A Comparative Analysis of Traditional and Smart Prosthetic Sockets: Enhancing Gait Symmetry and User Comfort

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Abstract

This study compares two different sockets, traditional and smart. It includes designs, manufacturing, and testing to evaluate the influence of the socket designs on gait symmetry. The proposed materials are locally available in the prosthetics center where traditional sockets are manufactured. and smart socket designs with the same materials as traditional additions. A simple electronic system programmed to control the movement of the stump by pneumatic pads and prevent slipping during movement is considered an advanced suspension system. A gait cycle test was carried out to evaluate the sockets. it was performed on a patient with AK amputation in two cases: the first when the patient was wearing the traditional and the second when wearing the smart. Where the difference in (gait cycle time, step velocity, heel contact, and mid-stance) between the left and right leg is equal to (0.54, 4.3, 0.19, and 0.34) respectively, when the patient uses the traditional, while these values reduce to (0.09, 0.7, 0.07, and 0.27) respectively when the patient used the smart, it improves comfort by modifying pressure distribution, relieving pressure points, and enhancing functionality through gait analysis. They adjust to the volume of the residual limb, ensuring an effective fit. Real-time monitoring and remote modifications decrease the need for in-person meetings and enhance user confidence. The smart socket, designed to fit user requirements, provides enhanced comfort, functionality, and independence. The studies will explore its long-term benefits and broader applications, focusing on its originality, practical implications, and outcome measurement.

Keywords: Smart Socket, Gait Cycle, Traditional Socket, AK, GRF.

تحليل مقارن لمقابس الاطراف الاصطناعية التقليدية والذكية: تعزيز تناسق المشية وراحة المستخدم

شهد صكبان ناصر، وجدي صادق عبود، صلاح الدين محمد حارس

الخلاصة:

تقارن هذه الدراسة بين مقبسين مختلفين، تقليدي وذكي. ويتضمن التصميم والتصنيع والاختبار لتقييم تأثير تصميات المقبس على تناسق المشية. والمواد المقترحة متوفرة محلياً في مركز الأطراف الصناعية حيث يتم تصنيع المقابس التقليدية. وتصميم المقبس الذكي بنفس المواد التقليدي. بالإضافة الى نظام إلكتروني بسيط مبرمج للتحكم في حركة الجذع عن طريق وسادات هوائية ومنع الانزلاق أثناء الحركة، ويعتبر نظام تعليق متطور. تم إجراء اختبار دورة المشي لتقييم المآخذ. تم إجراؤها على مريض بتر من نوع فوق الركبة في حالتين: الأولى عندما كان المريض يرتدي التقليدي والثانية عندما يرتدي الذكي. حيث يكون الفرق في (زمن دورة المشي، وسرعة الخطوة، وملامسة الكعب، والوقفة المتوسطة) بين الساق اليسرى واليمنى يساوي (0.54، 4.3، 0.19، 0.34) على التوالي عندما يستخدم المريض المقبس التقليدي، بينما هذه القيم تنخفض إلى (0.09، 0.7، 0.07، 0.27) على التوالي عندما يستخدم المريض المقبس الذكي. يوفر المقبس الذكي، المصمم ليناسب متطلبات المستخدم، راحة ووظيفة واستقلالية معززة. وسوف تستكشف الدراسات فوائدها طويلة المدى وتطبيقاتها الأوسع، مع التركيز على أصالتها وآثارها العملية وقياس النتائج.

1. Introduction

Major lower limb amputation can be classified into four main levels: through-knee (TK), above-knee (AK), below-knee (BK), and through-hip [1]. when it comes to amputation, people with (BK) amputations are more mobile than those with (AK) because BK amputations preserve the knee joint, which is a crucial component for walking and balance [2]. The knee joint is lost when an above-knee (AK) amputation occurs. This significantly impacts the biomechanics of walking. The individual must rely on the hip joint for propulsion. This work will focus on this type of amputation by designing a smart socket from materials that are available locally at a reasonable price, suitable for all patients, and result in better performance. In particular, lower extremity amputees repeatedly place their body weight on the prosthesis while walking**.** A prosthetic system for amputees of lower limbs, specifically those above the knee, primarily comprises a foot, knee, and socket [3], as shown in Figure (1).

