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Design and construction of a device for the capture of force and dorsal flexion of the foot in older adults of the Ecuadorian population

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ABSTRACT: *Anthropometry is the science that studies the dimensions of the human body, the knowledge and techniques to carry out measurements, as well as their statistical treatment. In Ecuador, the study and capture of anthropometric measurements of the elderly population has been very scarce since there are no technological instruments that must obtain measurements, and statistics to be able to establish a database of the Ecuadorian population. Taking this background, the purpose of this article is to present a new device option for capturing anthropometric dimensions specifically of the foot.*
The device consists of capturing data that can be shown in a table, where the records made by different users are found, with the following parameters: age, sex, strength (lbf.) And flexion (angle).

INTRODUCTION

Da Vinci in the fifteenth century, "the human foot is an engineering work of nature."

Our feet support between 2 and 4 times the weight of our body at each step, they contain 25% of the bones of our entire body, around the world there have been several studies related to the anthropometry of the foot, however, these studies focus on obtaining only meditations such as: foot length, foot width and heel width. Noting the lack of tables that evaluate the force and flexion applied to the feet.

This is how this project was born, which consists of designing a device focused on obtaining data on the force and flexion generated by the foot specifically in older adults, who are known to lose flexion and strength in their feet after 60 years of age. What this affects in the stability and strength of the foot during the march.

This pedal-shaped device will allow the data to be obtained from the user applying a force on the base of the device for at least 5 seconds and as for the bending, it will be obtained by means of slight forward and backward movements.

I. INTRODUCTION TO ANTHROPOMETRY AND ANTHROPOMETRIC MEASUREMENT DEVICES.

1.1. General description.

Anthropometry is a branch of anthropology that measures the physical (dimensions in a fixed position) and functional (movements) characteristics of the human body. [1]. The anthropometric is determined by parameters such as: weight, height, skin folds, diameters, lengths, perimeters, growth speed, nutritional level, among others;

which are defined through protocols for measuring and estimating body composition. In turn, anthropometric measurements always vary from one population to another.

1.2. Applications of anthropometry

The largest amount of research focuses on physical activity and sport, followed by studies by population sectors for the standardization of measures.

Among the applications of anthropometry is the estimation of body composition, which is a topic of interest for the sciences related to sports practices, to determine the optimal performance of an athlete and their state of health, defined among others by the balance between weight and relative body fat. In the area of public and community nutrition, theanthropometry to determine body composition [1].

1.3. Foot anthropometry

In the foot, the length, width, height, volume, weight and fat content of its structures can be measured, although the most interesting data will be obtained through longitudinal and transversal measurements.

In the professional field, anthropometry is closely linked with podiatry, since this discipline must frequently rely on anthropometric science to relate the feet under study with statistical measures of normality. In addition, thanks to anthropometric studies, the podiatrist can accurately calculate the place where each of the structures of the human foot is located [2].

1.4. Technologies for capturing the anthropometric dimensions of the foot

Anthropometric measurement methods can be direct and indirect, and there are various technologies for capturing anthropometric measurements. This data collection is carried out directly or indirectly from the person by means of one-dimensional, two-dimensional, and three-dimensional devices, which scan the subject and project the results in lengths and perimeters of segments of the foot. But there is no device on the market that helps to capture the flexor measurements of the foot, which represents a challenge or design opportunity to implement a device with which the data of the flexor measurements of the foot can be obtained, and also of the force that it applies.

II. The anatomy of the foot and how it should respond to movement 2.1. General description

2.1. General description

The foot is made up of 26 bones, to which are added the tibia and fibula at the ankle joint. The latter consists of a pivot, whichit involves only one possible movement (flexion / extension), which is performed in a sagittal plane [3].

A quarter of the bones in the body are found in the feet. Its bone structure is peculiar because it resembles a puzzle that can be divided into different sections and in fact there are several ways to classify its bones. Traditionally tarsus, metatarsal and fingers would be the three regions; but current didactics prefer to use the idea of forefoot or front foot, midfoot or middle foot and hindfoot or rear foot:

- Front foot, formed by the 14 phalanges (toes) and 5 metatarsal bones. The metatarsals form a bridge between the midfoot and the phalanges, which extend when the foot is bearing weight.
- Middle foot, consisting of 5 tarsi: scaphoid, cuboid and the three wedges (cuneiform).

