8,1º DF	14,9º DF	16,4º DF	-11,9º DF
HFTB	-39,3 EV	-52,6 EV	-56,0 EV	-60,5º EV	-58,5 EV
HFFF	-3,0 EV	-3,2º EV	-5,0 EV	-4,9º EV	1,5º IN
FFHX	11,9º DF	-9,2º PF	-5,8º PF	-9,5º PF	29,6º DF
Left foot					
Ankle	1,59º DF	0,5º DF	10,7º DF	12,7º DF	-10,4º PF
HFTB	-19,1º EV	-33,1 EV	-32,7º EV	-21,9º EV	-32,4º EV
HFFF	-4,8º EV	-4,4º EV	-6,4º EV	-5,4º EV	0,3º IN
FFHX	12,4º DF	2,3º DF	2,2º DF	6,2º DF	32,0º DF
	I.C.(0%)	**L.R.(22%)**	**M.S.(48%)**	**T.S.(76%)**	**P.Sw.(100%)**
Subject 4					
Right foot	**I.C.(0%)**	**L.R.(22%)**	**M.S.(42%)**	**T.S.(74%)**	**P.Sw(100%)**
Ankle	5,7º DF	4,8º DF	9,8º DF	15,8º DF	-14,1º PF
HFTB	13,4º IN	-1,38º EV	0,4º IN	10,9º IN	3,5º IN
HFFF	-37,8º EV	-36,2º EV	-36,1º EV	-37,6º EV	-28,4º EV
FFHX	-17,6º PF	-25,9º PF	-28,5º PF	-31,6º PF	-14,4º PF
Left foot					
Ankle	6,4º DF	4,7º DF	10,1º DF	14,7º DF	-10,8º DF
HFTB	-0,1º EV	-13,7º EV	-6,6º EV	3,5º IN	-2,3º EV
HFFF	-21,1º EV	-20,5º EV	-20,3º EV	-21,4º EV	-15,6º EV
FFHX	-20,0º PF	-19,7º PF	-21,7º PF	-20,4º PF	-0,5º PF
	I.C.(0%)	**L.R.(24%)**	**M.S.(50%)**	**T.S.(76%)**	**P.Sw(100%)**

Subject 5					
Right foot	**I.C.(0%)**	**L.R.(30%)**	**M.S.(52%)**	**T.S.(78%)**	**P.Sw(100%)**
Ankle	4,6º DF	8,9º DF	10,1º DF	10,0º DF	-15,3º PF
HFTB	2,3º IN	-15,4º EV	-10,6º EV	-1,94º EV	-9,9º EV
HFFF	4,2º IN	3,5º IN	2,8º IN	3,7º IN	11,9º IN
FFHX	-16,8º PF	-24,6º PF	-28,8º PF	-28,4º PF	-34,5º PF
Left foot					
Ankle	2,2º DF	7,1º DF	11,2º DF	12,3º DF	-16,8º PF
HFTB	4,4º IN	-9,2º EV	-1,7º E.V.	7,1º IN	-1,8º EV
HFFF	1,8º IN	1,8º IN	0,6º IN	-1,4º EV	9,3º IN
FFHX	-10,3º PF	-13,0º PF	-11,5º PF	-13,8º PF	-18,4º PF
	I.C. (0%)	**L.R. (26%)**	**M.S. (52º)**	**T.S. (76%)**	**P.Sw (100%)**

(Abbreviation: I.C. – Initial Contact; L.R. – Loading Response; M.S. – Midstance; T.S. – Terminal Stance; P. Sw. – Preswing; HFTB – Hindfoot/Tibia; HFFF – Hindfoot/Forefoot; FFHX – Forefoot/Hallux.)

Regarding the kinematic data, we can see that for the ankle angle, the initial contact occurs in all subjects and in both feet in dorsiflexion (see Table 5). This is bigger in the subjects who present with a bigger passive joint range (see Table 2).

The plantarflexion movement occurs from 0% to 10%. Its maximum value is variable for each subject as well as the percentage in which it occurs (Figs. 6A to 10A).