Figure (1): Prosthetic component of Ak [3]

The prosthetic socket is a crucial prosthetic limb component, providing support, suspension, and stabilization for the residual limb. The challenge in socket fabrication lies in achieving the correct geometry to ensure proper force distribution and comfort. A well-fitting socket is essential for successful prosthetic use, as it can prevent pain, skin issues, and discomfort [4]. Amputees typically experience changes in residual limb volume in their daily lives. It causes an uncomfortable fit of the socket by applying high pressure on the sensitive area of the residual limb or loosening the socket. this paper developed a transfemoral prosthetic socket for above-knee amputees that ensures a suitable socket fit by maintaining uniform and constant contact pressure despite volume changes in the residual limb. Patients with above-knee amputations face difficulties such as volume variations, inadequate socket fit, discomfort, and diminished quality of life. A smart socket can mitigate these challenges by adjusting to volume fluctuations, enhancing comfort, improving functionality, increasing confidence, and reducing healthcare expenses. In this study, a smart socket was developed that is affordable, customizable, and high-performing using locally available materials. Factors like material properties, manufacturing techniques, sensor technology, and actuator mechanisms were considered to improve comfort, function, and overall quality of life. The materials and methods section provide a detailed explanation.

2. Related Works

This section presents developing prosthetic socket designs and testing new prosthetic socket designs that incorporate advanced technologies:

In 2020, Paterno et al. [6] created fully personalized liners with designs allowing sensor integration. residual limb. Utilizing scanned three-dimensional image data of the patient, A liner with built-in sensors could offer a means to facilitate a workable and instrumented liner with highly personalized designs; a customized liner with temperature sensors developed in it, and humidity sensors was developed and examined using transtibial amputee.

In 2021, Seo et al. [7] were developed to compensate for the volume change of the residual limb. to better understand a shift in stump in a prosthetic socket. Using an inflatable air bladder, the proposed socket monitors the pressure in the socket and keeps the pressure distribution uniform and constant while walking; the air bladder is located between the liner and the prosthetic socket. The air bladder detects the pressure caused by the compression between the residual limb and the socket in real time and then changes its volume to compensate for the change in the volume of the residual limb. the proposed socket was tested only using the gait simulator, not a clinical test. The gait simulator can simulate a human's gait with weight loads.

B. Oldfrey et al. 2021 [8] presented several state-of-the-art methods for creating intelligent prosthetic liners. When assessing a transtibial amputee, temperature, and humidity sensors are integrated into customized lining sensors, a delightfully instrumented liner with highly adaptable designs. They illustrate how to make an electrically conductive elastomeric nanocomposite and printing methods flex sensors using it. In addition, they show the printing of fluidic tubes to provide active cooling within the liner and computerized casting techniques for specific liners. These advancements in soft materials technology facilitate more investigation into prosthesis-integrated function liners.

S. Abderahmane et al. 2023 [9] Examining the effects of different prosthetic liners and liner thickness on the shear stress and contact pressure at the relationship among the stump and prosthesis after transtibial amputation (TTA). The subjects of the investigation were the three kinds of artificial liners tested: polyurethane foam, thick liner, and gel. successfully decreased the stress at the stump

Linda et al. 2024[10] used a new prosthetic socket design combining a rigid frame with silicone for better comfort and support, allowing innovative technology integration to monitor user health and enhance interaction. It includes sensors for muscle signals, vibrations, and temperature, which help understand user intentions and provide feedback while tracking limb conditions. Testing showed good accuracy in decoding user intentions and high satisfaction with feedback, but improvements are needed for monitoring skin moisture.

Kubba et al. 2024 [11] This work investigates the use of pneumatic pads in socket design to account for variations in stump volume. Amputees may fit into the adjustable socket for a secure and comfortable fit. According to the experimental findings, appropriate pressure between the socket and the residual limb indicates that the pneumatic pads offer excellent suspension and adaptability.

Compared to the last study, the patient can adjust the air pressure in the socket pads using an air pump for insufficient suspension or slippage or by opening the valve to release air for excessive pressure or removing the prosthesis. In this research, the patient does not need all of this because the system is designed to control the air pads automatically, and the pads work continuously while the patient is moving to provide comfort and excellent suspension. This study aims to overcome the problems associated with the studies in this field. This study focuses on affordability, accessibility, user-friendliness, and a practical approach to making a smart socket accessible to a broader range of amputees. It uses locally available materials and pneumatic pads to address volume fluctuations and improve fit. An air pad was used inside the socket, and its location is in the anterior and posterior of the femur to absorb the force in that area so that slipping does not occur. This research created a liner suitable for AK amputations from materials obtained locally. The electronic system is constructed from basic parts and is cost-effective. Integration with the socket is easy and does not affect the patient. The mechanism works continuously while walking, and the readings show the pressure in real-time. The test was conducted on an actual case while performing daily tasks and produced excellent results, unlike previous studies, most of which were tested only in the laboratory.

