PTB prosthesis inspired by *Euplectella aspergillum* sponge to improve load distribution and prevent limb complications

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Abstract*– Transtibial prostheses are important devices for the replacement of a body part that has undergone amputation below the knee. However, their use can lead to complications such as ulcers, osteopenia, and muscle atrophy, due to inadequate load distribution, so a structural redesign of the transtibial prosthesis in Fusion 360 inspired by the skeletal organization of the marine sponge Euplectella Aspergillum is proposed, which would help to improve the distribution and dissipation of loads during walking and thus improve the quality of life of users. For the proposal, a bibliographic analysis of the structure of the marine sponge and the existing transtibial prostheses was carried out, considering their consequences for long and short-term use. On the other hand, Fusion 360, a 3D design program, was considered for the simulation and virtual fabrication of a bar that simulates the tibia and fibula, together with a suspension system in the ankle to increase cushioning. This redesign is expected to prevent complications and significantly improve the functionality and comfort of transtibial prostheses, presenting an innovative, nature-based solution to address the mobility challenges of transtibial amputees.

***Keywords*-- Transtibial prostheses, PTB, biomechanics, sustainable innovation, bioengineering.**

I. INTRODUCTION

Biomimetics is a science that studies and imitates the characteristics of living beings applying the knowledge obtained in the improvement of what already exists or in the invention of new products with design ideas based on nature to develop new technologies and designs of devices, vehicles, and all kinds of tools that can serve to improve the quality of life of people, taking into account the applications of biomimetics a redesign of Transtibial Prosthesis is proposed based on the structural characteristics of Euplectella Aspergillum [1].

Transtibial amputation is the total or partial loss of a limb below the knee because of injury, disease, or accident. It is a condition that affects millions of people in the world, with diverse causes and consequences. It implies a radical change in the patient's life, who must adapt to a new form of mobility and face the physical, psychological, and social challenges involved. A suitable prosthesis can facilitate this process and improve the patient's functionality, comfort, and quality of life [2].

These artificial devices can partially or replace the amputated limb, allowing the patient to recover part of the lost movement and stability. There are several types of transtibial prostheses, with different characteristics, materials, components, and fixation systems

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However, not all prostheses are accessible or suitable for all patients, since they depend on factors such as the level and type of amputation, residual limb conditions, functional needs, personal preferences, and available economic resources [3].

PTB (Patellar Tendon Bearing) type transtibial prostheses are among the most widely used because of their simplicity and economy. They are characterized by having a rigid socket that comes into contact with the patellar tendon for support.

However, these prostheses present several problems and inconveniences for users, such as poor distribution and dissipation of loads on the residual limb and the intact limb, which can lead to ulcers, osteopenia, muscle atrophy, and other pathologies.

In addition, these prostheses do not have a cushioning or articulation system in the ankle, which limits the adaptability to the terrain and the naturalness of the gait [4].

The need arises to look for alternative solutions to improve the design and performance of PTB-type transtibial prostheses, taking advantage of technological advances and available scientific knowledge.

One of these alternatives is biomimetics, which proposes to imitate the solutions that nature has developed over millions of years to solve problems similar to those faced by humans.

In this sense, the marine sponge Euplectella aspergillum, which has a skeletal organization made of silicon that allows it to support its body using a complex cylindrical structure formed by grids, with at least six hierarchical levels at length scales ranging from nanometers to centimeters, has been chosen as a model of inspiration. This structure gives them greater firmness and resistance to fracture since the force is distributed throughout the structure, dissipating the energy [5].

II. METHODOLOGY

The methodology employed was based on two approaches: the first is the qualitative approach, where a literature review of reliable sources on biomimetics, the Euplectella aspergillum marine sponge, and PTB-type transtibial prostheses was carried out, to understand the biological principles that inspire the redesign of the prosthesis and consider the structural characteristics of the marine sponge that could be applied to the design.

The quantitative approach was based on modeling and simulation of the prosthesis in Fusion 360, a computer-aided design software. In addition to the standard designs of existing transtibial prostheses and analyzed through literature, a suspension system was added at the ankle to increase the damping. this is with the help of pistons to achieve the movement of normal walking in the stance and swing phase [6], considering that for an individual weighing 80 kg the load considered is 400N, where the weight is distributed on each of the legs [7].

