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REVIEW ARTICLE

Biomechanical profile of vascular diseases. A systematic review

Perfil biomecánico de las enfermedades vasculares. Una revisión sistemática

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Abstract

Biomechanical profile includes the arches of the foot, foot tread, plantar pressures, ankle and knee position, pelvic limb length, spine position and walking speed. This is a systematic review addressing the biomechanical profile in vascular diseases. Search based on PRISMA using PubMed, PubMed Central and Cochrane. Inclusion criteria include Spanish/English studies, any decade, in venous, arterial and diabetic foot disease. To reduce observer and evaluation bias a double review was performed. 10,914 records screened; 9,038 excluded by automation tools and 1,858 by the author. Eighteen articles assessed for eligibility: 12 were eliminated and 6 were included. Only qualitative info analyzed as a limitation. Plantar pressures, spine position (scoliosis) and walking speed were the only three criteria considered. Biomechanics is an essential discipline and movement is the basis of all the cardiovascular system. The peripheral vascular system requires studying it through a broader spectrum, which is why the study propose a normal biomechanical profile.

Keywords: *Biomechanics. Biomechanopathology. Biomechanical profile. Venous disease. Diabetic foot disease.*

Resumen

El perfil biomecánico incluye los arcos del pie, pisada, presiones plantares, posición del tobillo y rodilla, metría pélvica, posición de la columna y velocidad de la marcha. Revisión sistemática, aborda el perfil biomecánico en las enfermedades vasculares. Búsqueda basada en el consenso PRISMA, en PubMed, PubMed Central y Cochrane. Se incluyen estudios en español/inglés, cualquier década, enfermedad venosa, arterial y pie diabético. Doble revisión para reducir sesgo de observador y evaluación. 10,914 registros examinados, 9,038 excluidos por herramientas de automatización y 1,858 por el autor. Dieciocho artículos para determinar su elegibilidad: se eliminaron 12 y se incluyeron 6. Sólo información cualitativa analizada como limitación. Las presiones plantares, la posición de la columna (escoliosis) y la velocidad al caminar fueron los únicos riterios considerados. La biomecánica es una disciplina esencial y el movimiento es la base del sistema cardiovascular. El sistema vascular periférico requiere estudiarse en un espectro más amplio, se propone un perfil biomecánico.

Palabras clave: *Biomecánica. Biomecanopatología. Perfil biomecánico. Enfermedad venosa. Pie diabético.*

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Introduction

We are used to understanding diseases through a certain independence between the different medical specialties, with the intention to comprehend them more easily. However, separating our studies among specialties could prevent us to be capable of seeing the bigger picture of the disease, at least in some of them like vascular diseases. As Vascular Medicine experts, we cannot deny how in the context of May-Thurner or Paget-Shroetter Syndrome, the main problem is extrinsic compression; and the same goes for when endofibrosis develops in a cyclist or a patient with popliteal entrapment develops arterial claudication. Those syndromes cannot be explained by merely hemodynamic changes within the vessel, because bone or muscle displacement, malformation even repeated abnormal movements are responsible for those vascular diseases. One rediscovered vascular disease in which we know for sure there could potentially exist a biomechanical profile[1] responsible for the functional deterioration in the dynamic and statical stability during movement: lipedema. There is an enormous possibility that I have and will continue addressing in future investigations, that lipedema can be complicated by venous, venous thrombotic, and lymphatic disease, among many reasons given the fact that those patients usually pronate the foot which is related to a Valgo position of the ankle and the knee, and potentially have higher rates of symptomatic anisometric legs (leg inequality) and scoliosis, which of course, must be related to the inadequate distribution of the plantar pressures, something observable in the right paraclinical studies, such as a baropodometry and plantoscopy. The main goal of this study is to try to analyze if any medical field has defined an anatomical or biomechanical movement profile in patients with the most common vascular diseases there are. The idea is to create the basis for future studies regarding this topic to couple them and contrast these biomechanical profiles. For example, venous disease, along with the clinical stages and standard hemodynamic studies like Plethysmography in its different variants.