3.Above-knee or transfemoral amputation

An amputation of the leg through the femur, above the condyles, removes the patella, and soft tissue flaps are created using leg muscle to cover the transected bone [12]. AK amputation it's can be at the proximal (short stump), mid-femur (medium stump), or supracondylar (long stump) [13], illustrated in Figure (2).

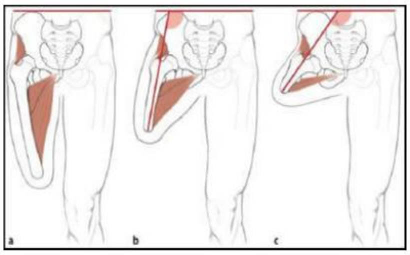


Figure (2): Levels of above-knee amputation. (a): Long (b): Medium (c): Short stump [13]

Long-length stumps offer better muscular balance, lever strength, and energy efficiency, making them suitable for ischial tuberosity-bearing prostheses. Medium-length stumps reduce adductor strength, increase energy expenditure, and cause imbalance, resulting in heavy prosthesis [14]. The patient was the long-length stump in this research, so the socket used a quadrilateral socket. AK amputation due to trauma, accidents, or diseases like diabetes or vascular disease results in the loss of the knee and ankle joints, which are crucial for human gait as they connect the thigh and shank muscles. This loss of function often leads to gait variations as age progresses [15]. The focus was on this type of amputation because it is difficult to rehabilitate the patient to walk. The specific criteria for selecting the patient for this study are illustrated in Table 1

Table (1): Patient Specifications.

Gender	Female
Age (years)	27
Height (cm)	156
Weight (kg)	58
Body Mass Index (kg/m^2)	24.2
Amputation level	Left above -knee (transfemoral)
Activity level	K3
Time since amputation	3 years
Cause of the amputation	Traumatic event

4. Design a Socket

The prosthetic socket is crucial for amputee rehabilitation, serving as the interface between the amputee's residual limb and the prosthesis. A good fit, efficient fit, adequate load transmission, and stability are essential. Many patients stop wearing prostheses due to socket-related issues, such as poor fit, biomechanics, and reduced control [16]. There is a knowledge gap regarding how the socket design affects in-socket mechanics and how in-socket mechanics affect patient-reported comfort and function [17]. During socket design, as a general rule, the prosthetist aims to achieve an adequate load distribution by compressing tolerant regions in the residual limb and relieving pressure from the intolerant areas to make the socket more comfortable for the amputee. as seen in Figure 3.

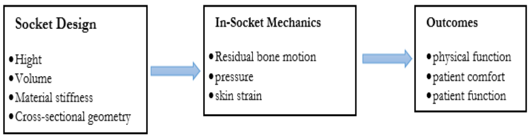


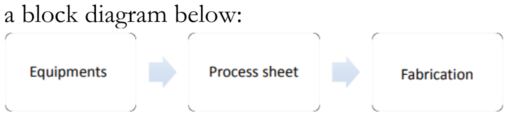
Fig (3): Key socket design parameter

5. Manufacturing of socket

The method of manufacture of prosthetic sockets is a complex and detailed process that requires precision and careful attention to detail.

5.1 Manufacturing Traditional Socket

The manufacturing of AK parts can be explained as a block diagram below:

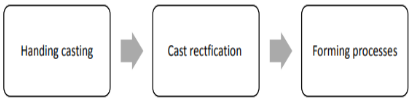


a) Equipment: The equipment employed in the manufacturing process of AK prostheses are medical scissors, an Indelible pen, a Stockinet, a Knife, a Tape measure, a Plaster of Paris, a Surform, Burke, a heater device, a cutting device, a smoothing device, Gum and PVA lamination bag. Figure 4 presents all materials used.

Figure (4): Materials used in manufacturing

b) Process sheet: Detailed measurements of the residual limb are taken to capture its shape and dimensions. Circumferences, lengths, and angles are recorded.

c) Fabrication: AK was manufactured in three can be explained as a block diagram below and Figures (5,6,7)



A B C

Fig (5): Handing casting

D E F

Figure 6: Cast rectification

G H I J

Figure 7: Forming processes

The final step is assembling Prosthetic Limbs. The parts for assembling the limb are shown in Figure 8.

