Design of a 3D Printed 4-Bar Linkage Low Cost Knee Prosthetic

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Introduction

The number of amputations keeps increasing globally, and the cost of advanced prostheses is on the rise everywhere. The cost to American insurance agencies is approximated to be $12 billion annually [1].

As such, it has become very important to design prostheses that are not only performance focused but also affordable. The significant portion of the costs lie in the industry and manufacturing of the prosthetics, even when the design is made of relatively less expensive materials.

The costs can be reduced significantly through the process of 3D printing. In fact, in addition to reducing the cost of manufacturing and resources, it will also allow an easy adaptation (fitting) of the model through the Computer Aided Design software (SolidWorks).

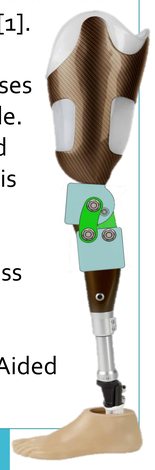

Figure 1. Attachment of knee joint on prosthetic leg [2].

Methods and Materials

A detailed research was conducted specifically on Polycentric Knee (Four bar joint design) to evaluate and analyse the pros and cons of the designs on patients. The chosen design was inspired by two knee designs that were closely studied and analysed:

1. **The Jaipur knee [3]** designed by a team of students at Stanford University. The knee prosthesis currently being fitted on amputees in India, was improved by the company D-Rev that renamed the design as the ReMotion Knee.
   - **Characteristics:** Maximum flexion degree 165°
   - **Component Weight:** 400g
   - **Material:** Nylon
   - **Maximum user weight:** not specified

Figure 2. Jaipur Knee.

Figure 3. ReMotion Knee.

2. **The ROADRUNNERFOOT POLYCENTRIC KNEE [4]** (Code 6.002.01)

- **Characteristics:** Maximum flexion degree 165°
- **Component Weight:** 520 g
- **Material:** Alluminium alloy
- **Maximum user weight:** 130 kg

Figure 4. ROADRUNNERFOOT Knee

Aim

This research focuses on designing a 4 bar linkage knee joint that can be simple enough to be 3D printed, while also being

- durable
- reliable
- affordable

Results-Design

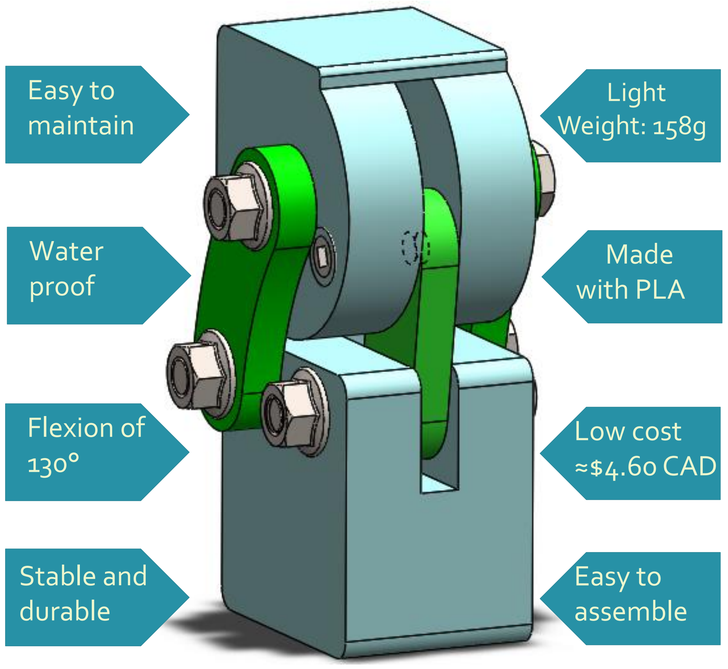

Figure 5. Full assembly of 4- bar knee joint prosthetics design.

