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DESIGN OF MECHANISM OF ANKLE JOINT FOR PROSTHETIC LEG

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Abstract: *Progress in the field of prosthetics is essential to achieve better integration of patients back into their everyday lives. The quality of prosthetic limbs directly impacts their quality of life, which is why improving their prosthetic devices is crucial. This article presents mechanisms designed for the ankle joint to enable additional ankle joint rotation during walking, thus achieving a larger contact area between the prosthetic foot and the ground.*

Key words: *prosthetics, ankle, joint, piston, rotation, axis.*

1. INTRODUCTION

The majority of lower prosthetic limbs share a common characteristic. There is only one degree of freedom in the ankle joint. Improving the properties of the prosthesis could be achieved by adding a degree of freedom in the ankle joint area [1][2]. One possibility is to add a spherical joint as can be seen in Figure 1. If a spherical joint were present in the prosthesis, the potential for the prosthesis to make contact with the ground would increase [3]. This is because, thanks to the spherical joint, the foot could rotate a few degrees in various axes, thereby providing a larger contact area with the ground and, consequently, greater stability [4]. It is evident that such a joint would need to be regulated by a mechanism that would define the range of movement or rotation of the joint and thus of the footstep itself [5] [6].

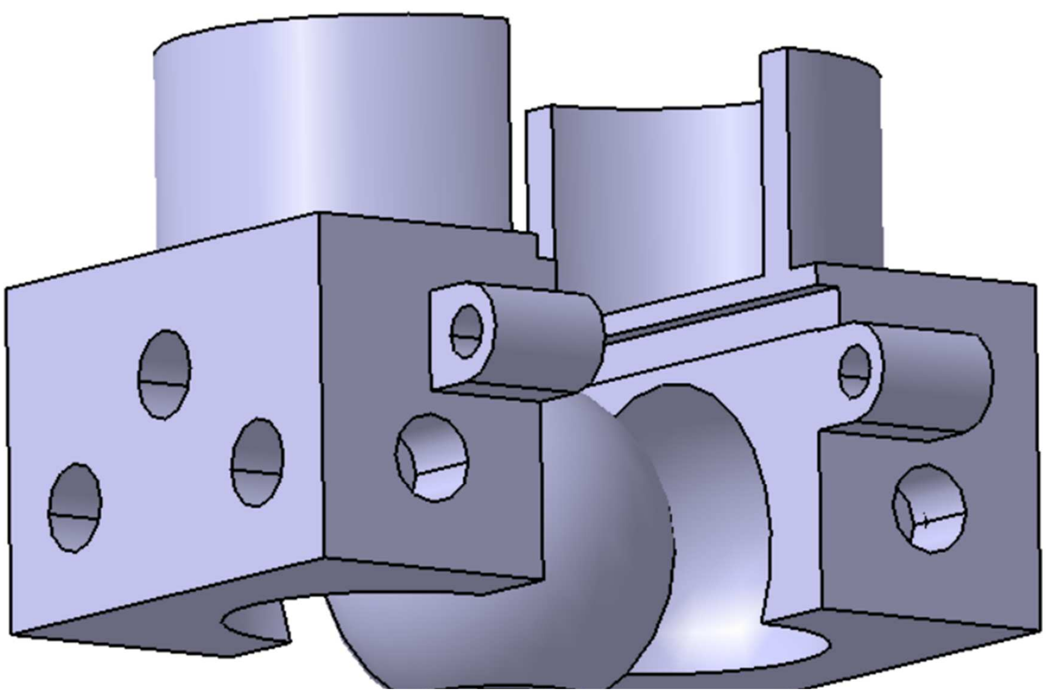

Fig. 1. Design of spherical joint for ankle joint in prothesis

2. IDEAS FOR MECHANISM

Control of the spherical joint could be ensured by various mechanisms. One of the proposed designs is the Rope Mechanism. This mechanism would consist of a group of fibers that would maintain the mechanism rigid, and their movement would rotate the joint on its axes as needed. Such a mechanism requires high precision for securing the individual fibers, as well as for the motor that would move them. This mechanism would simulate the tendons and muscles in the human foot. The advantage of this constructed mechanism is the possibility of creating various different end parts - foot shapes for the prosthesis, based on the wearer's preferences or the specific usage of different models.