After the first movement of plantarflexion, the dorsiflexion starts. This increases gradually until the T.S., which occurs between 74 and 80%.

The M.S. is where the biggest disturbances in the progressivity of the dorsiflexion movement occur. This is more obvious notorious in subjects 2 and 3. In subject 2 the disturbance only occurs on the left foot (Fig. 7A) and in subject 3 it occurs in both feet (Fig. 8A).

In evaluating the behaviour of the passive movement of the joint concerned, it was verified that in subject 2 the dorsiflexion of the left foot is much more limited than in the right foot. In subject 3, the passive dorsiflexion is equal in both feet, although *limited* by 8º.

The second movement of plantarflexion occurs in every subject in the instants of the second peak of maximum vertical force in the T.S. phase. After this instant the movement is progressive and reaches the maximum value of plantarflexion in the last contact between the foot and the ground.

With regard to the hindfoot/tibia angle (Figs. 6B to 10B), it was verified that in subjects 1, 2 and 3 the hindfoot is in all the support phase in eversion in relation to the tibia, whilst in subjects 4 and 5 there are phases in which the hindfoot is inverted in relation to the tibia.

When analyzing the pattern of the curves we verify that after the I.C. there is a movement toward eversion, with maximum eversion being reached during the L.R., although in subject 1 (Fig. 6B) the maximum eversion corresponds to the instant of the first maximum force peak in the stance phase.

After the maximum eversion the inversion movement starts and reaches its peak in the T.S. The movement then inverts until the final contact.

With regard to the ankle angle, we verify that the hindfoot/tibia angle is closest in subjects in whom there is a bigger similarity of this angle within the same subject. And when the dorsiflexion movement is smaller, the eversion is also smaller as well as the transition between eversion and inversion.

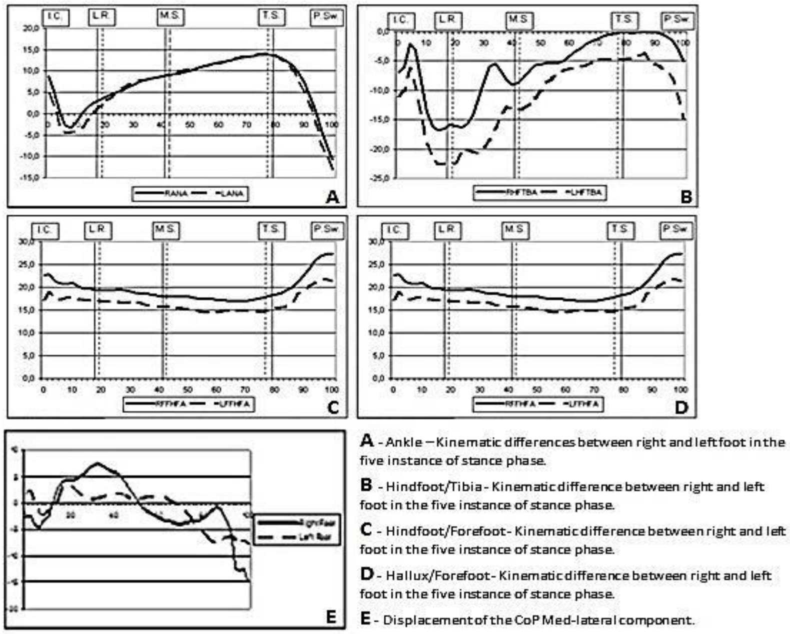
When comparing with the Helbing line (see table 2), we didn't find a relation between this angle, which is measured with the patients in quasi static position, and the hindfoot/tibia angle during the stance phase of the gait cycle.

As for the hindfoot/tibia angle (Fig. 6C to 10C), we verify that in subjects 1 and 5 (figure 6C to 10C) the forefoot is in inversion during all of the support phase and that in subjects 2, 3 and 4 (Figs. 7C, 8C and 9C) the forefoot is in eversion in relation to the hindfoot.