- Hind foot, for the 2 remaining tarsi, calcaneus and talus. This part is connected to two long bones in the leg (tibia and fibula), forming the joint that allows the foot to move up and down.

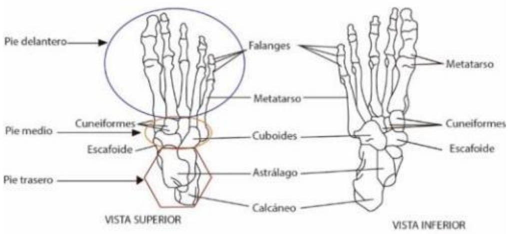

Figure1. Divisionsof the foot. Retrieved from https://www.redalyc.org/pdf/304/30421294008.pdf

To move, support and maintain the position of the bones, there is a network of muscles, tendons and ligaments.

The flexion / extension of the foot is done by the tibiotarsal joint. The faces of this joint are made up of: the upper part by the tibia and fibula, and the lower part by the talus. This type of joint does not allow lateral movements. The dorsiflexion movement of the foot is performed by the following muscles: tibialis anterior, extensor digitorum longus, extensor digitorum longus, and the peroneal anterior.

The plantar flexion movement is a bit more complex and involves a number of muscles. The lateral movements of the foot (pronation / supination) are carried out by the tarsal joint. The muscles responsible for pronation are the peroneal muscles. While those responsible for supination are the tibialis anterior and posterior, the extensor digitorum longus and the triceps surae. [4].

2.2. Plantar pressures in static

In bipodal support, the weight of the body is transmitted along both lower extremities, reaching 50% of its total value on each foot. The first bone of the foot, the talus, has the mission of distributing this force towards its support points. The foot in statics has two triangles, one posterior or support, that goes from the calcaneus to the head of the metatarsals, and another anterior or propulsion that is made up of the metatarsals and the toes.

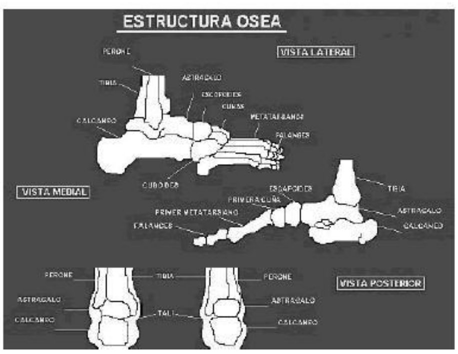

Figure2. Bony structure of the foot.Recovered from https://n9.cl/9b2ue

In general, almost all studies agree that the pressure in the heel is higher than that found in the rest of the foot, and that in the outer band of the midfoot the pressure values are very low. In the forefoot when carrying out a load, there is a descent of the transverse arch, with support from the heads of the five metatarsals, whose form of support has been much debated [5].

2.3. Factors influencing plantar pressures

The factors that influence the distribution of plantar pressures are weight, age and sex:

- *Weight*

  There is an important relationship between weight and plantar pressures. For example, some authors claim that both when walking and running, the lower the body weight, the lower the pressure on the entire foot, except for the toes. In fact, it seems that, in overweight people, both barefoot and in shoes, the distribution of plantar pressures is altered, since an increase is seen in the lateral area of the foot, especially in the middle phase of its contact, with lower peaks in the head of the first metatarsal. In general, it could be said that heavy subjects tend to use the medial forefoot less.

- *Age*

  In the elderly (from 60-70 years) there are variations in plantar flexion and the pressure exerted by the foot, as it decreases so that older adults begin to walk slower and take shorter steps.

- *Sex*

  Most authors agree that it is often not sex that determines the distribution of plantar pressures, but rather the use of different footwear and anthropometric characteristics, such as less weight in women. However, Henning describes very similar distribution patterns in girls and boys. On the other hand, joint flexion in women is generally greater and this may influence that men, with greater stiffness and less pronation in the stance phase, tend, as Pink and Jobe indicate, to locate the greatest pressure on the lateral area of the forefoot and toes [5].

2.4. Foot kinematics

The foot has a set of joints that allow movement in the 3 planes of space. These movements are flexion-extension in the sagittal plane, pronation-supination in the frontal plane, and abduction-abduction in the transverse plane. The movements carried out by the foot as a whole actually correspond to the combination of the movements produced in these planes, so that we know as inversion the association between flexion, adduction and external rotation of the foot; and as eversion to the combined movement of extension, adduction and internal rotation of the foot [6].