1. Socket: type is a quadrilateral socket
2. Adapter Socket: Adapter Socket with Rotation Adjustment,4R41 Ottobock
3. Knee: Otto Bock 3r60 prosthetic
4. Foot: Polyurethane multi-flex foot

Figure (8): AK traditional components.

5.2 Manufacturing Smart Socket

Smart socket prosthesis combines advanced technology with a prosthetic limb to create a more functional and comfortable device.

5.2.1 Particulars of the Design

The method of manufacturing this socket is similar to the traditional socket, which is the goal of this research. It is to design a smart socket from locally available materials that are less expensive and high-quality. It must be noted that it is a turning point for the patient when wearing it so that the patient does not feel strange, especially the material, some of which causes allergies to some people. Still, there are in addition to the socket, which is the electronic. All components were selected for their lightweight, local availability, low cost within the model, and ease of integration with other component systems that contain several components. Table 2 illustrates all components of the electrical system used. The design principles guiding the development of the smart socket appear to be:

1-Affordability and Accessibility: focusing on using locally sourced and economical resources.

2- User-Friendliness: focusing on an intuitive design that accommodates the patient.

3-Reliability and Durability: Choosing reliable and durable components will ensure the socket's long-term performance.

4-Integration with Conventional Socket Production: Using a manufacturing method akin to traditional sockets to reduce complexity and expenses.

The design of the smart socket matches that of the traditional socket in terms of installation and the materials used in its production. Emphasis must be placed on the design of the smart socket, which must be compatible with the traditional design in terms of materials and contain a lamination socket and the type of quadrilateral socket. Other parts of the prosthesis, including the knee joint, adapter socket, and foot, remain unchanged, which was the goal of designing the smart socket. As previously stated, this is the objective of the research. Locally available materials include electronic components like the pad, Arduino Nano, etc. The following Figure 9 illustrates the procedure for adding components.

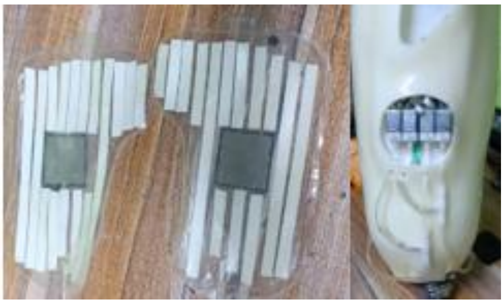
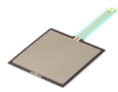


Figure 9: Smart socket design stage

Limitations of this study should include increasing sample size and diversity, using standardized protocols for data collection, conducting longitudinal studies, and gathering qualitative feedback. Addressing limitations in sample size and data collection methods, such as battery life and sensor accuracy, can help reduce the impact of individual variability. Providing personalized fitting and user training can also enhance the effectiveness of smart sockets. Technological advancements in sensor technology, battery technology, and machine learning algorithms can improve future smart socket designs. At the same time, robustness testing can assess the durability and reliability of smart socket components under real-world conditions. The prosthetic components, like the knee, Adapter Socket, and foot the patient usually uses, remain the same when the smart socket is manufactured because they are fairly good. Due to its light size, the added electronic system parts do not affect the socket's weight.

Table (2): System Components

Elements	Name	Description
	Arduino Nano FT232	is a microcontroller board. It is small, easy to use, and compatible with various add-on boards [18].
	Bluetooth HC-05 MODULE	is designed for wireless communication. The data transfer rate of the model is in the range of 10 meters [19]. To know the pressure readings over a distance while diagnosing the patient in the clinic, Bluetooth
	DC Boost Step-Up	A power Converter circuit can create a power bank that increases the voltage of a battery (typically 3.7V Lithium Ion) to a standard 5V for charging devices [20].
	Lipo battery	is a rechargeable battery commonly used in small electronic devices and stores a lot of power for its size and weight. They are also relatively lightweight and have a long lifespan.[21]
	Micro Air Pump - DC 12V	Vacuum Electric Pumping Booster is a small, electric pump that can be used to vacuum. It is commonly used in medical treatment instruments, small-size designs, and high airflow for good performance [22].
	Micro Sphygmomanometer Solenoid Valve	1-position 2way DC3- 5V, working principle: When the power is off, the air passage is open, and the passage is blocked when the power is turned on.
		Power test machine, the sound is crisp, and the response is fast.[23]
	Force Sensing Resistor Sensor FSR	is a flat, flexible device whose resistance to the force-sensing resistor varies significantly with the applied force. [24] The square shape was chosen because it is in an area with muscles, and we need to cover a larger area to know it. the pressure
	Temperature Sensor	used for temperature sensing. It's known for its simplicity, accuracy, and low cost, and it used to know temperature changes inside the stump while walking [25].
	Air pads	The air pads are taken from a locally available off-the-shelf medical orthosis called Air Cam Walker