In subjects 2 and 4 (Figs. 7C to 9C) there is a big difference between the left and the right foot. This difference is not reproduced in the same magnitude for the angles previously referred to with the exception of subject 2, who also shows differences between right and left foot in the same order of magnitude when measured with the goniometer (Table 2 and Fig. 7C).

The only event that crosses all subjects is the movement of inversion that occurs in the T.S. and is maintained up to the P.Sw.

With regard to the hallux/forefoot angle (figure 6D to 10D), we verify that until the M.S. a movement of plantarflexion occurs. And during the T.S. a movement of dorsiflexion begins until the last contact of the foot with the support surface, although this situation doesn't occur with subject 5 (Fig. 10A) in whom the movement is progressive toward plantarflexion. The left foot sees an abrupt increase to 94% in the stance phase. The goniometric measurement doesn't evaluate any limitation in the dorsiflexion and during the trials no disturbances in the normal collecting of the data occurred.



A - Ankle – Kinematic differences between right and left foot in the five instance of stance phase.

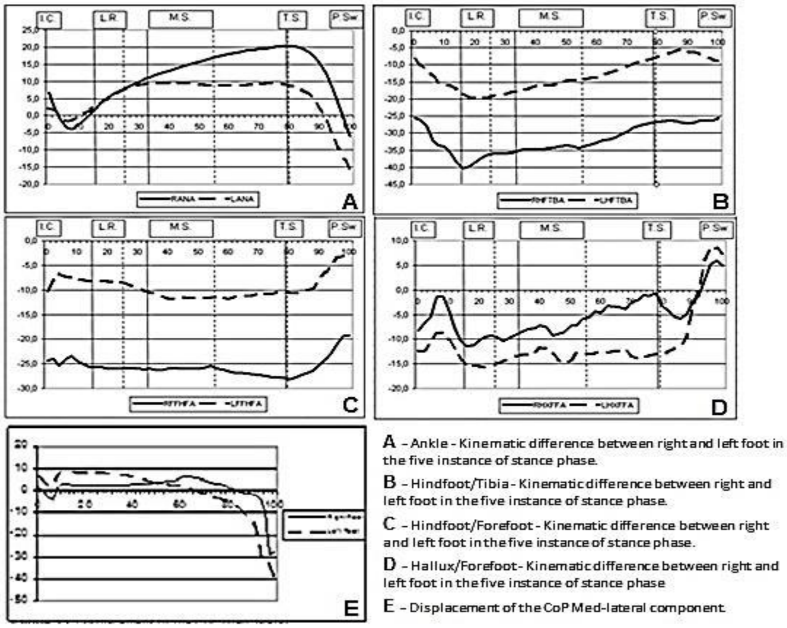
B - Hindfoot/Tibia - Kinematic difference between right and left foot in the five instance of stance phase.

C - Hindfoot/Forefoot - Kinematic difference between right and left foot in the five instance of stance phase.

D - Hallux/Forefoot - Kinematic difference between right and left foot in the five instance of stance phase.

E - Displacement of the CoP Med-lateral component.

Fig. 6. Kinematic difference between right and left foot in the five instance of stance phase in Subject 1



A - Ankle - Kinematic difference between right and left foot in the five instance of stance phase.