To analyze the mechanical behavior of the prosthesis and the design under different loading and material conditions, and compare it with that of a conventional PTB prosthesis, Fusion 360 software was used to evaluate the benefits of the proposed redesign in terms of reduced pressures on the residual limb, improved ground adaptability, prevention of injuries to the intact limb and increased quality of life of the users.

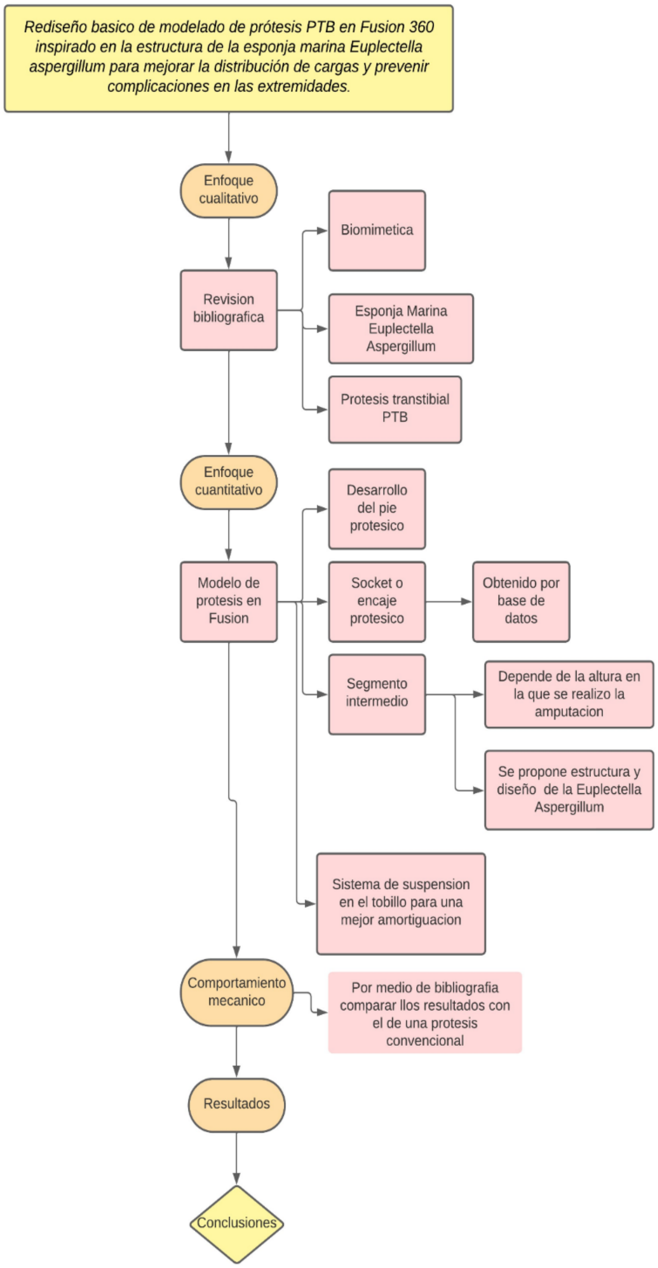

Figure 1. Flow diagram.

III. Results

The proposed PTB structure using Fusion 360, inspired by the skeletal organization of the marine sponge Euplectella Aspergillum, is established by the mesh design seen in Figure 2.

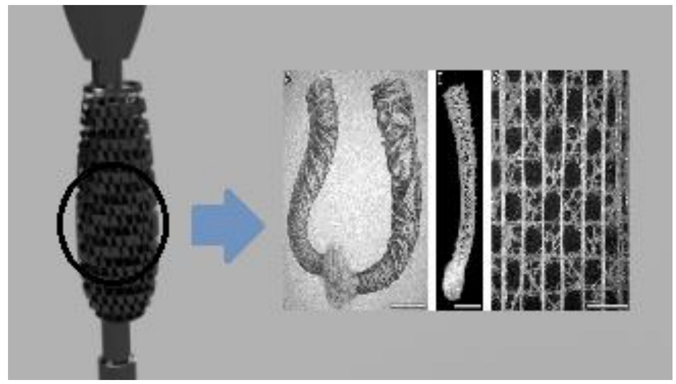

Figure 2. Application of *Euplectella Aspergillum* sponge biomimetics in the design of PTB prostheses.