5.2.2 The working principle of the smart socket

1) Airbags are placed inside the socket in front of and behind the femur. The air pads can be inflated to create a suction effect, which helps to suspend the stump within the socket and prevent movement. This is important for comfort and stability and to prevent skin breakdown. Actual Figure 10 shows the placement of air pads.

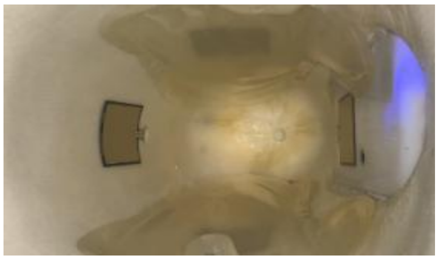


Figure (10): Location of pneumatic pads

2) The air pump and solenoid cannot be operated directly. Instead, they must be connected to a relay. The relay activates and begins inflating the air pads upon receiving a command from the Arduino program through programmed code to obtain the best FSR readings. It has 4 sensors directly attached to the inner wall of the socket. Two of these sensors have the pad directly connected, and the other 2 are on each sensor's side, measuring a particular pressure.

3) The sensor under the airbags detects the lowest pressure, and the air pads work by a solenoid valve; inflated air inside the pads and catching the stump in the correct position does not occur. The sensor was placed in this specific place based on where the most minor contact occurs between the socket and the stump.

4) The HC-05 Bluetooth chip and the Arduino Nano will be linked to the FSR. The last one will register a low pressure in one of the locations. Air pads will receive an instruction and begin to fill with air until they reach a certain amount.

5) The actuator (solenoid valve) is stopped when the pressure delivered by the pump reaches a preset limit, and the FSR continues to monitor the pressure while the patient is sitting or walking. The airbag works in the opposite direction as compensation. When there is high pressure in this direction, the second air pads fill

with air through the solenoid, and the procedure is repeated.

6) The pressure readings are transferred to the phone app via Bluetooth. As shown in Figure 12, all components are fixed on the outer wall of the socket and do not affect the patient during movement. Figure 11 demonstrates the complete process steps.

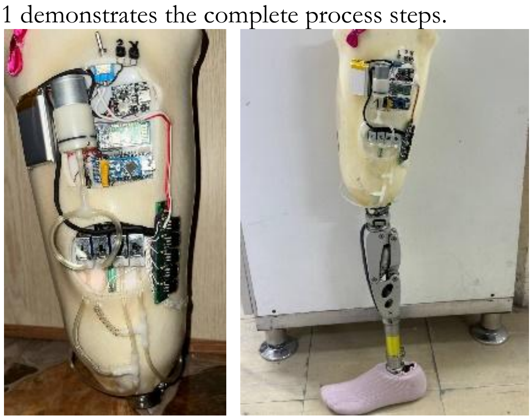


Figure (11): Smart socket assembly

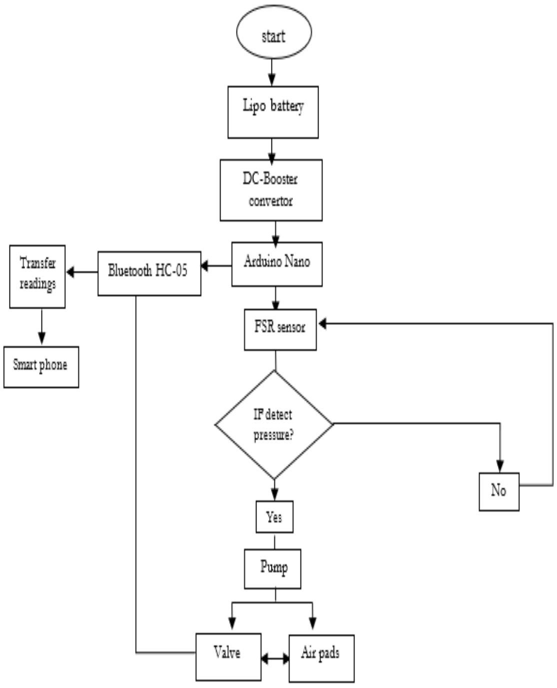


Figure (12): Principle of work on the pneumatic pads

Figure (13): Silicon liner with a Shuttle Lock [27]

