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# Introspective Study of Trans-Tibias Amputees in View of the Design of a Durable Prosthetic Foot

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## Abstract

The prosthesis is an artificial device that can replace an organ of a human body member to restore a compromised function. It is necessary following the removal of a human organ, which can occur as a result of an illness, trauma or congenital malformation. The trans-tibia prosthesis, in particular, allows the amputee patient to recover the impaired function and regain autonomy, while facilitating their daily social integration. The trans-tibia prosthesis consists of a socket, a sleeve, connecting elements and a prosthetic foot. Each of these components plays a very important role. Among these components, the prosthetic foot usually called "SACH foot" is very often replaced due to cracking and therefore has a fairly short lifespan. At the Center for Equipment and Rehabilitation of Kabalaye (CERK), the SACH foot made using polyurethane and wood is imported and is given to patients with reduced mobility. The aim of this article is twofold, on the one hand, to make a social and pathological study of trans-tibia amputees in relation to the use of the SACH foot prosthesis, on the other hand, to compare this foot with a new prosthetic foot proposed and which is manufactured using extruded polystyrene. The result of prosthetic tests carried out on twenty-four amputees showed that the foot manufactured using extruded polystyrene is better in terms of resistance, bulk and adaptability to active amputees.

## Keywords

Prosthesis, Prosthetic Foot, Trans-Tibia Amputee, SACH Foot

## 1. Introduction

Like developing countries, Chad has many amputees, for various reasons which

can be linked to trauma or the negative evolution of pathology. Patients who have recently had their tibia amputated must obviously face a sudden reduction in their mobility, especially when it comes to all or part of the lower limbs [1] [2]. But the impact is much wider, since amputation has serious consequences on the patient's quality of life at all levels: social, economic and medical [3] [4]. Technical solutions exist to help amputee patients adapt to their new living conditions and resume a normal life as much as possible [2] [5] [6]. Among these solutions, the most obvious and probably the most effective in Chad is the orthopaedic prosthesis [7]. After a clinical study of the patient, their life plan and their daily environment, the prosthetist suggests the equipment adapted to these needs in accordance with the prescription of the physical doctor [5]. In our case, we will analyze the CERK tibia prosthesis and propose a new prosthesis. Among the components of the tibia prosthesis, the SACH foot is the one that most often presents deformation and cracks. **Figure 1** below shows the new and cracked SACH foot.

(a) New foot

(b) Cracked foot

**Figure 1.** SACH foot: new (a) and cracked (b).

According to the High Authority of Health, the choice of prosthetic feet is determined according to the patient's activity level. While the SACH foot is assigned for patients moving inside and near buildings with a walking speed greater than 3 km/h and a walking perimeter greater than 500 meters [8]. After the First World War, manufacturers developed prosthetic feet [9]. Around the 1980s, the first energy-returning prosthetic feet appeared [10]. They are made of composite material, which is the carbon blade, the shape of which varies depending on the model [11]. When the heel touches the ground, the material deforms, and the shock is absorbed. Then, with the foot flat on the ground, the foot propels itself thanks to the restitution of energy stored in the carbon blade. Finally, when pushing off with the toes, the foot accumulates energy to restore it when taking a step [12]. Since 1979, the Center for Equipment and Rehabilitation of Kabalaye in Chad has been using the SACH prosthetic foot [13]. The SACH foot is the oldest and is imported to Chad [14]. It is the basic foot. It is light, strong, and reliable, and it can work in

water. It is made of rubber and wood; it does not have an ankle joint, but cushions the heel strike on the ground with a softer foam heel wedge. It is not dynamic and cannot adapt to uneven terrain [10] [15]. In this work, we adopt a craft manufacturing approach for the prosthetic foot that we call "AL-HANOUNA foot", which should allow amputee patients to carry out their activities without being tired. In the following sections, we present our approach for the study.