This goal requires establishing a definition of a Biomechanical profile, which the article defines by describing physical and anatomical aspects regarding the anatomy of the foot and leg, the position of the different anatomical landmarks, in addition to a method to evaluate the movement of the leg or foot; a definition that urges us to establish a normal biomechanical profile, so we can pinpoint the biomechanical profile for each vascular disease. This article focuses on vascular diseases without precision, to try to define if this topic has been addressed by other physicians and medical specialties, regarding venous disease, arterial disease, and diabetic foot disease. Given the fact that the most frequent vascular diseases target the leg; it is the biomechanical profile of the leg and the movement of the leg that we will focus more on this text. Anatomically, we must consider the leg as a functional unit, made up of muscles, ligaments, tendons, joints, skin, fascia, fat tissue, nerves, arteries, and veins, therefore, its understanding requires deep knowledge regarding those topics. Except for surgical anatomy, we tend not to take into consideration the possibility of needing to understand vascular diseases, along with the musculoskeletal and nervous pathologies that may coexist.

The aspects that should be analyzed for the normal biomechanical profile to mark the starting point of this and future studies starts from the bottom up: (1) The three arches of the foot which are internal and external longitudinal and transverse arches, through digital plantoscopy, with a normality parameter when the foot tripod is evenly distributed, and the agonistic and antagonistic forces of the foot are symmetrical[2], (2) Foot tread, through a video recording gait analysis, meaning normal when the foot moves through space performing a neutral foot tread each time, (3) Plantar pressures and vector tracking, through baropodometry, meaning normal when the plantar pressures are evenly distributed[3] and the tracking of the vector follows an helical path, (4) Ankle position, through a photo-gallery in different positions or a motion analysis software[4], meaning normal when the ankle is neutral and has no deviations in the Achilles tendon, (5) Pelvic limb length and leg inequality, through the measurement of a panoramic scanometry or a surface topography[5], meaning normal when < 2 cm, (6) Knee position, through a panoramic scanometry or goniometry, meaning normal when the knee has a normal 5-7° Valgo angle[6], (7) Spine position, through an X-ray of the spine, meaning normal when the Cobb angle is < 10°[7], and finally (8) The walking speed, through a video recording of the march, meaning normal when between 0.96 and 1.82 m*s for the spontaneous march[8]. The normal biomechanical profile ergo requires anatomical integrity and normal anatomic function without any movement impairment or deformation in any part of the lower limb, either leg or foot.

Materials and methods

This is a systematic review based on the Prisma 2020 checklist. This review was not registered because the protocol was created as the needs arose table 1. A search was conducted by the first and only author using PubMed, PubMed Central, and Cochrane to locate the most complete articles regarding the subject "Biomechanics of the movement in vascular diseases." The inclusion, exclusion, and elimination criteria considered are shown in table 1. Articles were grouped for the synthesis according to the medical field. The first search was conducted on May 30, 2024, and additional searches were conducted in June 2024, along with the analysis of the articles and the writing of the manuscript, dates will be shown in table 2.

A broad search strategy is presented in table 2. The initial search was tried with "Biomechanics of the movement in vascular diseases" and "Biomechanics in vascular diseases." Then Mesh terms used were "Biomechanics" {AND} "Venous disease"; "Biomechanics" {AND} "Arterial disease"; "Biomechanics" {AND} "Diabetic foot", I used too, "Biomechanopathology" instead of "Biomechanics" as a neologism of physiopathology.

Data collection process

The idea is to try to define a biomechanical profile with the current information on the topic, eliminating all the articles focused on specific treatments or comparison treatments but on the biomechanical profile among the vascular patients studied.

After analyzing each article, it will be determined if they state a biomechanical profile or not according to the following: It will be marked yes with a "Y" if the article states a biomechanical profile and when every column in the line can be fulfilled. If the article stated one or some of the columns but the line cannot be completed, it will be marked Incomplete with an "I".

Results will be separated by the medical discipline conducting the research. After the article selection, a table will be presented with the biomechanical profile described in the introduction, after that it will be discussed. All articles were reviewed by the only author twice. This manuscript will not include quantitative results but only qualitative, because it has the purpose of laying the foundations to start new lines of research in the vascular field.

