Universidad Continental

FACULTAD DE INGENIERÍA

Escuela Académico Profesional de Ingeniería Mecatrónica

Tesis

Mechanical and Electronic Design of a Prototype Lower Limb Prosthesis for Transfemoral Amputation

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Para optar el Título Profesional de
Ingeniero Mecatrónico

Huancayo, 2024

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Mechanical and electronic design of a prototype lower limb prosthesis for transfemoral amputation

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***Abstract*—In South America, there are few companies that are interested in the creation of prostheses and this, together with the little technological progress, makes patients with transfemoral amputation unable to perform their work. For this reason, the objective of this research is to design a prototype of a lower limb prosthesis for transfemoral amputation that helps the patient's mobility recovery, preventing the wear of the functional knee where an ergonomic design was considered for the patient's comfort. On the other hand, muscular sensors (EMG) were used to detect the intension of the movement, and triaxial accelerometers that capture the movement disturbances in the three axes X, Y, Z. The mechanical design was submitted to the Von Mises stress analysis simulation, these tests were performed in the SolidWorks software and the electronic circuit design was simulated in the Proteus software, where a correct interaction between the different sensors with the actuators of the prosthesis was achieved, in this way, the VDI 2206 methodology was applied. In the results it was possible to simulate the movements of the ankle by the implementation of the Stewart mechanism, also the pieces of the structure were subjected to an analysis where it is shown that efficiently support 68 kg this is related to the height of 165 cm. Finally, it was obtained that the suitable material is aluminum alloy 6061 T-6.**

Keywords*—*Design, transfemoral amputation, stress analysis, ergonomics, Stewart mechanism.

I. INTRODUCTION

According to figures from INEI and the National Disability Observatory for the month of April 2022, there are 234,084 inhabitants nationwide who suffer from locomotion limitations [1]; among these people are those who have suffered amputations due to various factors that can occur in the upper or lower limb [2-11]. In this situation, an artificial limb can be the basis to start a physical and psychological rehabilitation, allowing to develop a full and productive life [10].

As time goes by, the interest of people has been decreasing towards the development of artificial limbs [3]. Although it is not very credible, in Peru there are only two universities that offer their services to train their students as prosthetists or orthotists, so what happens to people who need an artificial limb? Patient satisfaction when using a mechanical prosthesis was previously studied, the responses are positive with respect to improvement [6], however, is the prosthesis fully functional and does it cover the patient's needs?

For the following research, the main patients were people who suffered transfemoral amputations caused by diabetes, tumors and traumatic amputations [4], thus EMG sensors were implemented, which will capture the electrical potential signals created by the contraction of the muscle that was once in operation. It is important to be interested in this topic, since patients suffer a strong personal, social and family impact, not to mention the economic part [2]. The main reason why many do not dare to ask for help is the fear of social rejection or the fear of facing the situation of not having a limb.

Ergonomic details for robotic prostheses are paramount if long-term mobility outcomes are to be maximized, this robot must ensure that the patient's limb does not exceed the joint range of motion [5-6-9]. Therefore, this work presents the proposal of a prosthesis to maintain the quality of life of an individual with transfemoral amputation, it is known from previous reports that at least 60% of people with this disability find it difficult to run with a prosthesis, a percentage that is known thanks to the asymmetric gait pattern they present compared to people without any disability [10], this together with the mechanics of the step and the range of motion show us that there is a noticeable difference when moving. An interesting fact that perhaps not many people think about is that patients with transfemoral amputation are prone to develop osteoarthritis problems for the knee that still works, due to the overload of the limb by the reaction forces of the ground [7].

The little information about the problem of amputations in our country motivated us to develop a challenging scientific effort. On the other hand, the present research differs by having as its main objective to design a prototype of a lower limb prosthesis for people whose height is 165cm, in addition the presented design will be able to perform all the movements that the human knee and ankle have [8-11], since a parallel robot mechanism will be implemented. Finally, it is expected that the design presented will be versatile due to the material chosen (Aluminum 606-T6), it should be light and long lasting as well as resistant.