First, a literature review is performed to identify the particularities of the skeleton of this species that could be incorporated into the design to replace the most overloaded parts in a common PTB, as shown in Figure 4 and Figure 5.

Grid and lattice organization, along with laminated skeletal elements, are discussed as an inspiration to improve load distribution and prosthesis strength.

The basic prosthesis design modeled in Fusion 360 also encompasses the implementation of a suspension system at the ankle, to dissipate the mechanical impact as the leg muscles and joint would do, which seeks to optimize load distribution and damping during gait, addressing deviations and possible lateral tilts that affect the comfort and efficiency of conventional prostheses depending on the level and type of amputation, so the standard design dimensions shown in Figure 3 and Figure 4 can be modified.

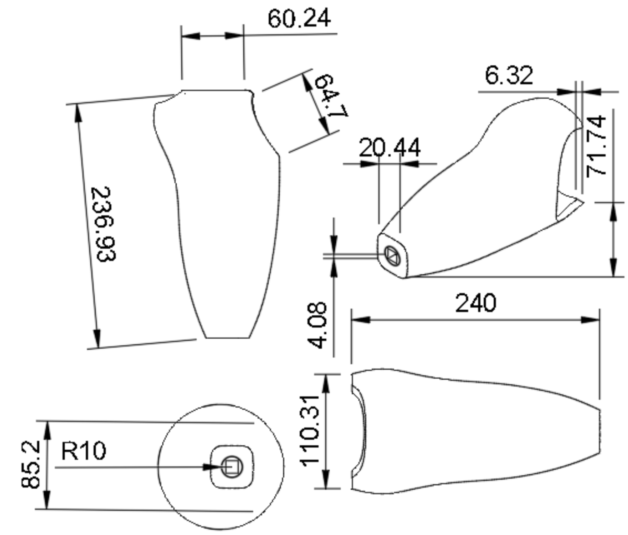

Figure 3. Fitting planes.

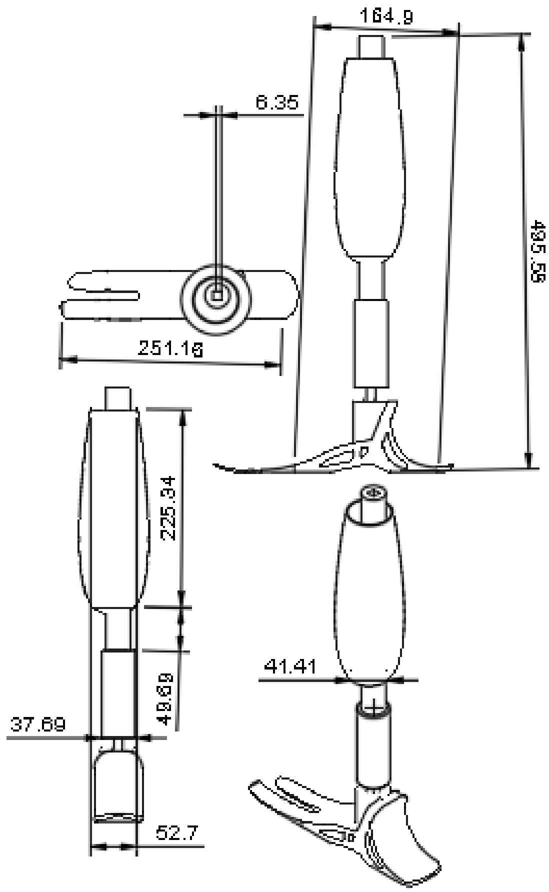

Figure 4. Plans of the prosthetic foot, intermediate segment, and socket.

The structure gives them greater firmness and resistance to fractures since the force is distributed throughout the structure dissipating the energy, which in case of fracture prevents it from spreading inside the body.

Observing the design of the PTB prosthesis, it is analyzed that the critical points are the foot, the ankle, the bar (tibia and fibula), and the user's socket, so these parts define characteristics such as mass, the center of mass, volume, surface, and inertia.

However, the part to be analyzed and where the animal design is applied will be the bar that simulates the tibia and fibula, in addition to a suspension system in the ankle, since common PTB prostheses present deviations between the average support and the pre-balance that is caused when the heel is lifted since the knee flexes and the body weight is transported to the toes, causing a lateral tilt in the prosthesis and several occasions premature or late flexion in the knee.