2.5. Baropodometry

Baropodometry is an analysis of the plantar pressures in dynamic and static position. Baropodometry gives us information about the loads that the foot supports in different areas. Depending on the quantity and quality of sensors that the baropodometric platform has, we will be able to refine more in terms of locating overloads. In addition, it allows us to measure the speed of the step in each of its phases and to carry out postural studies.

A patient comes to Podoactiva's consultation with pain in the lateral area of the right foot that is increasing. The patient indicates that he works all day walking and that all the shoes are worn by the same lateral area where the pain persists.

When performing the biomechanical study, we observed a foot with a lot of supination movement, that is, with a lot of support on the outside of the foot. This type of foot is characterized by having an increased plantar vault. In addition, an increase in pressure is also detected in the styloid process, the most prominent point of the foot on the outside. The pressure in the area is so increased that even the insoles of the shoe break [7].

2.6. Joints of motion

Its main function is dynamics, which is essential for the march.

Normal gait is the end product of a healthy neuromusculoskeletal system. A gait cycle is considered the movement performed by a single lower limb, from the contact of the heel to the next contact of the same heel.

In older adults, gait changes are evident, with serious modifications occurring in the central and peripheral nervous mechanisms that control balance and the locomotor system, these modify the normal gait pattern and constitute senile gait. Regarding the step this is widely reduced and the width slightly increased, in addition the cycle percentage in the bipodal phase increases between 25-30% of the gait cycle [8].

The foot is made up of several joints, some dedicated to the damping function (the first 3) and other joints to the movement function (4 and 5):

1. Subtalar joint (ASA). Union of the talus with the calcaneus. Midtarsal joint (TMA)

2. CHOPART joint. It is made up of two joints: medial or talar-scaphoid and lateral or calcane-cuboid.

3. Tarsometatarsal joint (TMJ) or LISFRANC joint. Junctions between the three cuneiform bones and the cuboid, with the bases of the five metatarsals.

4. Metatarsophalangeal joints (MTP). Union of the metatarsal heads with their respective phalanges.

5. Interphalangeal joints (IDA). There are two interphalangeal joints in each toe: proximal and distal interphalangeal, except in the hallux (great big toe) which has only one [9].

2.6.1. Joints of motion in older adults

During normal aging there is a progressive loss of the functionality of the systems that contribute to postural control, as well as changes at the musculoskeletal level that affect their function. All these factors lead to changes at the level of functional tasks such as walking, generating instability and increasing the risk of falling. One of the factors that change in the course of aging is the speed at which it is carried out. Older adults reduce their speed, increasing the angular variability of this task and generating changes in stability [10].

- Ankle joint

Ankle movements play a key role during human locomotion. During the march, the ankle allows to attenuate the impacts of the forces, helps to maintain the support and stability of the lower extremities. One of the effects of the decrease in plantar flexion in older adults is that it generates less propulsion during gait, which means that in situations common to their daily life, the speed and stability of their gait is affected.

Figure3. Functional and biomechanical anatomy of the ankle. Own elaboration. Adapted from(Spanish Journal of Rheumatology)

It is necessary to highlight the perfect congruence that exists between the trochlea and the tibiofibular mortise; the latter covers an angle of about 65 °, more than half the surface of the trochlea. If we consider that, during normal gait, in the period of limb support, the arc of motion is only about 25 °, this as a whole explains the low incidence of osteoarthritis in normal ankles [6].

The ankle presents a main movement, which takes place in the longitudinal plane and which is plantar and dorsal flexion of the foot (Fig. 4)

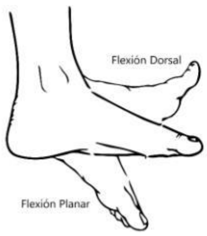

Figure4. Main Ankle Movement. Own elaboration. Adapted from https://n9.cl/pqh6

2.7. Foot kinetics

In the bipodal position the weight of the body is transmitted by the pelvis to the floor through the lower extremities. Each foot therefore supports half the weight of the body. Upon reaching the foot, the first bone encountered by the forces is the talus, whose main kinetic mission is to distribute the forces towards the different support points.

When the forces in the sagittal plane are analyzed, it has been possible to verify by baropodometric analysis that 60% of the forces are directed to the calcaneus and 40% to the forefoot [eleven].