II. METHODOLOGY

In developing the mechanical and electronic designs of a prototype lower limb prosthesis for transfemoral amputation, the VDI 2206 methodology shown in Fig. 1 was used to correctly select the mechanical materials and electronic components. This methodology consists of stages. In Phase 1 we find technical information for each component and each process, also, it is possible to obtain operational algorithms for the prosthesis system, which are detailed in the flowchart, with the objective of achieving a doctrine and an easy-to-understand process. Phase 2 describes the mechanical design, shows the structure of the prosthesis and the location of each component that conforms it. Phase 3 details the electronic circuit system where all the connections and interactions of the sensor are observed as inputs processed by the controller and provide the actuator movement as output. Finally, in Phase 4, the interaction of the mechanical and electronic parts is shown.

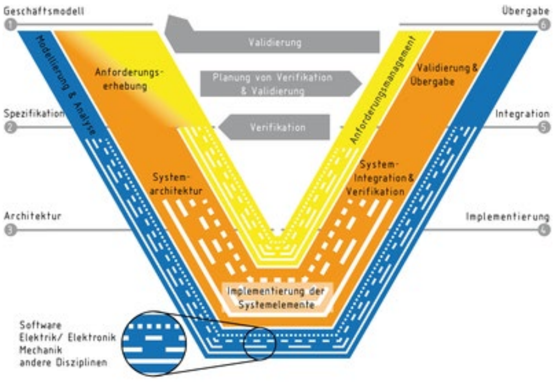

Fig. 1. VDI 2206 methodology [12].

A. Research Technology

The design of the lower limb prosthesis is focused on patients who have a transfemoral amputation, either due to some disease such as diabetes. Therefore, the design will feature EMG muscle sensors in the biceps femoris part as seen in Fig. 2.

Fig. 2. Location of EMG sensors [13].

On the other hand, the triaxial accelerometer will be located on the knee so that the movement can be simulated, as shown in Fig. 3.

Fig. 3. Location of the triaxial accelerometers [14].

Fig. 4 shows the design of the parallel robot in which the electric actuators with linear travel rods were used, having as reference a 30w /24v linear actuator [15].

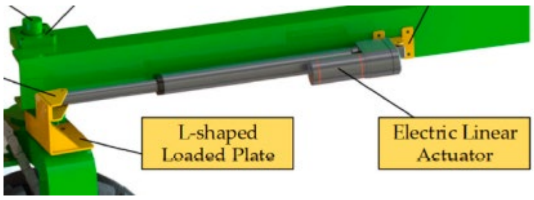

Fig. 4. 30 w/24 v electric linear actuator [15].

The flow diagram of the system is shown in Fig. 5, which starts when the EMG sensors detect the movement of the muscles causing the electric piston responsible for the movement of the knee, on the other hand, when there is disturbance, the triaxial accelerometer sensor recognizes these and activates the Stewart mechanisms, thus simulating the movements of the ankle, ending the process.

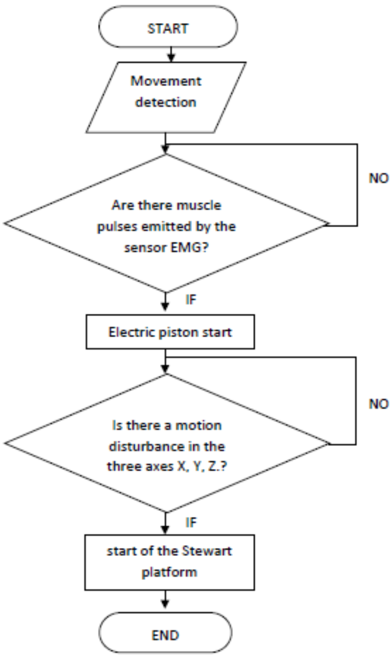

Fig. 5. Flow diagram of the prosthesis system.

B. Mechanical design

To design the prototype of the leg prosthesis we took standardized measurements as a reference, in Fig.6 we can see the measurements of each part of the body according to the height, the design of the prototype is aimed at people whose height is 165 cm.

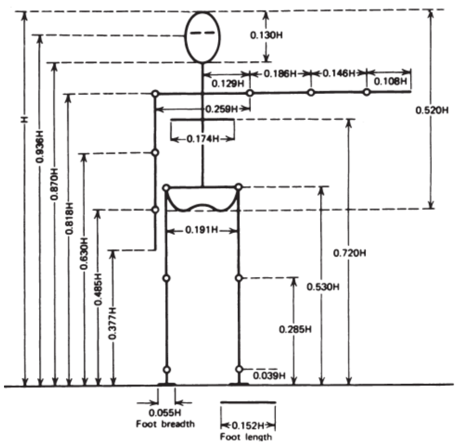

Fig. 6. Standardized proportions of the female and male body as a function of height. [16].