The discussion will include a case of a patient who agreed to participate in this present study and firmed the informed consent. The anonymity of the participant and the privacy of their information have been protected by eliminating their name in the reporting of the studies and preventing them from showing their full face only their body and extremities.

Table 1. Inclusion, exclusion, and elimination criteria

Criteria	
Inclusion	Articles from any decade. Spanish and English studies. Articles written by any medical field related to the biomechanical profile in venous disease. Articles written by any medical field related to the biomechanical profile in arterial disease. Articles written by any medical field related to the biomechanical profile in diabetic foot disease. Studies reporting at least one of the criteria for biomechanical profile.
Exclusion	Any article related to hemodynamics. Articles focused on results after specific treatments regarding vascular disease in the topic.
Elimination	Clinical case, case series, case-control studies, non-systemized reviews. Anything related to orthosis.

Studies selected

The studies selected were driven by the main purpose of this study, which is to understand if any medical specialty is studying the biomechanics of the movement in patients with vascular diseases through a biomechanical profile, as this article proposes, describing the potential role of the "biomechanopathology" among the different vascular diseases. The process can be better understood by tables 1, 2 and figure 1.

Results

The initial search yielded 10,914 articles which were reduced to 1,876 when applying the limits shown in table 2. After applying the inclusion and exclusion criteria shown in table 1, it was reduced to just eighteen articles, which were carefully analyzed by the only author applying elimination criteria and reducing the number of articles to just six.

Not even one of the articles included more than two of the parameters considered in the biomechanical profile described in the introduction, most of them just one. There are authors using the term biomechanics for other purposes, which could potentially confuse readers. For example, these two articles use the term biomechanics instead of kinematics[9,10], which is why they were eliminated, along with another one that uses the term biomechano for a signaling transduction study regarding cancer metastasis[11].

Table 2. Databases and full search strategies, including filters and limits used

Mesh term	Database	Found	Revised	Used	Field	Ref	Past consultation
"Biomechanics of the movement in vascular diseases"	PubMed	1,835	38**	2^{+}	Biomechanics	10, 12	Jun 13
	PubMed central	0	0	0	-	-	-
	Cochrane	0	0	0	-	-	-
"Biomechanics in vascular diseases"	PubMed	7,325	84**	2^{+}	Biomechanics	12-23	Jun 13
	PubMed central	0	0	0	-	-	-
	Cochrane	67	67	1	Biomechanics	9	Jun 16
"Biomechanics" {AND} "Venous disease" (Title)	PubMed	1	1	1^{++}	Physiotherapy	13	Jun 18
	PubMed central	4	4	1	Research	19	Jun 16
	Cochrane	0	0	0	-	-	-
"Biomechanics" {AND} "Venous disease" (Text Word)	PubMed central	97	97	6^{++}	Rehabilitation Research Biomechanics	13, 22 15, 20 16, 17	Jun 16 Jun 18 Jun 18
	PubMed	5	5	1^{++}	Physiotherapy	13	Jun 18
	Cochrane	0	0	0	-	-	-
"Biomechanics" {AND} "Arterial disease" (Title)	PubMed central	22	22	1	Biomechanics	24	Jun 16
	PubMed	12	12	0	-	-	-
	Cochrane	0	0	0	-	-	-
"Biomechanics" {AND} "Arterial disease" (Text Word)	PubMed central	36	36*	0	-	-	-
	PubMed	5	5*	0	-	-	-
	Cochrane	0	0	0	-	-	-
"Biomechanics" {AND} "Diabetic foot" (Title)	PubMed central	145	145	2	Biomechanics Rehabilitation	21 18	Jun 16 Jun 16
	PubMed	51	51	1	Biomechanics	14	Jun 18
	Cochrane	0	0	0	-	-	-
"Biomechanics" {AND} "Diabetic foot" (Text Word)	PubMed central	1,106	1,106**	0	-	-	-
	PubMed	192	192**	0	-	-	-
	Cochrane	0	0	0	-	-	-
"Biomechano pathology"	PubMed central	10	10	1^{--}	Biomechanics	11	Jun 16
	PubMed	1	1	1^{--}	Biomechanics	11	Jun 16
	Cochrane	0	0	0	-	-	-
	Total of articles	10,914	1,876	18^			Jun 18

$^{+}$The article was found in more than one searches. $^{++}$The article was found in another search. *It was necessary to limit the search with {NOT} Gait {NOT} Orthosis {NOT} Orthotic **Search was limited to analyze only systemized reviews. $^{--}$This article is repeated. ^The total value does not include the repeated articles.