6. Types of suspension

The suspension system and socket fitting in prosthetic devices are crucial factors in amputee comfort, mobility, and overall satisfaction. A secure suspension system helps prevent the residual limb from moving within the socket, ensuring a comfortable and stable fit. Poor suspension can lead to socket deterioration, pain, and skin ulcers, which may discourage amputees from using their prostheses [26].

6.1 Suspension for traditional socket

In this type, the Silicone liner with a Shuttle Lock is a popular choice for prosthetic sockets due to its durability, comfort, and scalability. However, it can be more expensive than other liner materials and requires frequent cleaning and maintenance. While shuttle locks offer convenience, as shown in Figure 13 [27], they can be limited by moisture and sweating. Common problems include skin irritation, infections, bacteria, slipperiness, reduced comfort, and decreased mobility.

6.2 Suspension for smart socket

Air Pneumatic Suspension Systems (APSS) are innovative prosthetic technologies designed to enhance comfort, stability, and mobility for individuals with transfemoral amputations. These systems utilize compressed air to adjust the suspension characteristics of the prosthetic limb, providing a more personalized and responsive fit. It can be customized to accommodate changes in limb volume and activity levels [28]. The proposed adjustable socket design can improve the pressure distribution on the residual limb, putting on or off the prosthetics, keeping the socket fitted during a wide range of activities, and providing more ability to support any minor changes in the stump volume and shape. Using pressure sensors to measure air pressure will provide feedback to control the pad volume. APSS's specific design and features may vary depending on the manufacturer and the user's requirements. The optimal location for the air pads was discovered after looking over several prior works, placing them above locations where complete contact is advised. The locations of the pads have been determined for the anterior and posterior femur [29], as shown in Figure (14), demonstrating their requirement for the green areas. Pressure cannot be applied to the red regions.

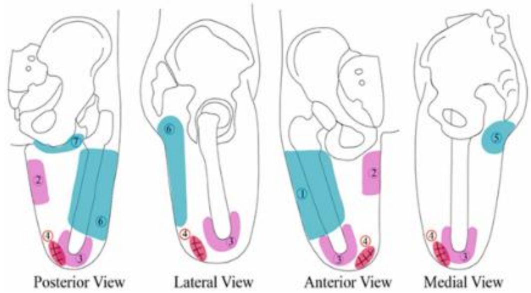


Figure (14): A transfemoral stump with the locations of the areas of pressure sensitive (pink& red) and pressure tolerant(blue) [29]

7. Experimental test

In this section, the ground reaction force test (GRF) has been presented. The ground response forces involved in human motion are measured in biomechanics investigations using force platforms, commonly called "force plates." They work well as a teaching tool to illustrate the dynamics and kinematics of motion. They are constructed of a metal plate with sensors attached, and the electrical output they produce is proportional to the force applied to the metal plate. In this test, the patient walks on force plate device sensors in two cases, first (the patient with a traditional socket) and second (the patient with a smart socket), as seen in Figure 15 below. The left wears traditional clothes, and the right wears smart sockets. The experiments were performed in the prosthetics laboratory at Al-Nahrin University, College of Engineering. The surrounding circumstances were suitable, ensuring minimal disruptions throughout the patient's ambulation and adequate laboratory temperature. Various factors can influence the outcomes of the walking test. The patient must be in optimal health while ambulating, and the socket must be suitable.

Figure (15): The patient walks on a force plate device. The left traditional and right smart socket.