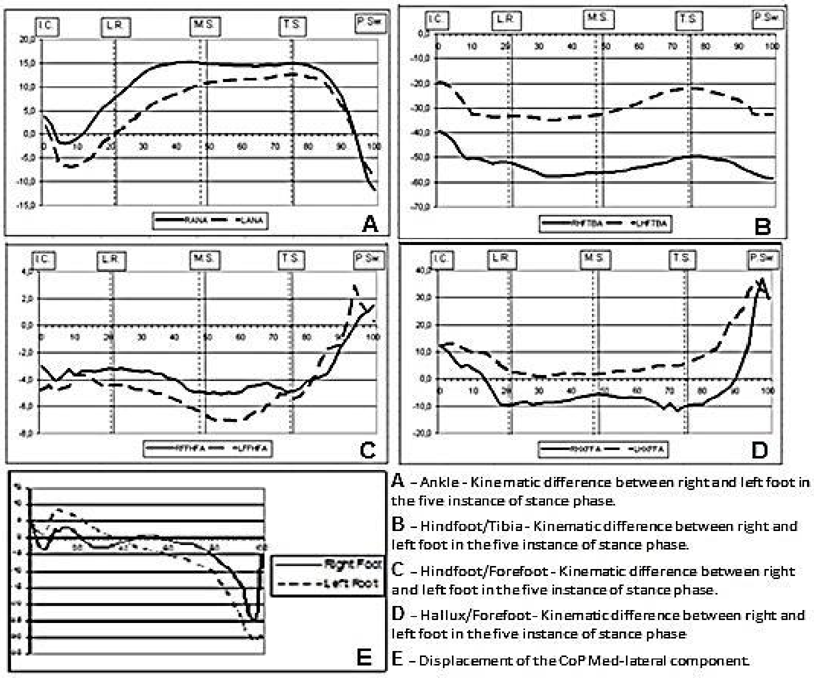
B - Hindfoot/Tibia - Kinematic difference between right and left foot in the five instance of stance phase.

C - Hindfoot/Forefoot - Kinematic difference between right and left foot in the five instance of stance phase.

D - Hallux/Forefoot - Kinematic difference between right and left foot in the five instance of stance phase

E - Displacement of the CoP Med-lateral component.

Fig. 7. Kinematic difference between right and left foot in the five instance of stance phase in Subject 2



A – Ankle - Kinematic difference between right and left foot in the five instance of stance phase.

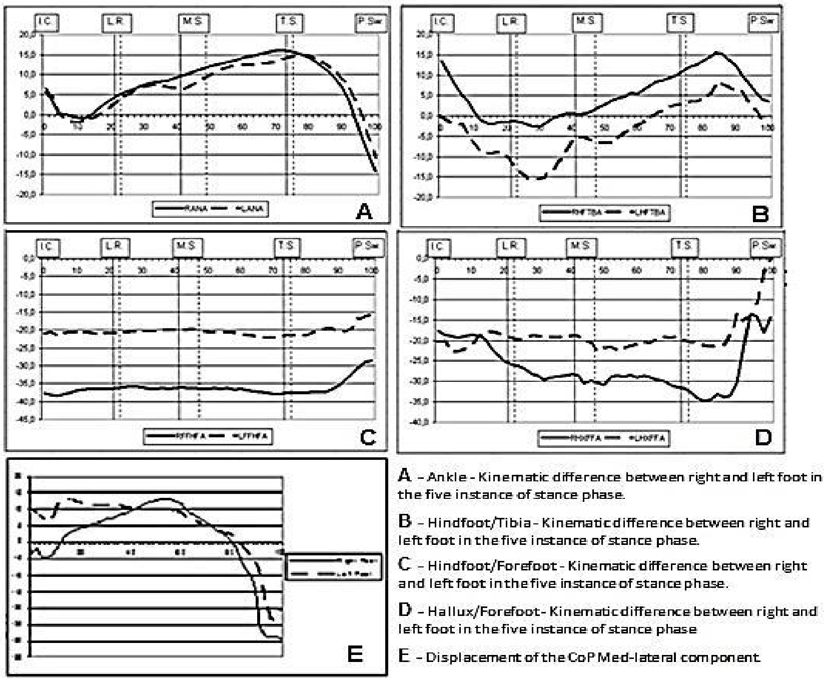
B – Hindfoot/Tibia - Kinematic difference between right and left foot in the five instance of stance phase.

C – Hindfoot/Forefoot - Kinematic difference between right and left foot in the five instance of stance phase.

D – Hallux/Forefoot - Kinematic difference between right and left foot in the five instance of stance phase

E – Displacement of the CoP Med-lateral component.

Fig. 8. Kinematic difference between right and left foot in the five instance of stance phase in Subject 3



A – Ankle - Kinematic difference between right and left foot in the five instance of stance phase.