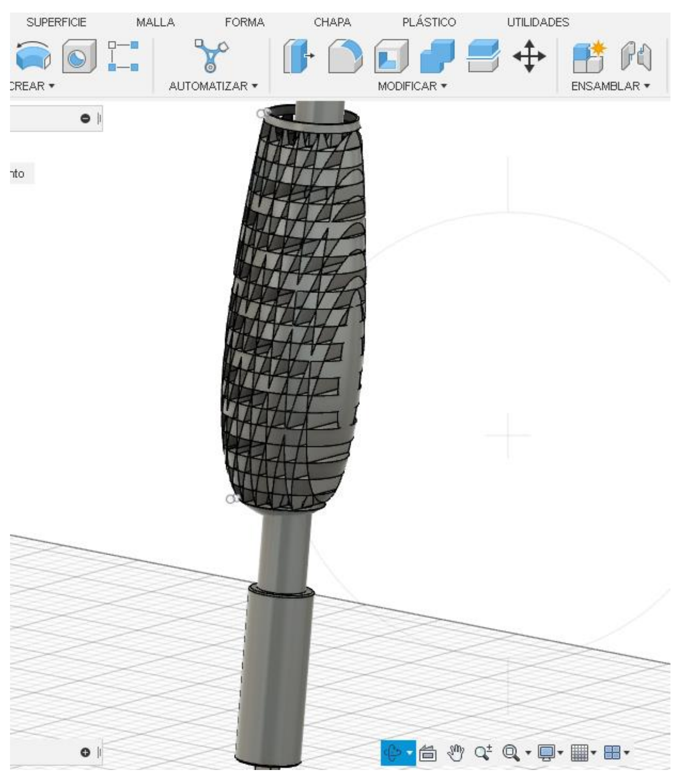

Figure 5. Intermediate segment design with structural features of Euplectella Aspergillum.

These prostheses, characterized by their simplicity and economy, often present inadequate load distribution and lack of cushioning, resulting in problems such as ulcers, calluses, osteopenia, and gait imbalances.

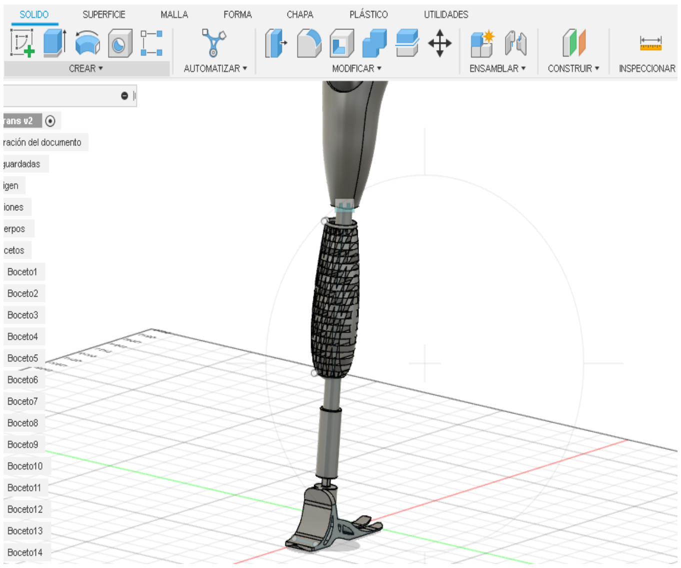

Figure 6. Position relationship with the socket.

The proposed design also seeks to address these issues by applying biomimetics based on Euplectella Aspergillum, which possesses a structure to dissipate loads and resist fractures, as evidenced in Figure 7 that presents an innovative approach to address the limitations of conventional prostheses, offering significant benefits in terms of comfort, load distribution, and long-term adaptation.

Figure 7. Final rendered design.

IV. CONCLUSIONS

The advancement of the proposed basic design from Euplectella Aspergillum promotes a perspective for the improvement of load distribution and prosthesis strength, which could have a significant impact on the long-term comfort and adaptation of users.

In addition, the introduction of an ankle suspension system, modeled after the biomechanical principles of the leg muscles and joints, is presented as a strategy to mitigate mechanical impact during gait, addressing postural deviations and imbalances.

By incorporating elements with biomimetic principles, a structure that efficiently distributes energy, decreasing the propagation of potential fractures into the body, could also have important implications in the prevention of pathologies related to gait imbalances, improving the quality of life of people who require such devices, while addressing current limitations and challenges within society.

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