## 2. Materials and Method

In this work, we carry out the study in two phases:

- In the first phase, we manufacture a prosthetic foot using extruded polystyrene.
- In the second phase, we carry out an introspective study by survey of amputee patients in order to evaluate the two feet (SACH and AL-HANOUNA) on the social, pathological and functional level.

### 2.1. Materials and Manufacturing

#### 2.1.1. Materials

For the manufacturing, we used the following materials:

- Wood which is the soul of the foot;
- EVA foam which is used to give the aesthetics of the foot;
- Polypropylene (PP) is used as the forefoot sole;
- Extruded polystyrene which envelops the soul of the foot;
- Glue which allows the extruded polystyrene sheets to adhere;
- A tip for fixing the PP and wood.

#### 2.1.2. Manufacturing

In this work, we proceed to manual manufacturing, which is a craft method in the field of orthopedics. The manufacturing process of the AL-HANOUNA prosthetic foot begins with the measurement of the healthy foot. Then, the manufacturing of the foot core and the last step is the wrapping of the core with extruded polystyrene to obtain the shape of the healthy foot and the aesthetics with EVA foam.

- First step

The first step is the measurement of the healthy foot. For this, we draw a line around the entire outer perimeter of a patient's foot in order to obtain an imprint. Then, we measure the length of this imprint, starting from the back line of the foot (heel) to the line of the longest toe (see **Figure 2**).

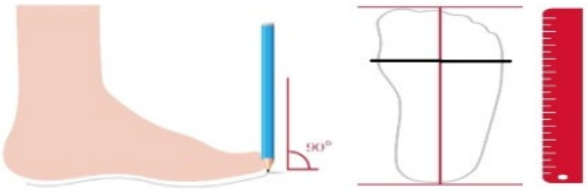


**Figure 2.** Healthy foot measurement.

- Second step

The second step of the manufacturing consists of the manufacturing of the wooden prosthesis core, shown in Figure 3 below.

Figure 3. The core of the prosthesis (made of wood).

- Third step

The third step is the wrapping of the core with the extruded polystyrene to obtain the shape of the healthy foot and the aesthetics using the EVA foam (see Figure 4(a) and Figure 4(b)).

(a) Interior view

(b) Top view

Figure 4. AL-HANOUNA prosthetic foot.

## 2.2. Method

As part of this introspective study conducted among patients, we submit a questionnaire to patients with tibia amputation. It is a closed questionnaire developed in agreement with the orthopedists of the prosthesis center. The questions asked to the amputees mainly concern the identification of the patient, the etiology, *i.e.* the cause of amputation, the type of stump of the amputee, the type of pain felt when wearing the prosthesis, comfort and discomfort, the lifespan of the prosthesis, the weight of the prosthesis, overall satisfaction and the question related to the problem of rehabilitation.

#### 2.2.1. Search Type

As part of this study, a quantitative study will be conducted. The data are collected and analyzed using the statistical analysis technique. This type of research will highlight the influence of the prosthesis on the quality of life of patients in terms of pain, comfort, discomfort, etc.

#### 2.2.2. Study Population

In this study, the study population consists of all lower limb amputees who came to the CERK in N'Djamena to have prostheses fitted and/or undergo walking rehabilitation.

#### 2.2.3. Target Population

It is made up of all the patients with tibia amputations from CERK, the distribution of which is given in Table 1 below.

Table 1. Distribution of study population: tibias amputees.

| Status | Men | Women | Total |
|---|---|---|---|
| Tibias amputees | 41 | 79 | 120 |

#### 2.2.4. Type of Sampling

For the investigation, we proceeded by a random draw to obtain the study sample. It is from the sampling that we will randomly choose the individuals required to compose the sample. Then, we randomly drew 24 individuals from the target population to constitute the sample on the basis of at least 20% representability rate. The choice of simple random sampling is justified by the fact that each unit of the sampling of the study population has an equal chance of being selected and included in the sample; this is the best in terms of chance. We also arbitrarily chose the number of individuals required to represent the entire study population or each member has an equal probability of being chosen.