For the design of the mechanical structure of the lower limb prosthesis, all movements performed by the ankle were considered in Fig.7.

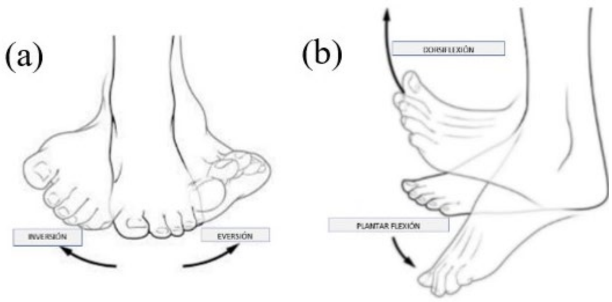

Fig. 7. Ankle movements, (a) Ankle inversion and eversion movements, (b) Dorsiflexion and plantar flexion movements [16].

For the design of the ankle, the parallel robot system, also known as the Stewart platform, was used as a reference, as shown in Fig. 8.

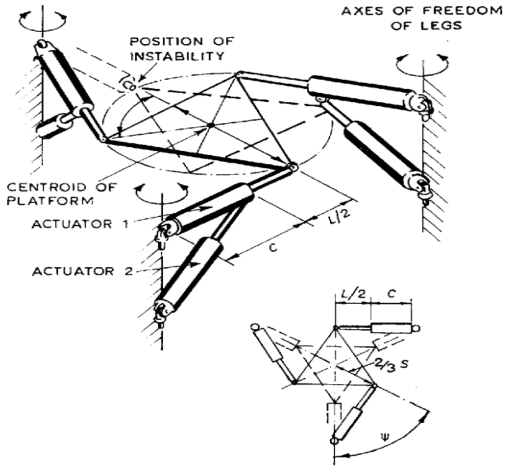

Fig. 8. Design of the Stewart platform mechanism [17].

Fig. 9 shows the Stewart mechanism in the design of the prototype leg prosthesis.

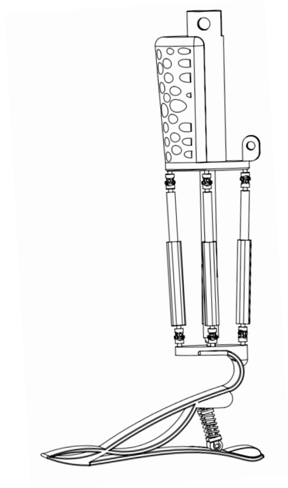

Fig. 9. Design of the Stewart mechanism in the lower limb prosthesis prototype.

In order to design the parallel robot, 4 linear actuators and a triaxial accelerometer were used to drive it. This electronic component will sense movement disturbances in the axes (X, Y, Z) to be processed by the controller and drive the appropriate linear actuator. Fig.10 shows the interaction of all the components that make up the proposed prototype structure, as well as the location of the electronic components.

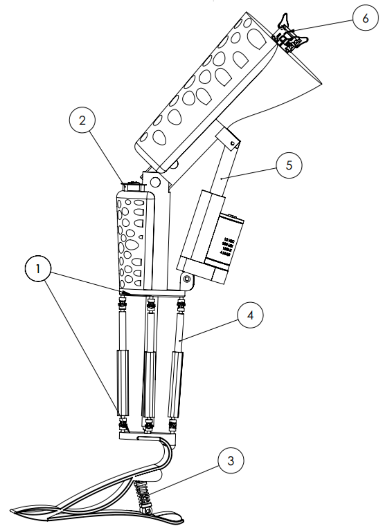

Fig. 10. Mechanical design of the lower limb prosthesis prototype.

- (1) Parallel robot mechanism or also known as Stewart platform, the application of this system is to achieve ankle movements.

- (2) The triaxial accelerometer will help to sense the motion disturbances in the three spatial axes (X, Y, Z), in order to drive the linear actuators that make up the parallel robot.