Activities	Knee Flexion	Compressive load (Body weight)
Normal gait/level	60°	1 BW
Stair climbing	80°	3.8 BW
Sitting/ rising from most chairs	90°	-
Sitting/ rising from toilet seat	115°	-
Cycling	60°-100°	1.2 BW
Walking	15°	3.0 BW

Table 1. Range of motion in daily activities. [5]

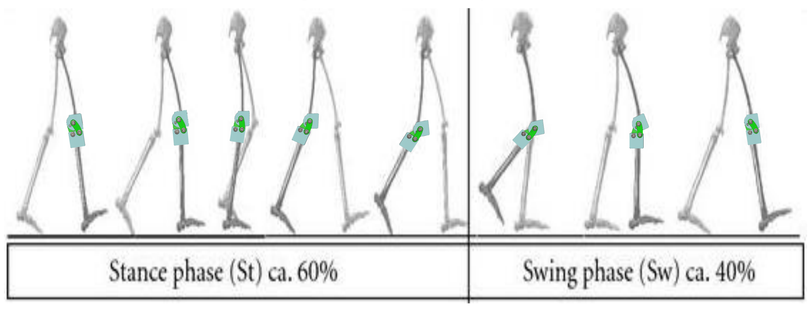

Figure 6. Gait cycle (%) with the knee prosthetic in motion [6]

Design Components

5 components: (3D printed)

- 1 femoral piece
- 1 tibial piece
- 2 arched external links
- 1 straight internal link

Fasteners and nuts

- 2 M10 hex flange bolt (80 mm long)
- 1 M10 hex flange bolt (60 mm long)
- 3 M10 hex flange locking nut
- 2 M10 flat head socket screws (25 mm long)

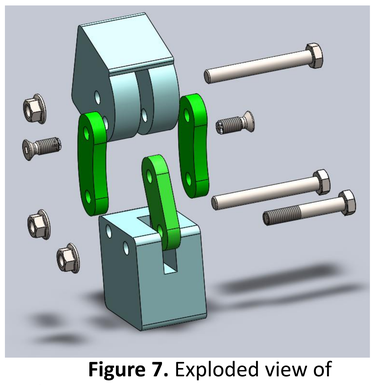

Figure 7. Exploded view of the model

Stability

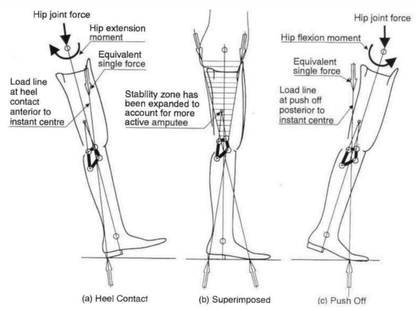

Figure 8. Stability diagram [7] - Hosmer voluntary control four-bar knee mechanism

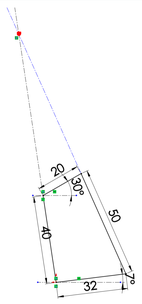

Figure 9. Instant Centre of rotation.

Limitations and Future Studies

Overall dimensions of the design :

- Height: 14 cm
- Width: 7 cm
- Depth: 5cm

Mechanical properties of PLA [8]:

- Flexural Strength: 80 MPa
- Strength to Weight Ratio: 40 kN-m/kg
- Elastic (Young's) Modulus: 3.5 GPa

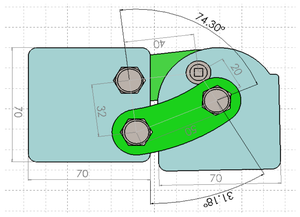

Figure 10. Dimensions in sagittal plane.

- **Kinematics:** Add a slider component to permit at full continuous rotation.
- **Material:** Explore other thermoplastics compatible with 3D printing .
- **Dimensions:** Keep the structural strength while reducing the overall dimensions to fit international standards.
- **Future projects:** the design can be further analysed in the load bearing and how the force is distributed between the components. This will allow a shear and fatigue analysis that will highlight the parts that must be strengthened due to possible failure after excessive usage.

Conclusion

Although this new prototype may result in the absence of some features present in the high end prosthetic knee joints, the overall performance was optimised in the proposed innovative design. This design can be used globally, but perhaps its impact will be felt greatly in third world countries.

Acknowledgments

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