#### 2.2.5. Study Sample

The patient quiz was administered at the CERK. Patients were selected based on the criterion of lower limb amputation (tibia), regardless of the etiology. The introspective study of patients covered 24 lower limb amputations. The patient quiz was designed using data from patient records, the anatomy and pathology registers, the orthopaedic surgery center register, and operating room report registers. The following data were collected: epidemiological data, clinical data, functional impact of amputation, and the number of patients fitted with orthopaedic surgery. Table 2 presents the study sample.

Table 2. Study sample.

| Respondents | Men | Women | Children | Total |
|---|---|---|---|---|
| Tibias amputees | 16 | 7 | 1 | 24 |

## 3. Results and Discussion

In this section, we present the results from the survey conducted among patients amputated on the SACH foot. Then we compare at the end, the SACH foot made of polyurethane with the AL-HANOUNA foot made using extruded polystyrene.

### 3.1. Social Status of Amputees

The social status of the respondents is shown in Figure 5. In this figure, the tibia amputation patients who work are in the order of 25%, the unemployed are 4.17% and the most numerous are the others at 70.83%, that's to say who are neither workers nor unemployed.

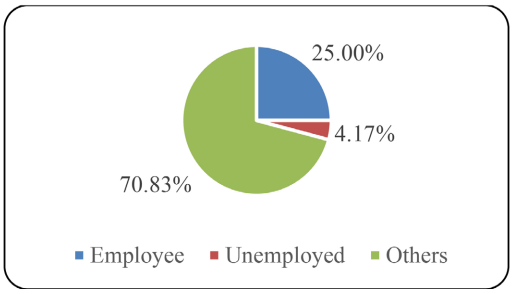



Figure 5. Social Status of respondents.

### 3.2. Family Status of Amputees

Figure 6 shows the family status of CARK tibia amputees responding to the survey quiz. Of the twenty-four (24) patients surveyed, fourteen (14) are married, or 58.33%, two (2) single, or 8.33%, one (1) child, or 4.16% and two (2), or 8.33% who did not comment.

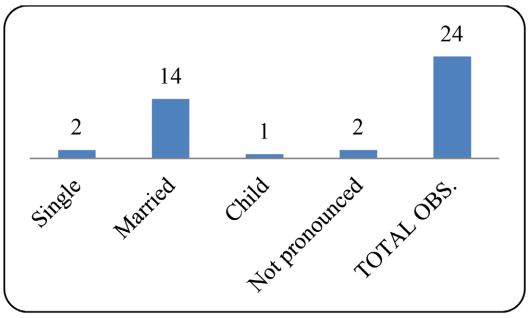



Figure 6. Family status of respondents.

### 3.3. Length of Time with a Disability

At CERK, the number of new amputees is higher than the number of old patients (see Figure 7). Among the respondents, there are 87.50% of new and 12.50% of old amputees. Given that many new patients are looking for prosthesis, even those who come just to change their SACH prosthetic foot, it can be said that the prosthesis is an appropriate solution to replace the amputated lower limbs.

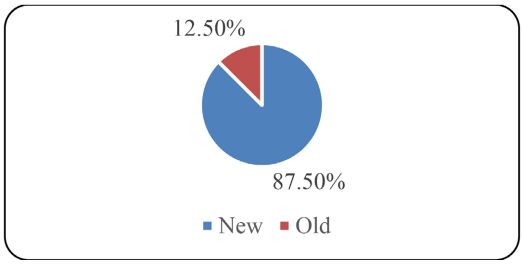



**Figure 7.** Length of time with a disability.

### 3.4. Treatment Support

Recently amputated patients are not lucky enough to be supported by partners (social fund, ICRC and HI). Of the twenty-four (24) surveyed, we have twenty-two (22), or 91.67% who took care of themselves personally and two (2), or 8.33% supported by Handicap International. Figure 8 shows the care of patients.