8. Results and discussions:

The results showed the difference between the left and right leg data due to the defect in the left leg in two cases. Still, the difference in parameters for the second case (the patient wears a smart socket) is less than the difference between the left and right limbs and more acceptable than the first case (the patient wears a traditional prosthetic). The simple difference between the legs confirms the stability of the smart prosthetic while walking and the patient's ability to control the limb's movement well. Fig (16) and (17) show the GRF to the left and right legs; the scheme painted in red indicates the GRF to the right leg (sound leg), while the sketch in green signifies the GRF to the left leg (amputation leg). When the patient wears the traditional socket, the right leg does not suffer any problems, while the left does. It is essential to focus on the peak force value, which was selected not at the start of walking but when the patient is stable and walking correctly on the force plate. The GRF for traditional socket Observations: Peak Forces: Both legs exhibit relatively high peak forces, suggesting substantial impact forces during walking. This is characteristic of traditional sockets that do not incorporate improved cushioning mechanisms. Symmetry: A significant difference in peak forces between the right (non-amputee) and left (amputee) legs can be seen. The right leg frequently demonstrates elevated peak forces, indicating possible asymmetry in gait and augmented burden on the non-amputee limb. Variability: The force patterns exhibit considerable variability, including changes in magnitude and time. This may result from causes like differences in gait velocity, stride length, and surface conditions. while the patient is wearing the smart socket, The GRF for the smart socket decreased Peak Forces: Compared to the conventional socket, the peak forces recorded in both legs are significantly decreased. This suggests that the smart socket significantly mitigates impact pressures during ambulation. Enhanced Symmetry: the difference in peak forces between the right (non-amputee) and left (amputee) legs is diminished in the smart socket. This indicates enhanced gait symmetry and a more even distribution of forces. Improved Force Profile: The force patterns exhibit excellent smoothness and consistency, with reduced sharp peaks and troughs. This signifies less shock transmission and more comfort for the user. Because the reaction in the traditional limb was more significant than in the smart limb. Results show lower GRF on both legs when wearing a smart socket. This could mean that the smart socket is better at absorbing shock or lowering the total load on the remaining limb. Because of the design of the Smart Socket to treat the problem of distribution pressure with the help of the air pads, it became more accessible for the patient to walk, and the patient had a sense of the place according to the weight of the body and the pressure of the foot with the socket. All results are illustrated in Tables (3) and (4).

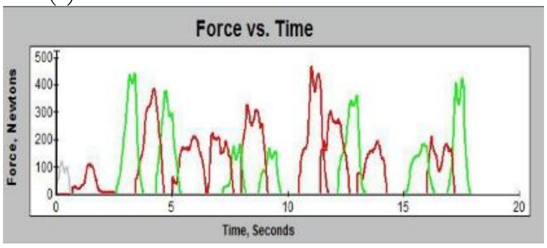


Figure (16): GRF in traditional socket

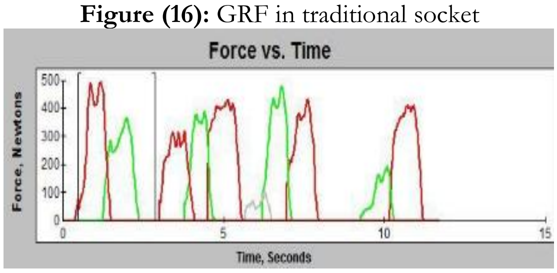


Figure (17): GRF in Smart socket

Where the difference in (gait cycle time, step velocity, heel contact, and mid-stance) between the left and right leg is equal to (0.54, 4.3, 0.19, and 0.34) respectively when the patient using the traditional prosthetic, while these values reduce to (0.09, 0.7, 0.07, and 0.27) respectively when the patient used the smart prosthetic. This indicates good stability and alignment of the smart prosthetic while walking the patient. It is worth noting that results varied among patients according to the socket type and the examination's nature. They cannot be compared with prior research regarding values; however, they can be assessed in terms of performance, gait improvement, and the individual's condition before using the smart socket.

In Table (3), The patient using the smart socket has a somewhat extended step time of 0.96 seconds, unlike the traditional socket user, who demonstrates a step time of 0.78 seconds. This indicates a possible variation in gait cadence. The patient using the traditional socket exhibits a larger step length (44.4 cm and 47.9 cm) than the smart socket user (27.1 cm and 27.7 cm). This signifies a variation in stride length. The patient using the traditional socket has a superior step velocity (57.3 cm/sec and 61.5 cm/sec) compared to the smart socket user (28.1 cm/sec and 27.4 cm/sec), which indicates a disparity in ambulation velocity. Step Width: Both patients exhibit comparable step widths, with a little discrepancy of 0.2 cm. The patient using the traditional socket generates a greater maximum force (62.3% and 73.0% of body weight) than the user of the smart socket (47.8% and 53.7% of body weight). This indicates a variation in force distribution while walking.