Of the six articles that met the inclusion criteria shown in table 3, five articles were approached by Biomechanists and one by the Rehabilitation field. Diabetic foot disease is the most and almost only topic addressed in five of the six articles, one article addressed venous disease and one arterial disease but in neuropathic diabetic patients. None of the articles stated a complete biomechanical profile, all of them were considered as incomplete (I). Four of the articles considered plantar pressures, one considered scoliosis, and two of them the walking speed. There was no information found regarding arch type, foot tread, vector tracking, ankle or

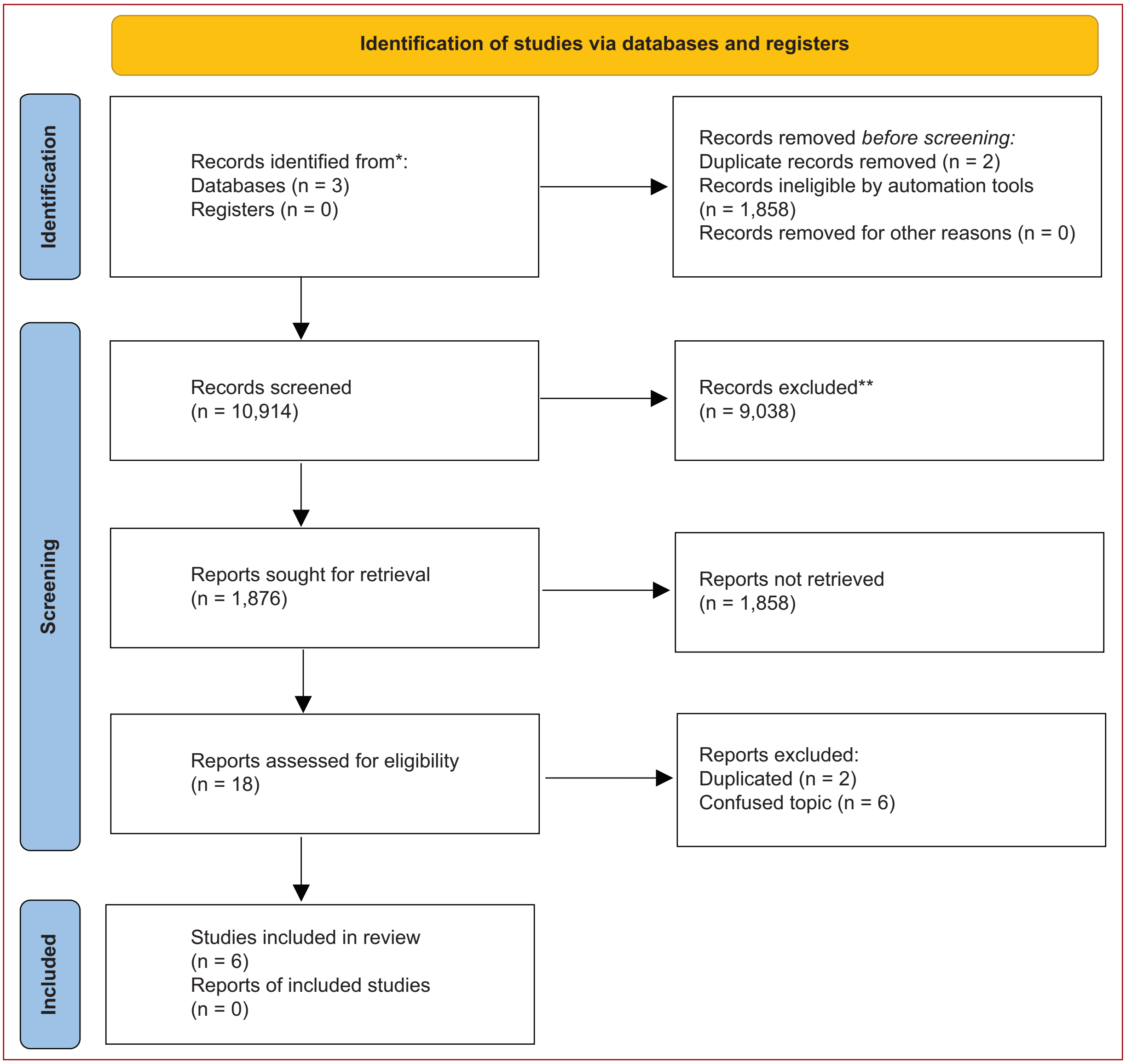

Figure 1. Prisma 2020 flow diagram from new systematic reviews, included searches of databases. *The number of records identified from each database searched can be consulted in table 1. **Automation tools were used; 1,858 records were excluded by human and 9,038 were excluded by automation tools.

knee position, midfoot abnormalities, or leg inequality, although the article regarding scoliosis written by the Rehabilitation field[12] does mention the correlation from scoliosis (specifically Adolescent Idiopathic Scoliosis) with leg inequality superior to 1 cm, contrary to the leg inequality normal parameter of 2 cm[5].

Articles eliminated include some which initially were accepted due to the lack of information despite the low level of evidence, which ultimately did not meet the inclusion criteria[13,14]; because none of them stated at least one of the criteria for biomechanical profile, or talked about anatomy but do not correlate it with biomechanics[15], the search engine confuses biomechanics with hemodynamics[16], or included another criteria not considered in the present article that could be added in future investigations, such as mobility impairment[17,23], kinematics forces[19] or footwear usage[20,21]; something considered as a bias.

Discussion

To my very best knowledge, this is the first article approaching this topic, which I consider of crucial importance in vascular pathologies. It is important to

Table 3. Registry of articles and list of potential criteria to analyze the biomechanical profile among patients with vascular diseases

References	Medical field	¿Does the article state a biomechanical profile?	Arch type	Foot tread	Plantar pressures and Vector tracking	Ankle position	Hallux or Quintus or Clawed toes	Knee position	Anisometry or Leg Inequality	Scoliosis	Walking speed
12	Biomechanics	I	-	-	Y	-	-	-	-	-	Y
13	Rehabilitation	I	-	-	-	-	-	-	-	Y	-
14	Biomechanics	I	-	-	Y	-	-	-	-	-	-
15	Biomechanics	I	-	-	-	-	-	-	-	-	Y
16	Biomechanics	I	-	-	Y	-	-	-	-	-	-
17	Biomechanics	I	-	-	Y	-	-	-	-	-	-

Y for Yes, - for None, I for Incomplete. References are in order of inclusion in the analysis. Table 3 is the result of the data collection sheet.

emphasize the high level of heterogeneity for most of the profile characteristics between the studies, even those that met all the criteria. Even considering that the five diabetic foot articles were analyzed by biomechanists, none of them met at least half of the criteria considered in the biomechanical profile.

These results indicate that we must begin to study the impact that the biomechanical profile has on vascular diseases. Fernando et al., agree that a better understanding of the biomechanical components is of vital importance for the better understanding of ulcer development[22] and theorized that it is probable that the elevated plantar pressure coupled with a longer period of time spent in stance in diabetic patients with peripheral neuropathy and reduced joint kinematics with muscle atrophy contributes to the susceptibility for skin damage through prolonged mechanical load on tissue, leading to skin breakdown and ulceration, although current knowledge is insufficient[22]. Vascular disease patients above all venous disease patients could be summited to the same biomechanical abnormalities, potentially explaining stasis dermatitis.