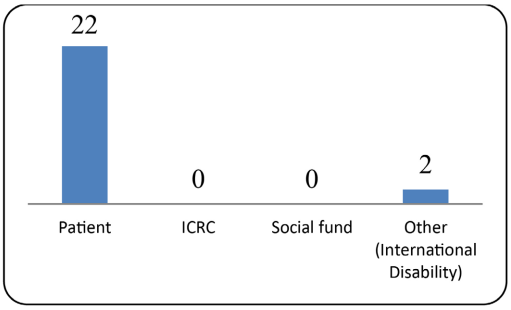



**Figure 8.** Treatment support.

### 3.5. Age of the Respondent

Among the patients who come to the center, there are different age groups. Among the respondents, patients aged 50 to 70 years represent 54.17%, those aged 30 to 49 years constitute 33.33% of the respondents, those aged 19 to 29 years are around 8.33% and patients aged 0 to 18 years represent a percentage of 4.17%. Figure 9 shows the different age groups of the respondents.

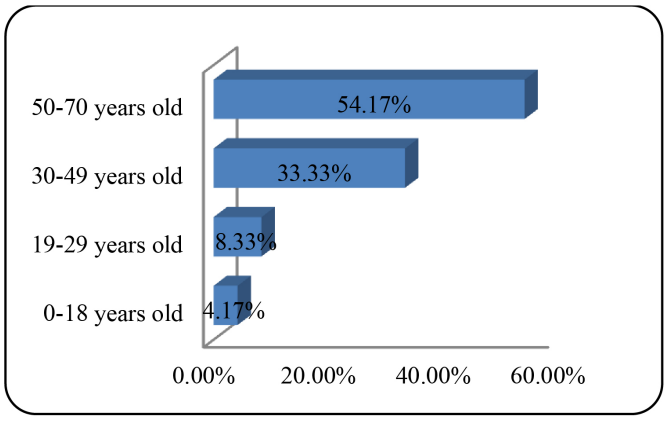



**Figure 9.** Age of respondents.

### 3.6. Gender of the Respondents

Of the registered patients, we found 66.67% men, 29.17% women and 4.16% children (see Figure 10).

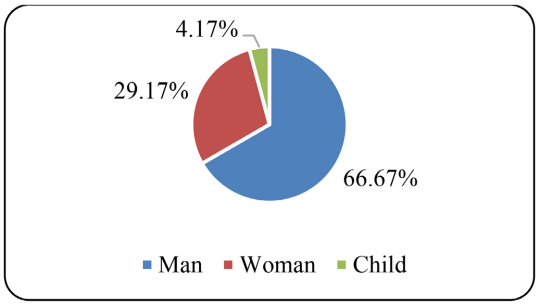



Figure 10. Gender of respondent.

### 3.7. Language of Patients

During this survey, we found that the majority of amputees are people who did not attend school. The 91.67% of tibial amputees who spoke their local language and the 8.33% are intellectuals who speak French (see Figure 11).

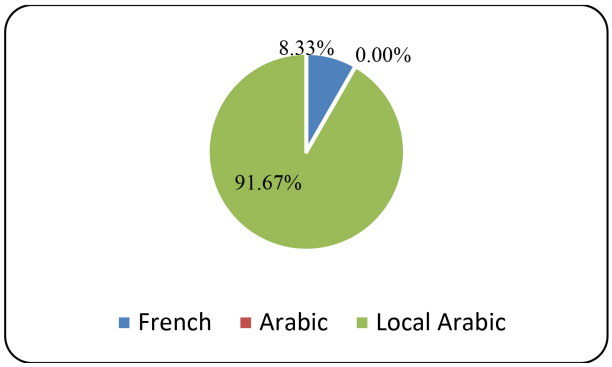



Figure 11. Language of patients.

### 3.8. Level of Tibia Amputation

There are three levels of amputation, namely: long, medium and short stump. Figure 12 shows the proportions of the stump types.