This ratio varies considerably when lifting the heel off the ground, at which point the load on the forefoot increases.

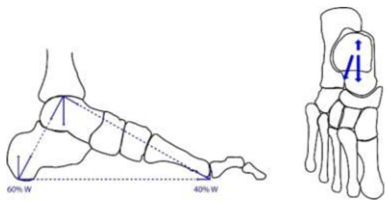

Figure 5. Force distribution. Own elaboration. Adapted from(Spanish Journal of Rheumatology)

2.8. Flexion (dorsal and plantar)

To assess the flexion of the ankle we start from a neutral position, which we achieve when the sole of the foot is perpendicular to the axis of the leg. From this position, ankle flexion is defined as the movement that brings the back of the foot closer to the front of the leg, also called dorsiflexion or dorsiflexion. The joint dorsiflexion range of motion is between 20o to 30o with a minimum amplitude required for gait of 10o. Conversely, ankle extension is defined as the movement that moves the back of the foot away from the anterior or ventral aspect of the leg, also called plantar flexion or plantar flexion. The range of plantar flexion joint movement is between 40o and 50o with a minimum amplitude necessary to perform a physiological gait of 20o [11].

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This flexibility acquired by the foot serves to cushion the impact of the foot with the ground and to adapt to the terrain.

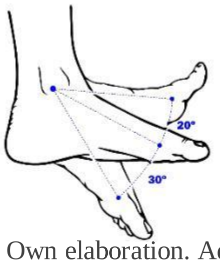

Figure 6. Foot flexion ranges Own elaboration. Adapted from: https://n9.cl/pqh

2.9. Foot movements.

The wide set of joints of the foot, together with the axial rotation of the knee, is equivalent to a single joint with three senses of freedom, which allow adapting and orienting the plantar arch according to terrain features. The three main axes of this joint complex (Fig. 1) intersect at the back of the foot and, in the anatomical reference position, are perpendicular to each other. It is around these axes that the movements of flexion-extension, adduction-abduction and pronation-supination of the foot are carried out (Fig. 2). The transverse axis X passes through the malleoli and corresponds to the axis of the tibiotarsal joint. It conditions the flexion-extension movements of the foot, which are carried out in a sagittal plane. The longitudinal axis of leg Z is vertical and determines the adduction-abduction movements of the foot, which are carried out in a transverse plane. These movements take place in the posterior tarsal joints. Finally, the longitudinal axis of the foot Y is horizontal and determines the orientation of the sole of the foot, in other words, it conditions the pronation-supination movements.

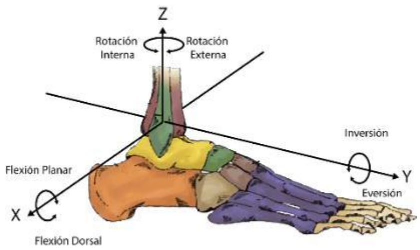

Figure 7. Bending axes. Own elaboration Adapted from: https://n9.cl/ac1d

Figure 8. Foot movements. Own elaboration

III. Aspects for taking data and measurements of the foot.

a. To take measurements of the foot, it is recommended to do it in the morning, since during the course of the day it can be delayed by the increase in environmental temperature or by the body heat released as a result of the activities carried out during a day. Measurements are taken at certain points on the foot defined by certain authors. The main measurements to be taken are: length, length of the instep, diagonal and horizontal width, width of the heel, circumference of the instep, circumference of the heel, height from the base of the foot to the base of the ankle, height from the base of the foot to the mid-ankle point, instep height, and the angles of the big toe.

b. To carry out a correct anthropometric evaluation, a profile and a standardized methodology must be followed, in order to be able to make comparisons with other populations and guarantee precision, reliability and reproducibility of the measurements. There will always be variability in the measurement, so the technical measurement error (ETM) must be taken into account, which is reduced by calibrating the equipment, using a correct measurement technique and experienced personnel. Among the methodological recommendations for measurement are: inform the subject of the measurements to be carried out and, during the measurement, they should remain standing, with their feet slightly apart; repeat measurements at least twice to take average or median values for data analysis;

3.1 Anthropometric Devices

The existing technologies for capturing anthropometric dimensions and the way in which anthropometric data can be obtained are varied and these data can be obtained in various formats such as: one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D).