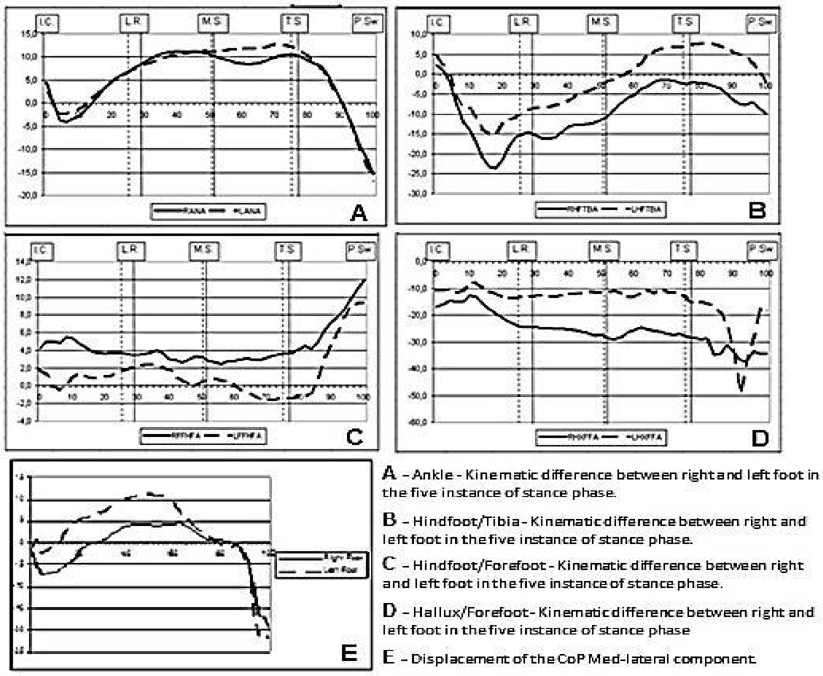
B – Hindfoot/Tibia - Kinematic difference between right and left foot in the five instance of stance phase.

C – Hindfoot/Forefoot - Kinematic difference between right and left foot in the five instance of stance phase.

D – Hallux/Forefoot - Kinematic difference between right and left foot in the five instance of stance phase

E – Displacement of the CoP Med-lateral component.

Fig. 9. Kinematic difference between right and left foot in the five instance of stance phase in Subject 4. A - Ankle; B – Hindfoot/Tibia; C – Hindfoot/Forefoot; D – Hallux/Forefoot; E – Displacement of the CoP in is med-lateral component



A – Ankle - Kinematic difference between right and left foot in the five instance of stance phase.

B – Hindfoot/Tibia - Kinematic difference between right and left foot in the five instance of stance phase.

C – Hindfoot/Forefoot - Kinematic difference between right and left foot in the five instance of stance phase.

D – Hallux/Forefoot - Kinematic difference between right and left foot in the five instance of stance phase

E – Displacement of the CoP Med-lateral component

Fig. 10. Kinematic difference between right and left foot in the five instance of stance phase in Subject 5. A - Ankle; B – Hindfoot/Tibia ; C – Hindfoot/Forefoot; D – Hallux/Forefoot; E – Displacement of the CoP in is med-lateral component

4. DISCUSSION

The analysis of walking is a complex activity where many segments are interrelated. The development of gait analysis techniques enables the preview and quantification of biomechanical parameters in a more reliable way. These might be kinetics (involved forces) or kinematics (angular displacement) and they seek to establish a parameter of normal gait [4].

Initially biomechanical studies used biomechanical models that considered the foot as a rigid body without intrinsic movements. This left many questions unanswered [4,13,22,25-28].

The creation of multisegmental models, amongst them the Oxford Foot Model, emerged as a way of understanding the biomechanics of the foot and its relation to other segments [23,28–35]. However, its use in the clinical environment, especially in podiatry, is not very frequent.