In Table (4), The patient using the traditional socket exhibits a larger gait cycle time of 2.24 seconds, in contrast to the smart socket user, who has a gait cycle time of 1.78 seconds. This indicates a possible variation in gait cadence. The patient using the traditional socket exhibits a longer stance time (1.28 seconds) than the smart socket user (1.31 seconds). This signifies a variation in the foot's duration in contact with the ground. The patient using the traditional socket has a longer swing time of 0.64 seconds, unlike the smart socket user, who demonstrates a swing time of 0.59 seconds. This signifies a variation in the duration with the foot elevated off the ground. The patient using the traditional socket exhibits a longer single support time (1.20 seconds) than the user of the smart socket (0.54 seconds). This indicates a variation in the duration when a single foot is in touch with the ground. Total Double Support Time: The two patients exhibit comparable total double support times, differing by only 0.07 seconds. Heel Contact Duration: The traditional socket patient exhibits a higher heel contact duration (0.72 seconds) than the smart socket user (0.66 seconds). This signifies a variation in the heel's duration in contact with the ground. The patient using the traditional socket has a lengthier foot flat time of 0.28 seconds, unlike the smart socket user, who has a foot flat time of 0.22 seconds. This signifies a variation in the duration the entire foot remains in contact with the ground. The patient using the traditional socket exhibits a more significant mid-stance duration (0.31 seconds) than the user of the smart socket (0.67 seconds). This signifies a variation in the duration during which the body weight is positioned directly over the stance foot.

Table (3): Step table patient

Step table	**Patient with traditional socket**			**Patient with a smart socket**		
	Left leg	**Right leg**	**Difference**	**Left leg**	**Right leg**	**Difference**
Step time (sec)	0.78	0.78	0	0.96	1.01	0.05
Step length (cm)	44.4	47.9	3.5	27.1	27.7	0.6
Step velocity (cm\sec)	57.3	61.5	4.3	28.1	27.4	0.7
Step width (cm)	13.4	13.6	0.2	13.6	13.8	0.2
Maximum force(%BM)	62.3	73.0	10.8	47.8	53.7	5.9

Table (4): Gait cycle patient

Gait cycle table(sec)	**Patient with traditional socket**			**Patient with a smart socket**		
	Left leg	Right leg	Difference	Left leg	Right leg	Difference
Gait cycle Time	1.50	2.24	0.74	1.70	1.78	0.09
Stance Time(sec)	0.87	1.28	0.41	1.11	1.31	0.21
Swing Time(sec)	0.45	0.64	0.19	0.47	0.59	0.12
Single support Time	0.38	1.20	0.82	0.40	0.54	0.15
Total Double support time	0.47	0.47	0	0.61	0.61	0
Heel Contact Time	0.53	0.72	0.19	0.59	0.66	0.07
Foot Flat Time	0.18	0.28	0.10	0.11	0.22	0.11
Mid-Stance Time	0.58	0.31	0.26	0.33	0.67	0.35

9. Conclusion

The walking cycle results concluded that the smart socket results were more acceptable and had less difference in data between the right leg (sound) and the left leg (amputated). The decreased muscular effort of the amputated leg is when the smart socket is worn, while the muscle effort of the leg muscles is increased when the traditional socket is worn. the muscular activity of the amputee leg muscles is reduced, and the muscular activity of the same muscle increases when the traditional prosthetic is worn. The success of the socket design in terms of regular walking and smooth movement of the smart prosthetic. The socket design offers additional control and adjustability with pneumatic pads that work with air pressure to give a more effective suspension. Depending on the user's pressure between the socket and the stump, the smart socket's gait cycle is more acceptable, stable, and balanced than traditional socket wear. The design offers additional control and adjustability with pneumatic pads that work with air pressure to provide a more effective suspension. depending on the user's pressure between the socket and the stump. gait cycle is more stable and balanced than traditional socket wear. To understand the smart sockets' better impact on the user's experience and mobility, it is necessary to explain its review feeding operations. And take sensory, visual, and auditory feedback to enhance the user's deep feeling and awareness. However, in this research, there are no readings about the innovator's method for the phone application, and no findings can be known. Moreover, the ability of the smart socket to adapt to the fluctuating adaptation can enable the improvement of the infiltration method, safely and securely, and safe for a lifetime for amputees to deal with. This study corresponds with these developments by focusing on price, accessibility, and effectiveness. It aims to provide a practical and affordable solution for AK amputees, especially in resource-limited environments.

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