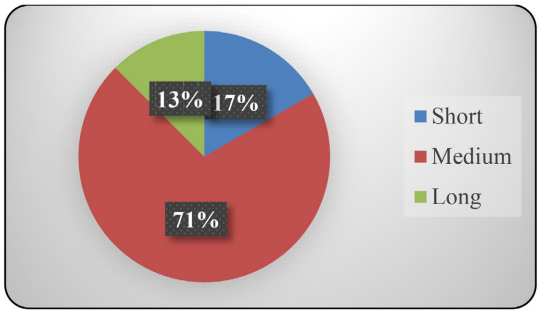



Figure 12. Type of stump.

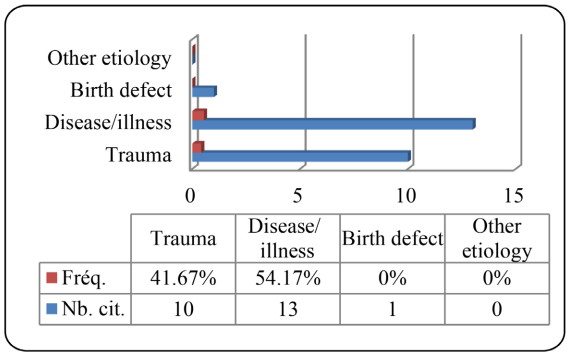
In this figure:

- Long stump amputees are made up of 12%, this stump is performed on the lower part of the tibia on which the surgeon removes the distal end and part of the fibula. This amputation preserves a large part of the leg flexor muscles and generates little flexum.
- Medium stump amputees constitute 71% of respondents and therefore the majority of respondents. This amputation is performed on the diaphyseal part of the tibia. It preserves a good part of the calf flexor muscles but can cause knee flexum.
- Short stump amputees are around 17% of respondents.

### 3.9. Etiology of Amputation

Etiology is the study of the causes of amputation and the factors of a disease in general. Generally, three causes of amputation are distinguished: pathological causes, traumatic causes and amputations due to congenital malformations.

At CERK, according to the survey, vascular diseases are the cause in 54.17% of cases, trauma in 41.67% of cases, and congenital disease in 4.16% of cases. Figure 13 shows the proportions of the causes of amputation of the respondents.




| | Trauma | Disease/ illness | Birth defect | Other etiology |
|---|---|---|---|---|
| Fréq. | 41.67% | 54.17% | 0% | 0% |
| Nb. cit. | 10 | 13 | 1 | 0 |

Figure 13. Etiology.

### 3.10. Disease/Affection

The causes of amputation of patients include trauma, congenital malformation and disease affection. Among these etiologies, the most common is disease affection which represents a percentage of 54.17%. In disease affections, we find different kinds of diseases which are Tumor (23.08%), Madura (15.38%), Diabetes (46.15%), and Neurology (15.38%). Figure 14 shows the proportions of different disease affections.

### 3.11. Trauma

Trauma, on the other hand, can have different origins, including difficult childbirth, animal bites, burns, landmines, war, road accidents, etc.

Figure 15 shows that war and road accidents constitute the majority of traumas of amputee patients at the center.

