CHAPTER 6

DEVELOPMENT & TESTING OF NOVEL PROSTHETIC FOOT

This chapter discusses the detailed procedure for the development and testing of a novel prosthetic foot model for lower limb amputation level patients as per their requirements. Various parameters analysis was conducted on the foot structure model for material optimization. Based on the best design data available, a prototype model was created using 3D printing technology. Finally, the manufacturing process for the prosthesis foot structure was completed by using a 3-axis Vertical Milling Center machine. The novel prosthetic foot model was tailored to the patient, and basic gait analysis data for different viewing angles such as lateral, posterior, and anterior were taken into account.

6.1 THE DEVELOPMENT PROCESS OF NOVEL PROSTHETIC FOOT

A prosthesis is a device that substitutes one or more of the human ankle-foot system's functions. Traditional production processes for prosthetic and orthotic elements waste materials are more, take a long time, and are labor-intensive. The benefit of AM technology is that it can overcome these issues. Engineers, design, and development teams can benefit from rapid prototyping in the following ways;

- Ability to explore and implement concepts faster
- Apply the design iteratively and incorporate changes that allow product evaluation and testing
- Be able to convey the concept concisely and effectively
- Ability to thoroughly test and improve the concept
- Save time and money as no setup or tools are required

In recent years, developers have created a variety of technologically improved prosthetic legs, broadening the spectrum of devices accessible. Therefore, cost-efficient prosthetic elements that are created using **economical technology** are significantly needed. Our primary objective is to design and create lightweight structural components that make the production process easier. Designers need to understand the many models that help them find the best solution for engineering design verification. The prototype phase of new product development is critical, and numerous decisions must be taken to ensure that a quality, defect-free product is delivered on time and at the lowest possible cost.

The medical professional is continually on the lookout for innovative, cutting-edge technology that might improve traditional processes. As a result, the combination of 3D scanning and additive manufacturing has already made progress in the healthcare industry (Gibson, et al., 2021). These practices are rapidly upgrading while boosting patient experience and comfort. The use of 3D imaging in conjunction with 3D printing technology is becoming increasingly popular in a variety of medical sectors. (Geierlehner, Malferrari, & Kalaskar, 2019)

'Slicing' your 3D model implies breaking down your design (typically in a .stl file) into separate layers. After that, the program creates the tool path (.gcode) that the printer will use to print. The program workflow from input Stl format to output G-code format is depicted in Figure 6.1 to Figure 6.6, transforming a 3D representation into 3DP instructions.