- (3) The integration of shock absorbers in the design of the prototype will help in the absorption of shocks that may be generated when the patient is wearing the prosthesis, in addition these shock absorbers will take care of the integrity of the residual limb.

- (4) For the movement of the parallel robot, 4 linear actuators are considered, these motors are the most appropriate to move the platforms according to the signals sent by the triaxial accelerometer.

- (5) A linear actuator with a rod travel of 10 centimeters is used to move the knee. The control of this actuator depends on the signal from the EMG sensor.

- (6) Two EMG sensors are used to capture the movement intension generated by the thigh.

C. Electronic design

For the electronic system of the prototype, it is necessary to consider a controller that has at least 5 analog strips in Fig.11 you can see the interaction of sensors, controller and actuators.

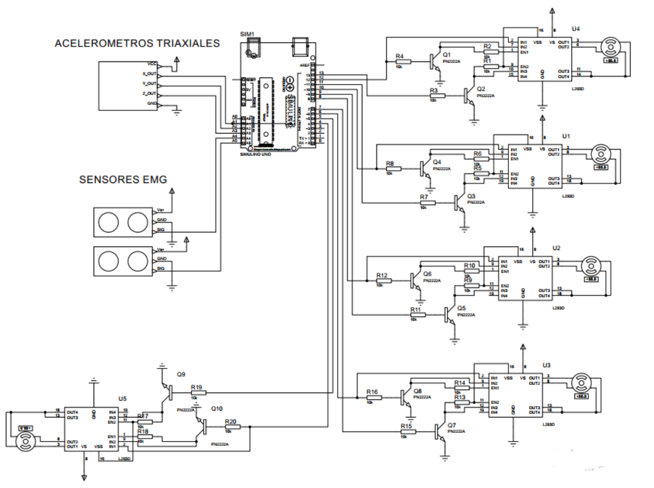

Fig. 11. Electronic circuit of the lower limb prosthesis.

In Fig. 11, the electronic system can be seen, which consists of 2 EMG sensors, which are located on the thigh and have the ability to collect muscle pulses, these will be sent to the microcontroller, then, the knee actuator will be driven. The triaxial accelerometers have the function of contributing to the actuation of the linear actuators that compose the parallel robot. Each actuator has a L293D driver that has an H-bridge circuit inside, this circuit allows the rods of the linear motors to extend or contract depending on the signals emitted by the sensors.

The Arduino Uno microcontroller is in charge of processing the signals from the EMG sensors, which use the A5 and A4 input ports. For the triaxial accelerometer the analog input ports A1 (X signals), A2 (Y signals) and A3 (Z signals) are used.

The actuators that make up the parallel robot use output ports 6 through 13 in consecutive order, and the linear actuator that performs the knee movements uses output ports 4 and 5, as shown in Fig. 10.

Table I shows the list of components used in the electronic circuit.

TABLE I. LIST OF ELECTRONIC COMPONENTS

Components	Description	Amount
Arduino UNO	Motor control card	1
Sensor EMG	The capture of the muscular pulses of the leg	2
Driver L293D	Control of the clockwise and anti-clockwise rotation of the motors	6
Triaxial accelerometer	located in the shoulder because it has two degrees of freedom	2

D. System integration

Fig.12 shows the interaction of the mechanical system, the electronic system and the location of each electronic component in the robotic structure of the prosthetic leg.

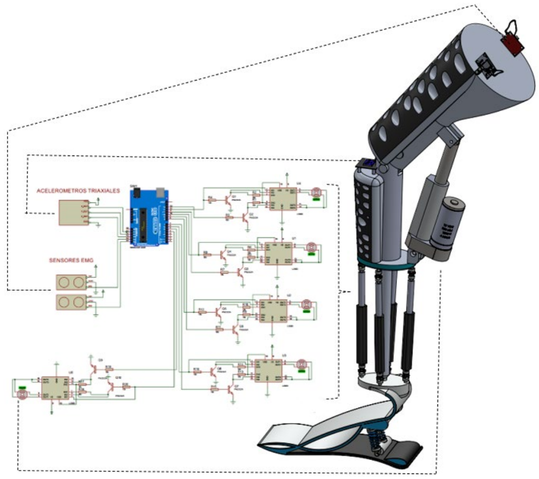

Fig. 12. Interaction of the mechanical system and the electronic system.