Zijun et al., found that diabetic peripheral neuropathy (DPN) and peripheral arterial disease (PAD) lead to increased peak pressure in the forefoot, probably related to reduced motion at the ankle, less foot rotation, and less first metatarsophalangeal movement, something previously observed in patients with peripheral neuropathy, a history of plantar ulceration, with reduced swing phase and extended stance phase in instrumented biomechanical gait analysis in PAD patients[14]. Similar results can be found in Fernando et al., implicating the first metatarsophalangeal joint as a site of biomechanical dysfunction that leads to elevated plantar pressures during gait, promoting ulceration in diabetic foot patients at that site[22]. Although Zijun et al., found that the combination of DPN and PAD did not cause further increases in peak pressures, it does cause a larger area of high pressure[14]. Wrobel and Najafi reported similar results for peak plantar pressures, but on a gait analysis found that patients with diabetes frequently exhibits a conservative gait strategy where there is a slower walking speed, the only criteria considered in the biomechanical profile we are studying, but a wider base of gait and a prolonged double support time too; associating it with skin hardening, tendon thickening, muscle atrophy, joints with limited mobility, fat pads less thick and osteoporosis[24]. Something similar found by Sawacha et al.[19] even in diabetic subjects without a clinical diagnosis of peripheral neuropathy.