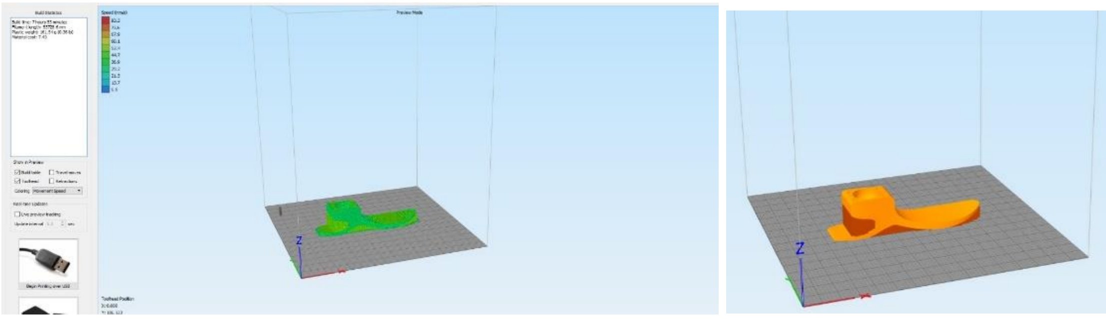


Figure 6.1: Slicing tools for prosthetic foot model

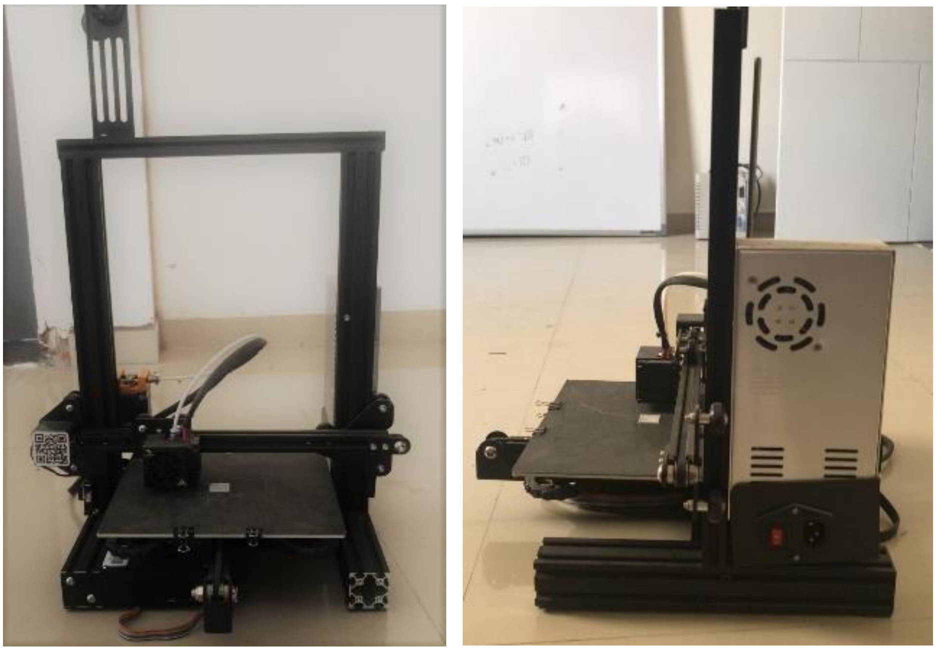


Figure 6.2: FDM machine (Ender-3 V2)

Table 6.1 displays the technical parameters of the 3D printer machine.

Table 6.1: Machine specifications for FDM

Sr. No.	Specification data	Value of data
1	Technology for modeling	FDM
2	Size of machine	475*470*620 mm
3	Dimension of printing	220*220*250 mm
4	Diameter of the filament	1.75 mm
5	Filament material	ABS/PLA/TPU/PETG
6	Hot bed temperature	≤100 ℃
7	The layer thickness	0.1-0.4 mm
8	Print accuracy	±0.1 mm
9	Slicing software	Simplify 3D / Cura
10	Power source	Input AC 115V/230V; Output DC 24V 270W
11	Supporting OS	MAC/Windows XP/7/8/10
12	Mode of operation	Online or SD card offline

Figure 6.3: Prototype model of the prosthetic foot

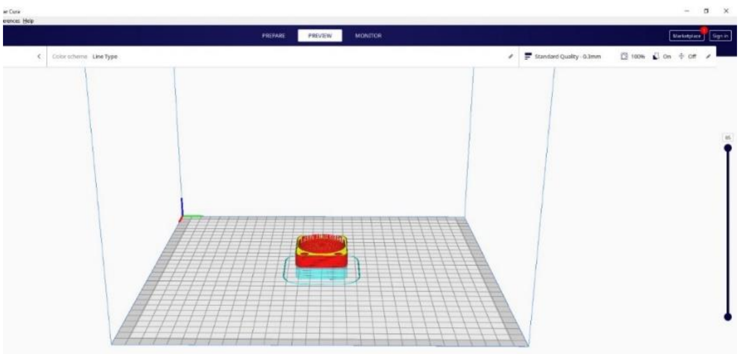


Figure 6.4: Slicing tools for the mounting bracket

Figure 6.5: Prototype model of the mounting bracket

Figure 6.6: Prosthetic model assembly process

A lot of things should be taken into account while constructing a better physical prototype for any new product, and the same is true when using the prototype as a benchmark. Designers can choose an appropriate form of prototype process for their new product based on these variables.

The knowledge from the combination of benchmarking result analysis is used to construct these models. Using this approach, the designer and manufacturer may enhance the production of prototype parts and offer their innovative, high-performing, zero-defect product to the market in the shortest amount of time at the lowest feasible cost.