Fig. 13 shows the front view and Fig. 14 shows the isometric view (a) and the lateral view (b) of the prototype using a model of the person, this is aimed at users measuring 165 cm.

Fig. 13. Front view of the lower limb prosthesis design.

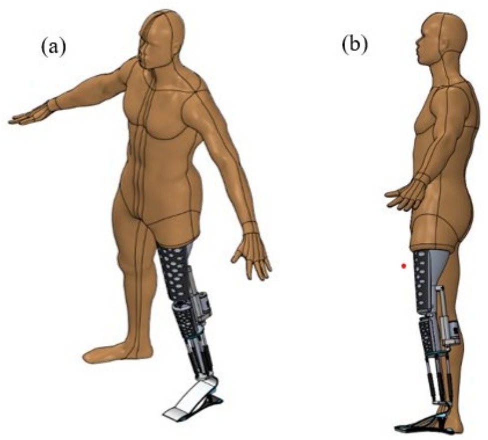

Fig. 14. Isometric view (a) and lateral view (b) of the lower limb prosthesis design.

III. RESULTS

A. Mechanical ankle motion analysis

To check the proper functioning of the ankle movements, the parallel robot mechanism is simulated performing the inversion, eversion, dorsiflexion and plantar flexion movements. Fig. 15 shows that the parallel robot mechanism performed all of the above movements.

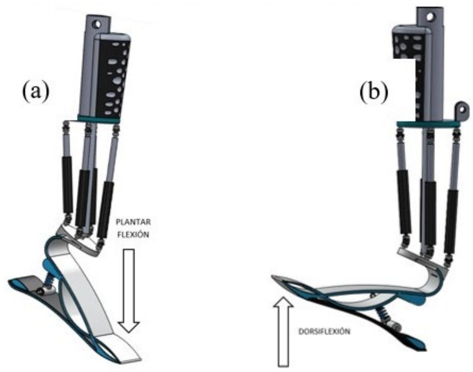

Fig. 15. Ankle movements, (a) plantar flexion movement, (b) dorsiflexion movements.

Fig.16 shows the mechanism of the ankle performing the inversion and eversion movements.

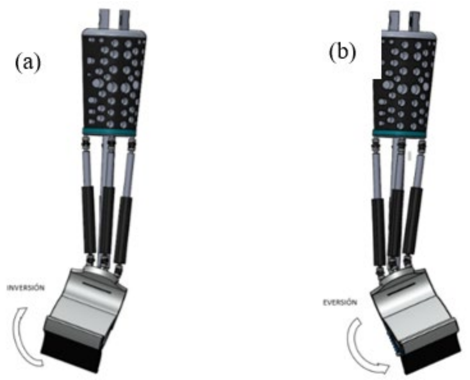

Fig. 16. Ankle movements, (a) inversion movement, (b) eversion movements.

B. Mechanical analysis of knee motion.

To check the correct movement of the knee of the mechanism, the knee movement simulation is performed in the SolidWorks software. Fig. 16 shows the flexion and extension movements achieved by the mechanical design.

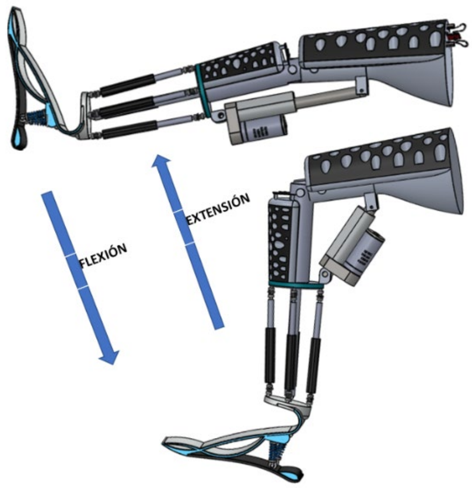

Fig. 17. Flexural and extensional motion analysis tests of the mechanical design.

With these motion tests, we can say that the applied design of the parallel robot complies with all the movements performed by a human ankle.

verify that the proposed prototype is able to support the weight of 68 kilograms, a Von Mises static stress analysis is performed. After performing the stress analysis simulation, the SolidWorks program gives us as a result that the appropriate material is aluminum alloy 6061-T6, which is light, resistant and commercially available.