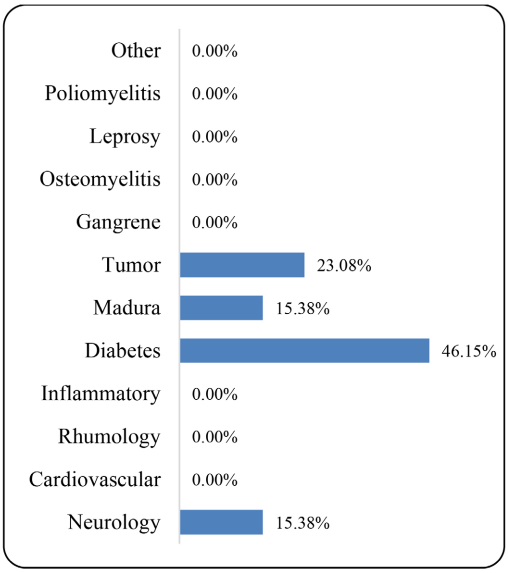



**Figure 14.** Disease/affection.

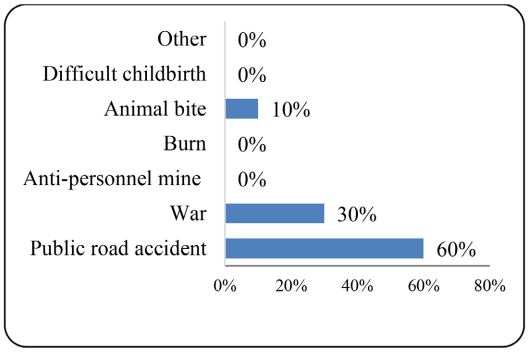



**Figure 15.** Type of trauma.

## 3.12. The Different Types of Pain Felt

We count different types of pain felt by patients with tibia amputations. Of the 24 patients surveyed, 25% have Neuropathy type pain, 20.83% Nociceptive type pain and 54.17% feel nothing (see Figure 16).

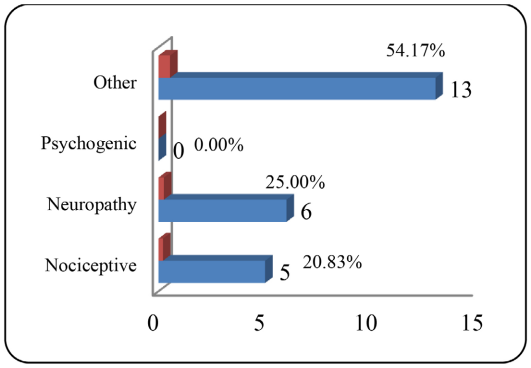



**Figure 16.** Type of pain felt.

**Leg pain**

Patients have one leg amputated, the other leg is healthy. To the question do you feel pain in the amputated leg, 50% of respondents answered yes and 50% answered no. To the question do you feel pain in the healthy leg, 100% answered no (see Figure 17).

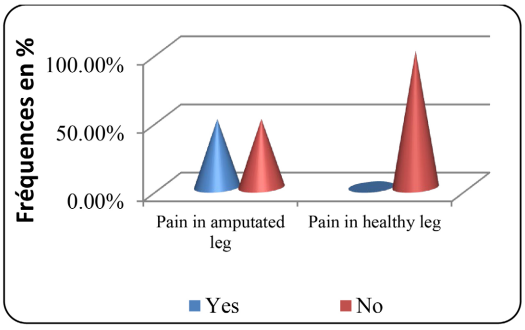



Figure 17. Leg pain.

**Thermal Comfort**

For static thermal comfort, 4% of respondents think that wearing the prosthesis is pleasant, while 96% think that the SACH foot prosthesis is unpleasant in thermal comfort and 0% thinks that it is less pleasant. Regarding to the dynamic thermal comfort, 100% of respondents think that the prosthesis is less pleasant. Figure 18 shows the two types of thermal comfort.

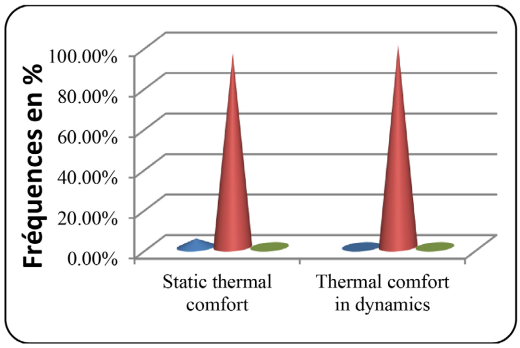



Figure 18. Thermal comfort.

**Pressure comfort**

Regarding pressure comfort, 66.67% of respondents say that the support is not painful while 33.33% think that the support is painful (see Figure 19).