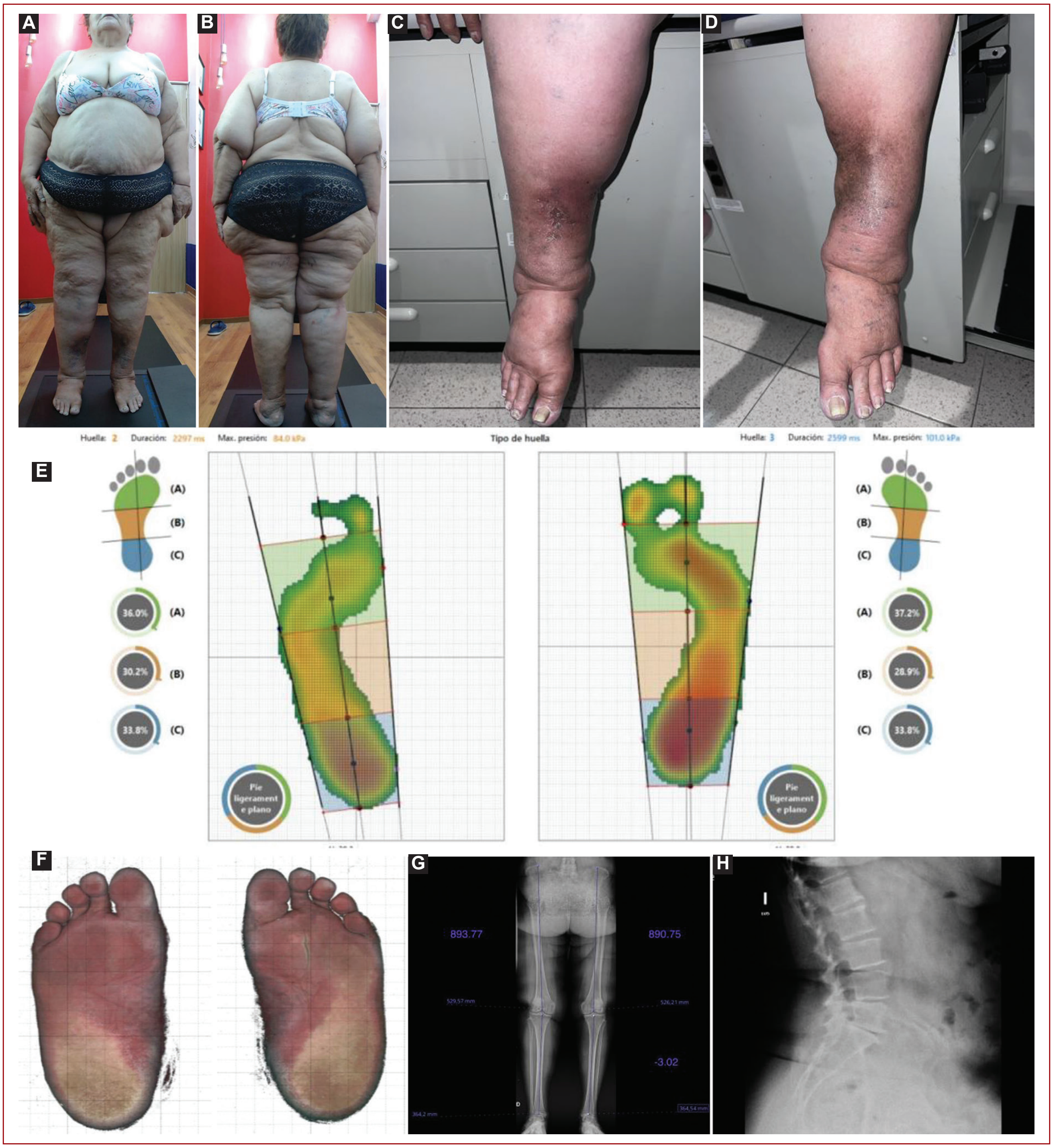

Figure 2. Patient with lipedema and venous disease. **A:** we can observe this patient with traditional lipedema, in the front view. **B:** and the posterior view can be appreciated in the Valgo position of the knees. **B:** in the posterior view it can be seen to the Valgo position of the ankle with Achilles sulci. **C:** the more diseased leg is the right leg, **D**: compared to the left leg **E:** and it correlates with the foot with the higher plantar pressures. **F:** secondary to the greater collapse of the transverse arch and longitudinal external arch, **G:** which correlates with the larger of the two legs, by 3 mm. **A and B:** and the proclivity to position the forefoot in abduction. She has venous disease C4c bilaterally with eczema in the right one, as well as more edema, correlating with the larger leg, **H:** forefoot in the abduction and the higher plantar pressures, associated with spondyloarthropathy.

The most studied biomechanical profile parameter is for sure plantar pressures, studied by Castro-Martins et al., too whom concluded that instrumented insoles with the largest number of sensors are recommended because they can be a critical factor in measurements[25] and consider plantar pressure thresholds as a strategy for the prevention of diabetic foot ulcers[26] stating it in 200 kPa as for risk of ulcer formation and a 32-35 mmHg for a capillary perfusion pressure.

As for venous disease, Talic et al., recognize the changes in the spinal and lower extremities as a risk factor for the development of venous disease, due to congenital or acquired bone deformities of lower legs and even pelvis, which along with pelvis tilt, leg discrepancy or inequality that might lead to disproportion on biomechanical forces on lower extremities, suggesting the potential possibility of pathological collagen synthesis as a consequence[12]; information that is to be confirmed in high-level evidence studies. It is of most importance to not forget the clear evidence suggesting that scoliosis increases the risk of developing varicose veins as shown by Talic et al., which could even potentially explain why some authors associate traditional neuropathic symptoms with venous symptoms such as heaviness, itching, cramps and paresthesia[27].