With the present study we aim to objectively quantify the variables previously described (joint range, kinematic and dynamic variables, through the OFM output and kinetic variables, through the force platform) and so contribute so that biomechanics studies can become an excellent complementary diagnosis method to clinical practice.

The study represents a set of studies that took samples of healthy subjects without any type of lesion or limitation. The data collected support the need for each subject to be analyzed as "unique," presenting specificities related to their motor control developed according to the requested tasks.

Table 2 represents the range of the joints previously described. This enables us to see the existing difference, not only between subjects, but also between the same subject's left and right foot, as well as reference values for each joint.

According to the consulted authors [22–24], the obtained values (Table 6) for the different joint ranges are within normality. The only exception is found in the dorsiflexion of the ankle joint as we obtained a minimum FD value of 8° and a maximum of 18°. According to the consulted authors, the reference value for the ankle FD is 20°, however the same authors also say that 10° is enough to obtain a normal gait.

Table 6. Comparison of goniometric values obtained with reference values

		Right foot	Left foot	Reference value
MTPh	**DF**	54º-80º	50º-70º	50º to 70º
	PF	52º-70º	56º-72º	70º to 90º
Ankle	**DF**	8º-18º	8º-14º	20º
	PF	44º-62º	48º-64º	40º to 50º
MT	**Inv**	30º-40	24º-42º	35º
	Eve	12º-28º	18º-34º	15º
Helbing	--	2º-5º Valgo	2º-5º Valgo	3º to 5º Valgo

(Abbreviation: MTPh – Metatarsophalange; MT – Midtarsal; DF – Dorsiflexion; PF – Plantarflexion; Inv – Invertion; Eve – Evertion.)

The FD value of the passive joint range under 10º was obtained in subject 3, however this subject doesn't have any incapacity that excludes him from the inclusion criteria defined. Comparing these data with the kinematic data of the OFM, we verify that the maximum FD obtained was 16º in the right foot and 13º in the left foot (Fig. 8A). This means that during the stance phase of the gait cycle the subject obtained a joint range above the authors' considered value as restrictive for a “normal” walk. However, we can't fail to mention that from 35% to 75% the increase of the FD is not as expected. This situation is also noticeable in subject 2, in whom the passive joint range in the left foot is 10º of FD and 18º in the right one. And when comparing this with the kinematic data, there is a significant difference in the trend of the curves. In the left foot, from 30% to 80% there isn't any increase in FD during the support phase. This doesn't happen with the right foot, in which from 5% to 80% there is a constant and progressive increase in FD, peaking at a maximum of 20º (Fig. 7A).

Such a range is not achieved in any other subject and the same happened for the passive joint range. This means that subject 2 was the only one to obtain 18º of FD, in this case in the right foot only.

For the remaining joints, the same parallelism between the passive joint range, measured with the goniometer, and the joint range, obtained through OFM, wasn't found.

According to the remaining analyzed variables, the plantar pressure and the CoP also present differences, not only in each subject but also between subjects. This way it is possible to observe different areas of maximum pressure. The maximum pressure obtained is also different between subjects and in the same subject when comparing the right and the left foot. This finding is also evident in the CoP displacement as well as in Δx CoP.

The consulted bibliography [11,34-40] is not very consensual regarding the areas of maximum pressure and the behaviour and CoP variation, however some explanations are given regarding this matter.

According to Scott et al. [37], the presence of digital deformities associated with age, like bunions (HAV), claw toes and even weakness of the flexor muscles of the toes, translates into changes in plantar pressures. The same author also says that the length of the step as well as a lower cadence of the steps are factors that translate into lower plantar pressures, in particular in the heel, the forefoot and in the Hallux [37].

In the same way, Menz and Morris [36] say that the maximum heel plantar pressure is related to the contact speed of the heel with the support surface as well as the fat tissue and the flexibility of the ankle. According to the same authors, the lower pressure underneath the first metatarsal head may be related to a limitation of the joint range of the first joint MTF, thereby making the propulsive phase less effective [36].