The 1D data consists of heights, lengths, and perimeters of body segments. They allow to establish the size of the human body, but not the shape. 2D data consists of silhouettes or body sections; They are contours formed by curves or points (x, y). 3D anthropometry is made up of point clouds with coordinates (x, y, z) that represent the surface of the body. An example is 3D scans of the body, made up of point clouds that usually contain between 20,000 and 300,000 points. The acquisition, treatment and analysis of data increases considerably in complexity from 1D data to 3D data (Vicente, 2015). Anthropometric measurement methods can be direct and indirect [12].

The estimated cost of acquiring a module of this equipment is $ 2,668, which constitutes a disadvantage for its acquisition.

3.2 Main advantages of using hand instruments:

- Allows to measure all anthropometric dimensions.

The reading of the measurements is direct. Main disadvantages of using hand instruments:

- Requires trained personnel to perform measurements.

- The measurements are taken one by one, for each of the subjects.

The time for measuring, recording and processing information is long. Over the years, the development of technologies has allowed the creation of systems for capturing anthropometric dimensions without the need to interact with the person directly (Indirect method). 3D digital anthropometry arose with the idea of reducing the type of acquisition per subject, and that the scan is reduced to a few seconds, and the processing software can provide the anthropometric dimensions automatically, being able to obtain data that is necessary at any time [12]. 3D scanners can be full-body or of a specific part of the body, such as the feet or the head. There are different types, such as structured light technology, manufactured by the French company Telmat Industrie (SYMCAD) or the one developed by the Textile Clothingand Technology Corporation (TC2) company. As an alternative, laser projection scanners arise, which, although they are more expensive, the precision of the resulting 3D shape is much higher and are used in most anthropometric studies in Spain. As an example of these scanners we have those of Cyberware (USA) and Human Solutions (Germany) [12].

3.3 Comparative analysis of anthropometric devices

Table 1. Comparative analysis of anthropometric devices.
Recovered from(Lescay, Becerra, & Gonzales, 2016)

CARACTERISTICAS DE LOS DISPOSITIVOS DE MEDICION ANTROPOMETRICA				
DISPOSITIVO	**METODO DE MEDICIÓM**	**PRECISIÓN**	**DIMENCIONES**	**TIEMPO**
Instrumentos Manuales	Directo	Poco preciso	Todas las dimensiones antropométricas	45 a 60 minutos por sujeto
(Láseres) Termografía infrarroja	Indirecto	Preciso	Es posible captar más de 200 dimensiones	8 a 10 segundos por sujeto
Medición con fotografía	Indirecto	Preciso	No es posible captar todas las dimensiones antropométricas (circunferencia y perímetros)	1 a 2 minutos por sujeto
Kinect	Indirecto	Poco Preciso	Todas las dimensiones antropométricas	1 a 2 minutos por sujeto
Aplicaciones Android para medición	Indirecto	Poco Preciso	Es posible captar más de 200 dimensiones	1 a 2 minutos por sujeto

IV. Redesign summary

The proposed model is the result of a study based on the problems that older adults present as they age from the age of 70 in older adults there is a 3% decrease in their flexibility and a 15% decrease in their gait [13], causing. instability when walking. Currently there are anthropometric devices that allow longitudinal measurements of the foot to be obtained, but there is no device specifically aimed at power take-off and flexion of the foot in general, and much less aimed at older adults.

Therefore, we opted for the design of a pedal-shaped device that reflects the data on a screen, from the fact that the older adult exerts some pressure on the pedal, and makes slight forward and backward movements that facilitate the data collection of force and flexion respectively of older adults.

V. Proposal

A pedal will be designed with a force sensor that will allow to obtain an electrical signal proportional to the force of the foot that is applied on the base of the device, this will send the result of the force applied to the LCD screen.

In the same way, the same pedal will be used to measure the flexion of the foot, by means of slight forward and backward movements as shown in Fig. 12, by means of a potentiometer that will allow to measure the degree of inclination of the foot, and send the result to the screen.

1. Characteristics of the device to be designed for taking force and flexion measurements of the foot.

- Accuracy: equipped with a tension and angularity sensor, which provides an accurate and instantaneous digital reading of the force exerted by the foot and the user's flexion.

- Easy to use: the user will press the pedal with the foot, with the maximum isometric force for at least 5 seconds. After the test, the LCD screen will automatically show the maximum force value and the age and gender in each test will be recorded in a table, and the data of the foot flexion will be taken in the same way.