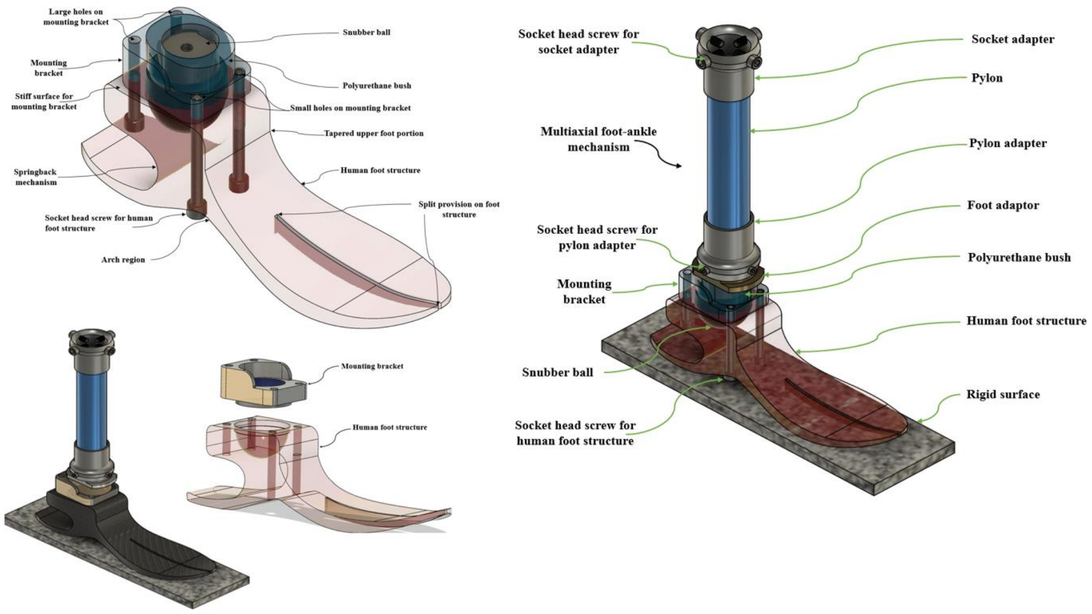


Figure 6.7: CAD model of novel prosthetic foot

The novelty of the present creation lies in the design of the multiaxial foot structure that allows the desired rotation on its axis and offers the freedom to move in a medial-lateral direction (Figure 6.7).

The main novelty of the present development is the semi-circular cavity of the human foot structure which extends from the top profile of the human foot structure up to the starting of the tapered upper foot portion that holds the snubber ball concerning the prosthetic foot adaptor for the multiaxial rotation ankle. The semi-circular cavity offers the most flexibility of the ankle mechanism in terms of movement in the front and back side as well as medial-lateral direction.

Split provision on foot structure from toes to the mid-foot surface is to accommodate inversion/eversion for stability on uneven terrain. The shape of the arch region is designed like a spring; it supports the body's weight and absorbs the shock generated by the movement. The spring back mechanism is also defined by the c-shaped aperture for providing more flexibility control during plantar flexion.

The bottom rigid surface is for alignment only and proper weight distribution, the pylon should always be 90° vertically. The mechanism in the present creation is designed in such a way that the foot structure will fit on the lower limb prosthetic endoskeleton system with a 30 mm pylon tube. The length of the pylon is dependent on the structural height of the patient and accordingly, the pylon is cut to the shortest length as per the requirement of the user. Most amputees can use this low-cost multiaxial prosthetic foot to move on farmland/staircases/ramps/uneven road surfaces.

The item mentioned is comprised of materials that are extremely robust and capable of absorbing shocks caused by walking. Despite having great material qualities such as excellent physical strength, high dimensional rigidity, low thermal expansion, low abrasion, and biological inertness, carbon fiber is expensive to create. This material can be used to create the prosthetic human foot structure. For the development of prosthetic human foot structures, Ultra High Molecular Weight Polyethylene (UHMWPE) can be used because it possesses the best qualities, featuring exceptional toughness and durability, great abrasion resistance, superior chemical protection, minimal wettability, and ease of fabrication with cheap manufacturing costs. Delrin, a material with outstanding impact and creep resistance, good dimensional stability, great machinability, high fatigue endurance, chemical resistance, and high strength and stiffness qualities, may be used to make the mounting bracket. Injection molding is the best production method with delrin/nylon 6 material for low-cost community projects and prosthetics.

Using a 3-axis Vertical Milling Center device (Figure 6.8), the prosthetic foot manufacturing (Dhokia, et al., 2017) process was finally completed.

S. No.	DESCRIPTION OF REQUIREMENT	REQUIRED
1	**Technical Specification**	
1.1	**Capacity**	
1.1.1	Length of table	700 min
1.1.2	Width of table	400 min
1.1.3	Max load on table	300 kg
1.1.4	X travel	700 mm min
1.1.5	Y travel	400 mm min
1.1.6	Z travel	300 mm min
1.2	**Machine Spindle**	
1.2.1	Spindle Speed	Min 8000 Rpm
1.2.7	Main Spindle Power	7Kw or more
1.2.8	Spindle taper	ISO/BT/SK 40/50
1.3	ATC	15 min
1.4	**Accuracy**	
1.4.1	Positional accuracy	0.01 mm in full length
1.4.2	Repeatability	0.005 or better
1.5	**Coolant System**	
1.5.1	Tank capacity	Min 100 Ltr
1.5.2	High presuure filteration system	Min 20 Bar with filteration system
1.6	**Axis drive and Control**	
1.6.1	Digital controlled drive and motors	**For all Axis**
1.6.2	Guide way	**LM guide way**
1.6.3	Rapid Speed	**Min 20m/min**
1.6.4	Feed rate	**Min 6m/min**