The second mechanism that is considered is the belt mechanism. In this case, it would consist of a pair of belts and a pair of gearwheels that would move the belts [7]. These wheels would be driven by small motors. In this case, one belt would create the movement on the prosthesis that is common in currently existing prostheses. This movement would imitate raising the tip of the foot or switching the tip. The second belt would be perpendicular to the first one, and its role would be to rotate the foot sideways in cases when the foot departs from the body's axis and rotating the foot is necessary to achieve higher stability.

Another option for adding a second degree of freedom involves replacing the traditional rotational linkage with a system of spherical joints (Figure 2) that define the range of movement and ensure proper positioning of the mechanism. These spherical joints would be located in the ankle joint area. Specifically, there would be three pistons arranged in an equilateral triangle, where the pistons replace the wearer's ankle and are interconnected with the foot of the prosthetic limb using spherical joints [8][9].

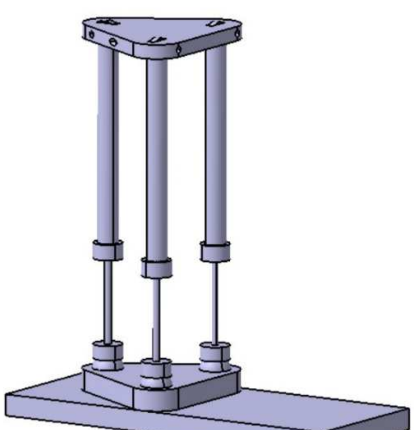

Fig. 2. Design of mechanism including pistons and spherical joints

At the upper part where the mechanism connects with the socket of the prosthetic limb or the knee joint of the prosthesis, the pistons' attachment is ensured by rotational linkages. These linkages would allow the pistons to rotate only in the desired directions and are necessary for the proper functioning of the mechanism. They are arranged in the shape of an equilateral triangle as can be seen in Figure 3.

The lengths of the pistons themselves depend on the wearer's height. Similarly, the piston lifts

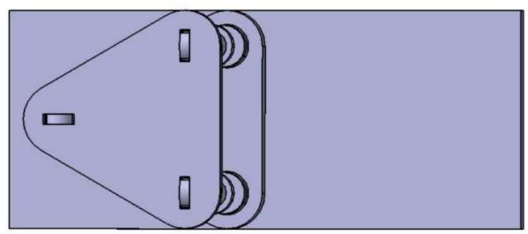

Fig. 3. Top part of mechanism

should be adjusted based on the size of the prosthetic foot to achieve optimal tip elevation. The lift as can be seen in Figure 4, and the distance of the rear piston, which determines the rotation in the ankle joint, are interdependent. If

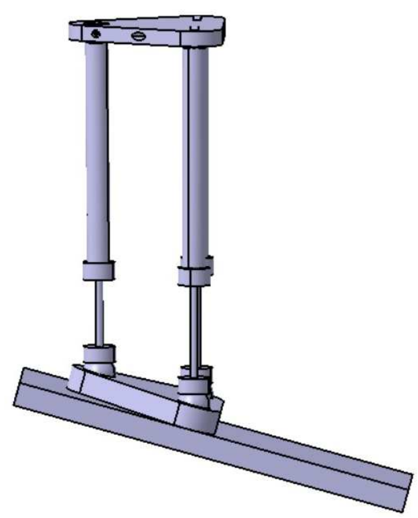

Fig. 4. Rotation of ankle joint (Heel goes up)

we reduce the distance of the spherical joint of the rear piston from the other two, it's possible to decrease the piston lift required to achieve the same tip displacement in the desired direction. When lifting the tip during a step phase where the foot doesn't touch the ground and the tip is raised to prevent tripping as you can see in