- Memory with records: the device can store data of up to 15 configured users, whose records can be consulted at any time; In addition, it automatically shows the gradual increase or decrease since the last record from comparisons after each test.

- Easy to read: by means of an LCD screen the visibility of all the data will be obtained clearly.

VI. Reliability and validity

- Programming and digital construction of the circuit through a simulation in Tinkercad, to verify the functionality of the proposed device.

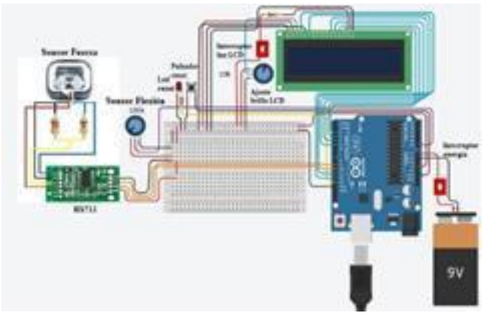

Figure 9. Operation of the mechanism in Arduino through a simulator. Own elaboration.

- Construction of the internal circuit of the device for data collection and correction of errors in programming.

Figure 10. Arduino operation Own elaboration.

- Conceptual proposal of the device using 3D modeling (SolidWorks)

Figure 11 Digital model of the force and bending meter. Own elaboration

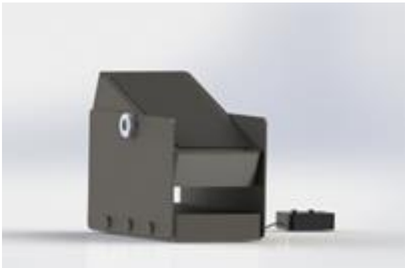

Figure 12 View of the device in operation. Own elaboration

Figure 13 Data visualization screen Own elaboration

- Functional prototype for data collection that includes: user code, age, sex, force and flexion value.

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Figure 14. Functional device to measure the force and flexion of the foot. Own elaboration.

6.1 Table of data acquired with the device.

- Data obtained from the strength of the left foot (10 people)

Table 2. Data on the strength of the left foot of older adults Own elaboration

Data	Gender	Age	Strength
1	F	64	12
2	M	61	11.2
3	M	60	12.2
4	F	62	12.2
5	F	60	11.2
6	M	64	11.2
7	F	61	11.8
8	F	62	11.8
9	M	63	11.8
10	M	60	12.2
SUMMARY			117.6 lbf
HALF			**11.76 lbf**

- Data obtained from the strength of the right foot (10 people)

Table 3. Data on the strength of the right foot of older adults Own elaboration

Data	Gender	Age	Strength
1	F	64	13.6
2	M	61	14.4
3	M	60	14.4
4	F	62	13.4
5	F	60	13
6	M	64	14.2
7	F	61	14.4
8	F	62	13.2
9	M	63	14.2

10	M	60	14.4
SUMMARY			139.2 lbf
HALF			**13.92 lbf**

- Data obtained from flexion of the left foot (10 people)

Table 4. Data on flexion of the left foot in older adults Own elaboration

Data	Gender	Age	Flexion
1	F	64	40 °
2	M	61	41
3	M	60	40 °
4	F	62	45 °
5	F	60	46 °
6	M	64	39 °
7	F	61	46 °
8	F	62	40 °
9	M	63	43
10	M	60	45 °
SUMMARY			425 °
HALF			42.5 °

- Data obtained from the flexion of the right foot (10 people)

Table 5. Data on flexion of the right foot in older adults. Own elaboration

Data	Gender	Age	Flexion
1	F	64	42 °
2	M	61	45 °
3	M	60	46 °
4	F	62	43
5	F	60	42 °

6	M	64	41
7	F	61	43
8	F	62	40 °
9	M	63	46 °
10	M	60	44th
SUMMARY			432 °
HALF			43.2 °

Conclusions of data collection with the device

- The right foot has more strength than the left foot.
- The right foot has more flexion than the left foot
- The flexion range of the left and right foot is from 40 ° to 46 °.
- Left foot strength is in the range of 11.2 to 12.2 lbf. and the right foot goes from 13 to 14.4 lbf.
- In the measurements made, all the samples were taken from right-handed people, and as they have a greater preference for using the right part of the body, therefore, the data reflected results in the force and flexion of the right foot being higher than the foot. left.

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