Table II shows all technical specifications of the material used for the simulation.

TABLE II. CHARACTERISTICS OF ALUMINUM ALLOY 6061-T6

Aluminum alloy 6061-T6	
Elastic module	69 GPa
Poisson's ratio	0.33
Traction limit	310 MPa
Elastic limit	275 MPa
Bulk density	2700 kg/m'3

Note. The data acquired was from the SolidWorks simulator.

To perform the analysis of the structure of the prosthesis prototype, it is subjected to a weight load of 68 kilograms, this weight is based on the BMI of a person whose height is 165 centimeters.

Fig. 17 shows the Von Mises stress analysis in the SolidWorks simulator, where the results show that the part that is fitted with the trunnion has the capacity to support 68 kilograms.

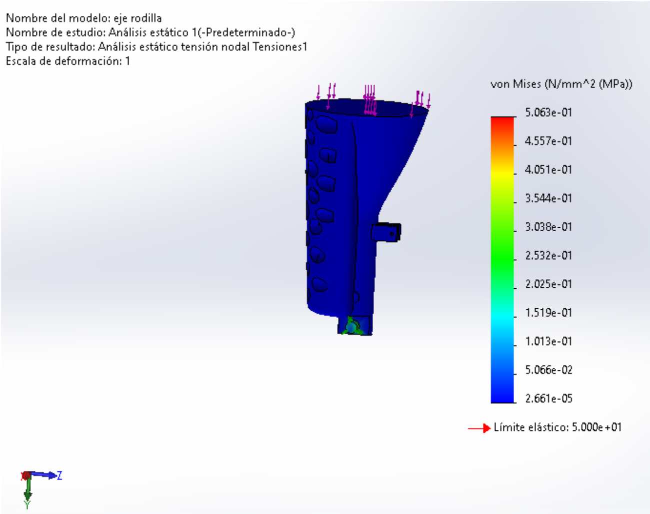

Fig. 18. Von Mises stress analysis of the thigh piece.

Fig. 18 shows the Von Mises stress analysis applied to the knee with the parallel robotic mechanism, the simulation was performed in SolidWorks software where it is shown that the structure has the capacity to support the applied load.

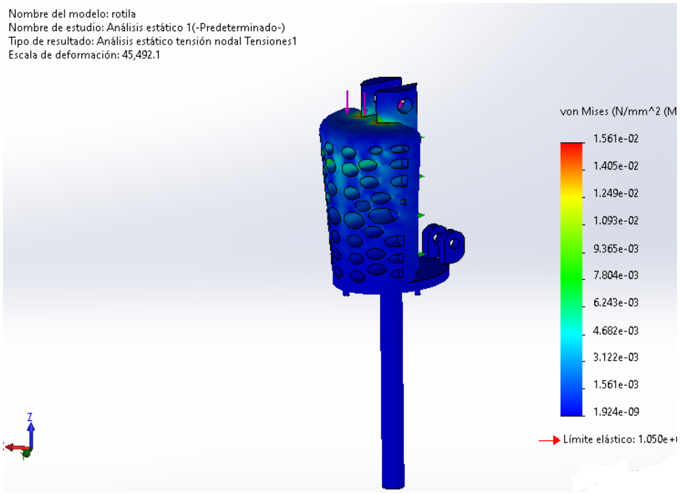

Fig. 19. Von Mises stress analysis of the structure containing the parallel robot mechanism.

IV. CONCLUSIONS

With the results obtained it can be said that the material used is Aluminum 606-T6 is capable of supporting the weight of a person measuring 168 centimeters and according to the body mass index the maximum weight is 68 kilograms.

The proposed design of the lower limb prosthesis prototype was realized through the mechanism of a parallel robot that fulfills all the movements generated by a human ankle. On the other hand, the knee mechanism was able to perform the flexion and extension movements optimally, because the linear actuator responds to the signals emitted by the EMG sensor.

The interaction of the electronic system and the mechanical system makes the design a versatile prototype. The EMG sensors play an important role in this interaction by capturing the movement intention of the amputated leg.

With this prototype proposal it is desired to obtain the future welfare of patients with transfemoral amputation covering the need and at the same time it is expected that the prosthesis complies with helping the recovery of mobility, preventing wear of the functional knee and that is not uncomfortable to use as mechanical prostheses.

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