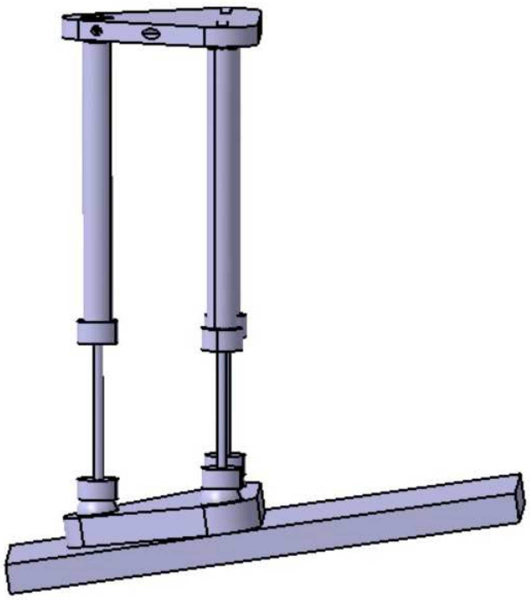

Fig. 5. Rotation of ankle joint (Heel goes down)

Figure 5, the rear piston needs to extend [10]. If the wearer touches the ground and enters the step phase just before lifting the limb off the ground, it leads to pressing down the tip. In this case, the rear piston needs to retract. The rear piston should provide the rotation in the ankle joint, similar to how it's done in currently available prostheses on the market.

Using the other two pistons, the rotation of the foot in other directions should be ensured. The combination of piston movements would achieve foot rotation in different directions. Walking itself is a highly complex process that seems basic to a typical person. However, with only one rotational linkage that facilitates raising the tip, problems with balance can arise if the wearer encounters uneven surfaces. In the case of foot rotation, a larger contact area on uneven surfaces can be achieved. This adjustment can be accomplished by changing the extension of one or more pistons, leading to differences in foot orientation in the proposed model.

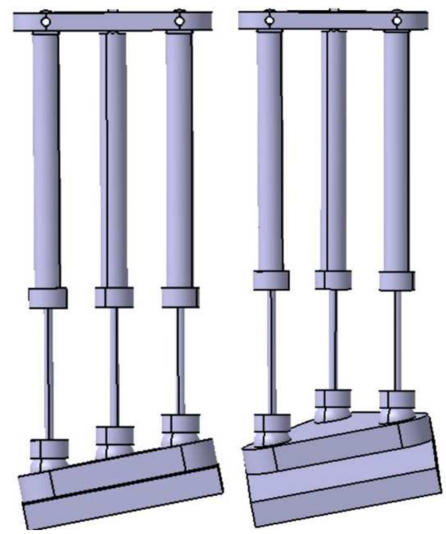

Fig. 6. Rotation of ankle joint in second axis and combined

The mechanism depicted in the images is a basic model designed to verify the proper functioning of the mechanism; it is not adjusted to the shape of the foot. It also does not include elements for connecting to the socket or knee joint of the prosthetic limb. The model was validated by setting up kinematic constraints and subsequently simulating individual piston lifts or their combinations, observing the rotation of the prosthetic limb's foot. Simultaneously, the tip elevation and the lengths of piston lifts required for optimal foot alignment were monitored [11].