**Suspension comfort**

Speaking about suspension comfort, 92% of respondents confirmed that the prosthesis is stable in terms of suspension and 8% of respondents think that the prosthesis is mobile (see Figure 20).

**The lifespan of the tibia prosthesis**

Regarding the lifespan of the tibia prosthesis, 83.33% are new and can give a

correct opinion. On the other hand, among the old ones, 12.50% think they will use the prosthesis for more than 2 years and 4.17% think that the prosthesis only lasts one year (see Figure 21).

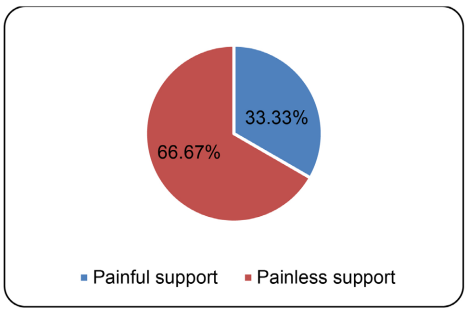



Figure 19. Pressure comfort.

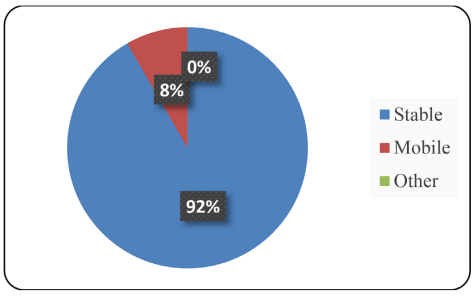



Figure 20. Suspension comfort.

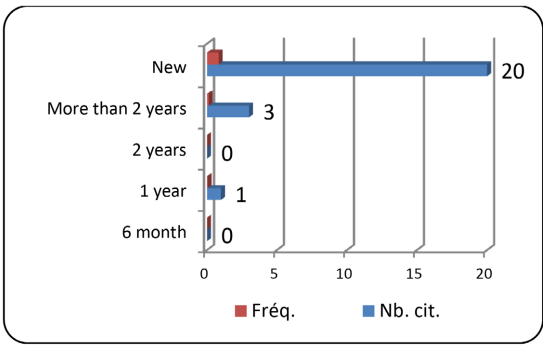



Figure 21. Lifespan of the tibia prosthesis.

**Weight and size of the prosthesis**

On the question of the weight of the prosthesis, 92% think that the prosthesis is heavy and 8% think that it is less heavy. On the question of the size of the prosthesis, 96% of respondents answered no, that the prosthesis is not bulky and only 4% answered yes (see Figure 22).

**Improvement/rehabilitation**

Regarding the use of the prosthesis, particularly the problem of walking, 58% of respondents answered no and 42% answered yes, that they have a problem of walking while wearing SACH foot prosthesis. In terms of rehabilitation time, the

opinions of the respondents are divided, 50% think that rehabilitation takes too much time and 50% no (see Figure 23).

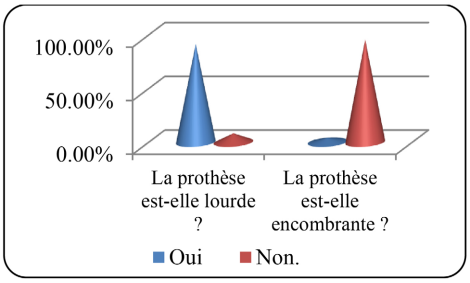



Figure 22. Weight and size of the prosthesis.

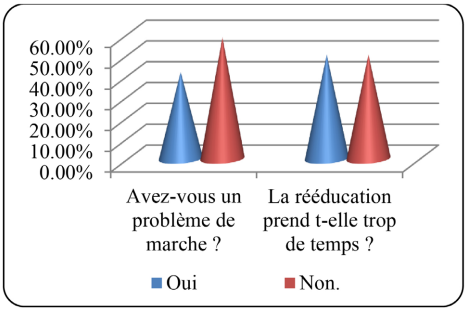



Figure 23. Improvement/rehabilitation.