Limitations in this review include that the phases while walking (gait analysis) and angles of joint movement are not considered in this review, while other articles did it. These parameters should be considered too in future investigations. Another limitation is that this article does not analyze quantitative information but only qualitative, however, it was not the primary objective of this article, and the very heterogeneous results combined with the lack of enough articles addressing the topic, made it impossible. Bias considered are observer and evaluation bias because the manuscript is designed, searched, analyzed, and discussed by only one author, while it is recommended that the evaluation of the methodological quality of the studies should be carried out for at least two independent and blinded researchers. To try to reduce bias, a double review of the searches and articles was performed.

The biomechanical profile must be considered in all future investigations regarding vascular diseases, to understand them from a comprehensive perspective. I will use lipedema and venous disease as an example of the biomechanical profile to allow any researcher to use these as bases, which can be seen in figure 2.

Conclusion

Biomechanics is an essential discipline when studying movement patterns and the movement itself is the basis of all the cardiovascular system. That is why we study hemodynamics so deeply, and both require studying the peripheral vascular system through a broader spectrum, which is why I propose a normal biomechanical profile.

I therefore encourage, along with Fernando et al.[22], to perform future biomechanical studies; but I would reaffirm that it is essential to return to the foundations, the mobile for this article.

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Conflicts of interest

The author declares no conflicts of interest.

Ethical disclosures

Protection of human and animal subjects. The author declares that no experiments were performed on humans or animals for this study.

Confidentiality of data. The author declares that he has followed the protocols of their work center on the publication of patient data.

Right to privacy and informed consent. The author has obtained the written informed consent of the patients or subjects mentioned in the article. The corresponding author is in possession of this document.

Use of artificial intelligence for generating text. The author declares that he has not used any type of generative artificial intelligence for the writing of this manuscript or for the creation of images, graphics, tables, or their corresponding captions.

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