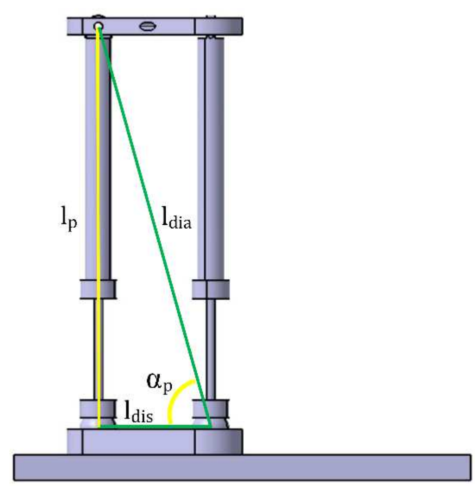

Fig. 7. Description used for calculations of distances

The heights of piston lifts depend on the distances (Figure 7) of the individual spherical joints from the axis of the prosthetic limb. A simple calculation can be created based on the parameters specified for the upper part of the ankle joint, where the connection to the socket or knee joint will be located.

Yellow line in Figure 7 symbolize value l_p that is key value for the pistons. Extension or insertion of that piston change the value l_p and create the rotation in ankle joint. That rotation affects value α_p that is shown with yellow mark on the picture.

$$l_p = \sqrt{{l_{dia}}^2 - {l_{dis}}^2} \tag{1}$$

$$\alpha_p = \sin^{-1}(\frac{l_p}{l_{dia}}) \tag{2}$$

For optimal movement of ankle joint were used values 15 degrees rotation of ankle joint for extension of piston and 30 degrees rotation of ankle joint for insertion of the piston for angle α. α_m symbolize value of angle after rotation of ankle joint [12].

$$l_m = \sqrt[2]{\left({l_{dis}}^2 + {l_{dia}}^2 - 2 * l_{dis} * l_{dia} * \cos(\alpha_m)\right)} \tag{3}$$

$$l_p = l_m \rightarrow \alpha_p = \alpha_m \tag{4}$$

$$l_e = l_p - l_m \tag{5}$$

Time equal to make one single step for person is calculated to be 0,625s, but only 20% of that time include the phase of moving the mechanism such as extension or insertion. That makes time t=0,125s. We can calculate the speed v_e, necessary for extension or insertion for pistons.

$$v_e = \frac{l_e}{t} \tag{6}$$

After that calculations we must consider the weight of the patient that is needed to be lifted or held. That relates to the power necessary to lift the person [13][14].

3. CONCLUSION

The main advantage of the piston-based mechanism should be the potential for partial mass production, as the pistons can be manufactured in bulk. Also, the hydraulics has advantage because of power of the mechanisms. Proposals for mechanisms for a prosthetic limb are design solutions considering a specific issue, with the goal of enabling movement of the ankle joint in an additional axis.

Despite the fact that these proposed mechanisms achieve this requirement, they may encounter challenges during implementation due to the weight of the structure, power supply, or movement speed.

These issues could potentially be resolved through the production of prototypes, but that would require a detailed analysis for material usage and power supply.

Another advantage of this designed mechanism is the potential for its utilization in exoskeletons for individuals who may have suffered musculoskeletal injuries.

Such a mechanism could also find application in exoskeletons aimed at facilitating people's work or walking under challenging conditions, such as heavy loads and similar scenarios.

Exoskeletons designed to alleviate the strain on individuals during work are already in use today.

Additionally, they can serve as support for the wearer's musculoskeletal system, especially when performing tasks in unnatural body positions, where maintaining proper posture can be achieved with the assistance of an exoskeleton.

4. ACKNOWLEDGEMENT

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PROIECTAREA MECANISMULUI ARTICULAȚIEI DE GLEZNĂ PENTRU PICIOR PROTEZAT

Rezumat: Progresul în domeniul protezării este esențial pentru a obține o integrare mai bună a pacienților în viața de zi cu zi. Calitatea membrelor protetice influențează direct calitatea vieții lor, motiv pentru care îmbunătățirea dispozitivelor protetice este crucială. Acest articol prezintă

mecanisme concepute pentru articulația gleznei, pentru a permite o rotație suplimentară a acesteia în timpul mersului, realizând astfel o suprafață de contact mai mare între piciorul protetic și sol.

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