For the authors Rosenbaum and Becker [38] and Queen et al. [39], the different plantar pressures are directly related to the anthropometric factors and the different types of feet. In other words, cavus feet and flat feet create different types of pressure [38,39].

Like us, Stebbins et al. [40] also obtained the maximum pressure values in the heel as well as in the central area of the forefoot. On the other hand Gurney et al. [41] obtained the maximum pressure in the heel and medial forefoot. As for Pataky et al. [42], the maximum pressure was obtained at the heel and fourth metatarsal. Thus, the consulted authors were in agreement over the maximum pressure at the heel. The same does not occur in the forefoot area.

Regarding the CoP, De Cock et al. [11] associated its displacement and its variation according to the pronation and supination movements occurring throughout the support phase of the walking cycle as well as with the height of the internal longitudinal arch. In other words, lower arches lead to CoP over internal and higher arches lead to CoP over lateral. The same authors also state that medio-lateral variation of the CoP is related to tibial rotation and foot flexibility [11].

Gurney et al. [41] also say that the Δx CoP is relatively low, about 18% of the foot's length due to the refined motor control of the complex “Foot and Ankle”.

The correct collection and analysis of the above data are important, because they often translate into overloads that potentiate lesions. These are excellent auxiliary means in clinical practice [10,39,41].

With regard to the kinematic data, these were obtained through the output of the OFM and had as reference five instants of the vertical component of the reactive force on stance (IC, LR, MS, TS and P. Sw.) [12].

Through the obtained data, differences are noted between the left and right foot of the same subject in terms of Fz during the five instants previously mentioned. The percentages in which these peaks are reached are also distinct. These differences observed, not only in the FRA, but also in the remaining variables analyzed, take us to the subject-matter of the human variable in healthy subjects [43,44].

Although it is possible to obtain the angular values in the three orthogonal axes for all the segments through the OFM [19], our study only collected data regarding the main movements of each joint. For the ankle the dorsiflexion and plantarflexion were quantified, for the tibia/hindfoot angle the inversion and eversion were quantified, for the hindfoot/forefoot angle it was the inversion and eversion and for the forefoot/Hallux angle, the movements of dorsiflexion and plantarflexion.

When analyzing the kinematics of the ankle it was verified that in all studied subjects the beginning of the support phase occurs with the ankle in FD. The FP of the ankle occurs immediately after, between 6 and 10% of the support phase. After this phase the movement of FD, which endures until 80%, takes place. However, it changes from subject to subject as seen in Figs. 6A to 10A. In the final phase of support the FP movement occurs again. In all subjects this transition phase from FD to FP coincides with the T.S. instant, in other words the Fxz3.

Analyzing the L.R. in the Fxz1 instant and the M.S. in the Fxz2 instant it was verified that in all subjects in Fz1 the FD movement is already occurring and in some cases in the same subject the registered FD at this instant is different. In Fxz2 the FD movement is still occurring, although it is during the MS phase that the biggest disturbances or even a change in the direction of movement occur during the MS. This way it is possible to observe similar behaviour in the consulted articles, although in a more subtle way [1,4,10,15,19,25,45,46].

In the hindfoot/tibia angle we verify that a bigger difference occurs, not only within the subjects but also between subjects with different absolute values when comparing the consulted bibliography [19,25]. Despite the observed differences, the pattern of the curves is identical both between subjects and when comparing the left and right foot of the same subject.

When associating the kinematic and kinetic data we verify that the Fxz1 not always occurs during the maximum eversion instant of the hindfoot/tibia angle as expected.

In the MS phase, the movement is reversed; in other words, we have an inversion movement, although in subjects 1 and 4 a punctual inversion of the movement occurs at the Fxz2 instant.

According to the studied bibliography, the movement in inversion also occurs although in a less evident way [19,25,44]. In Alonsi-Vázquez et al. [1], the obtained movement was contrary to the one we obtained. This situation is justified by the fact that the pathology that the author analyses favors the increasing of the eversion [1].