### Comparison between the SACH foot and the AL-HANOUNA foot

We designed twenty-four prosthetic feet called AL-HANOUNA that we submitted to twenty-four amputee patients aged 50 to 70 years, for walking tests over three kilometers (3 Km) round trip. The objective was to compare AL-HANOUNA with extruded polystyrene with the SACH foot with polyurethane. Knowing that the polystyrene material is certified by the association for the certification of insulating materials (ACEMI). Figure 24 shows the results of the prosthetic tests on the two types of feet.

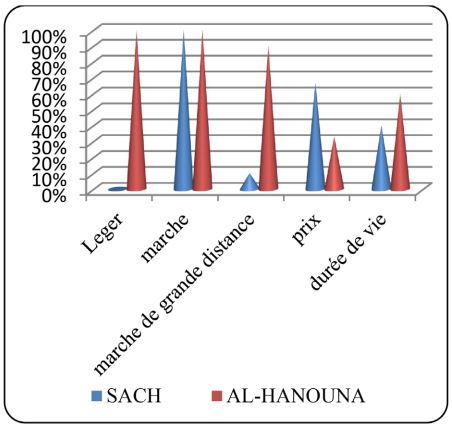



Figure 24. Testing of prosthetic feet.

It appears that out of the 24 amputees, 100% responded that the AL-HANOUNA foot is very light and has a fairly long life than the SACH foot. Both prosthetic feet allow walking, but when walking long distances, amputees prefer the AL-HANOUNA foot for its lightness. Another advantage of the AL-HANOUNA foot is that it costs less than the SACH foot.

**Overall opinion of amputee patients**

When asked about overall satisfaction with the prosthesis, 96% of the 24 amputees responded that they were satisfied with the AL-HANOUNA foot prosthesis (see Figure 25).

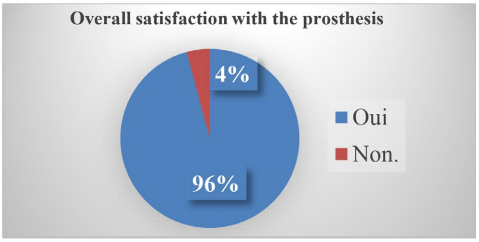



**Figure 25.** Overall satisfaction.

## 4. Conclusions

In this article, we proposed another prosthetic foot made from extruded polystyrene that we called "AL-HANOUNA prosthetic foot". This foot is handcrafted at the Center for Equipment and Rehabilitation of Kabalaye (CERK) in N'Djamena. Twenty-four (24) extruded polystyrene prosthetic feet were made and subjected to walking tests on twenty-four (24) tibia amputees with the aim of finding a prosthetic foot that is best suited for an active amputee, in order to restore an optimal quality of life to amputees.

A comparative satisfaction quiz regarding the two prosthetic feet was sent to the amputees. The result showed that among these two feet, the one that satisfies active amputees in terms of walking over a long distance, weight, and lifespan is the AL-HANOUNA prosthesis with the prosthetic foot. This is what we now offer to amputees with permanent mobility. However, in the current era, the ALHANOUNA foot is manufactured in an artisanal way. To popularize it and make it available to all amputees of the Center, it would be necessary to proceed methodically as follows:

1) Finding a way to mold the foot to make it aesthetic and homogeneous: in this case, the current manufacturing method must be adapted for small or medium series manufacturing;

2) Simulating the foot and the mold in order to optimize the geometry of the foot and reducing the concentrations of stresses causing cracks when walking. For this, the geometry of the foot must be defined in Computer Aided Design (CAD) in order to carry out mechanical characterization studies in bending and compression on both feet;

3) Carrying out an experimental mechanical characterization is necessary to

determine the maximum bending and compression forces that each foot can support.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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