With respect to the last phase of the support phase, there is a new eversion movement that is coincident with the maximum instant of FxZ3, with the exception of subjects 2 and 4 in whom this movement occurs slightly later.

According to Alonso-Vázquez et al. [1], in this last stance phase (T.S.) an increase of inversion occurs. This is inverted only in the P. Sw. phase [1].

According to Carson et al. [19], the movement also occurs in the T.S. phase, although the observed movements are smaller.

Analyzing the movement of inversion/eversion, in the forefoot with respect to the hindfoot we verify that its range is smaller when comparing the other segments. This situation is also seen in the goniometric measurement and the MT joint is the one that has less variation. According to the same bibliography, it was also possible to realize that the standard deviation is very high, showing the high variability of this joint [1,19,46,47].

In this segment the difference obtained not only between subjects but also within subjects was the biggest when compared to the remaining segments. Only in subjects 1 and 5 is the support phase done in inversion. In the other cases the forefoot is found in eversion with respect to the hindfoot. However, in all the sample subjects an inversion movement is initiated after the T.S. until the P. Sw. in which a change occurs in the direction of the movement.

According to Carson et al., the values obtained were from IC to P.Sw. whilst for Myers et al. the values were negative for the same segment. For Jenkyn and Nicol and Simon et al. the IC begins in eversion and the P.Sw. ends in inversion [19,25,45,46].

One of the explanations for the results is the fact that within the sample subjects with different types of feet as well as different joint range and muscle tone could exist, although the subjects do not present any type of problem that would stop them participating in the study.

Regarding the dorsiflexion and plantarflexion movements of the Hallux in relation to the forefoot, we also found big intersubject as well as intrasubject differences, although the curve pattern is similar between the subjects of the sample and the consulted bibliography [1,19,45,46].

Unlike what was expected, the IC does not begin with the Hallux in slight FD, since the muscle extensor of the hallux aids the front muscles of the leg to avoid the abrupt fall of the forefoot on the ground, although previously an FP movement occurs that is initiated with the L.R. and terminates with the T.S.

During the take-off phase that begins with the T.S., the hallux begins an FD movement, as expected and according to the consulted and previously mentioned articles. This doesn't occur with subject 5, increasing even more the FP. This can be justified by the fact that in the anterior segment (FFHFA) after the T.S., a variation of around 10º takes place in the direction of inversion and so the hallux is forced to perform one plantarflexion.

In clinic practice is not possible have all the equipment to do a complete and quantitative assessment, so in some situation or some kind of patients we believe be useful ask a biomechanical assessment like a complementary exam with is specific report.

On some kind of pathologies the clinical assessments like goniometry or plantar pressures or even observational test are enough for others situations is very useful have a laboratory support, per example before and after a specific treatment.

5. CONCLUSION

The methodology developed in the present study shows evidence that it is possible, despite the sample size of 5, to quantify, during the walk, the angles of the ankle, of the leg in relation to the hindfoot, of the hindfoot in relation to the forefoot and of the forefoot in relation to the hallux. And as in the goniometric assessment, the obtained values are different from subject to subject as well as within the same subjects when comparing the left and right feet.

The ankle joint is the one where the data are most consistent, not only in this study but also when comparing the bibliography. On the other hand, the tibia/hindfoot and hindfoot/forefoot segments are the ones that present a bigger quantitative difference both in the route of the curve when comparing subjects within the sample and when comparing the left and right feet of the same subject.

We also concluded that besides the direct observation and quantification of each segment of the OFM, it is possible to draw lessons about the relation between the different segments. In other words, when a disturbance occurs in a specific segment it is possible to see the effect that this causes in the other segments.

Through this study it is also possible to discover the importance of previous clinical examinations in order to understand certain dynamic foot behaviours' and not expect similar kinematic and kinetic behaviours within the same subject or within different subjects.

The present results show the development of the project implementation of an effective transfer of laboratorial biomechanics knowledge to clinical knowledge.

CONSENT

Al subjects agreed to participate in the study with signed consent.

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COMPETING INTERESTS

The authors declare no competing interests exist.

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