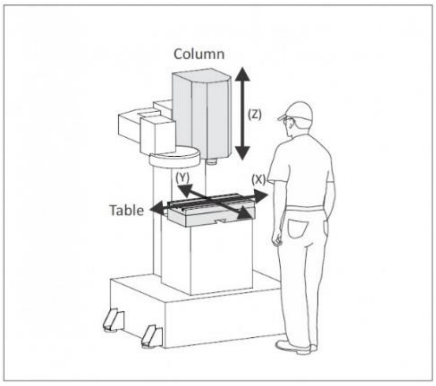


Figure 6.8: Vertical Milling Center with 3-axis

Table 6.2: Raw material datasheet

Sr. No	Raw Material (Size: 350 x 75 x 75) mm^3	Approx. Cost (Rs.)
1	UHMW-PE	1650
2	Delrin	1200
3	Nylon	1700
4	Carbon Fiber Composite	40000 - 45000
5	Teflon	3000 - 4000

The UHMWPE material (Li & Burstein, 1994) was selected for the preparation of the prosthetic foot model as per its desirable material properties. The raw material (Table 6.2) of size 350 x 75 x 75 mm^3 was considered as per the final product size of the foot structure model as shown in Figure 6.9.

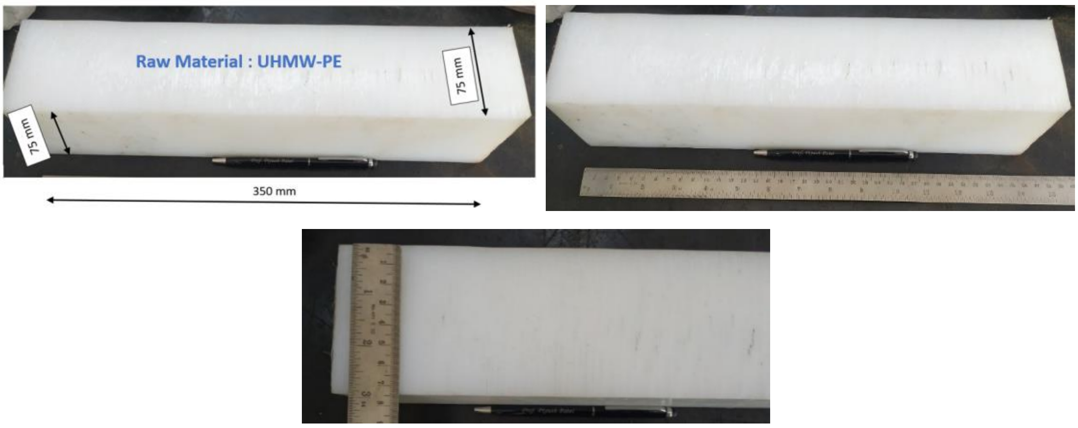


Figure 6.9: UHMW-PE raw material block

The material block was mounted on the fixture device as shown in Figure 6.10 and the manufacturing process for the prosthetic foot was completed in approximately 8 hours by using a 3-axis Vertical Milling Center machine (Figure 6.11).

Figure 6.10: Machining process of prosthetic foot model

Figure 6.11: A realized model of a prosthetic foot

The material block was mounted on the fixture as shown in Figure 6.12 and the manufacturing process for the mounting bracket was completed in approximately 3 hours by using a 3-axis Vertical Milling Center machine (Figure 6.13).

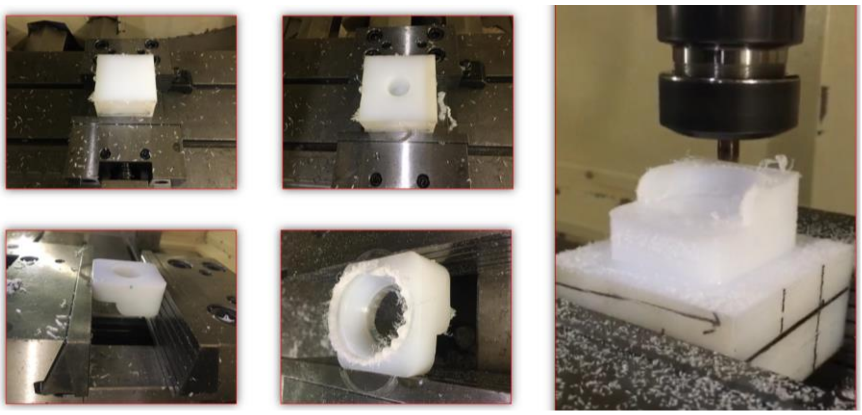


Figure 6.12: Machining process of the mounting bracket

Figure 6.13: A realized model of the mounting bracket

The polyurethane bush was inserted into the extended part of the snubber ball up to the polyurethane bush mounting area placed above the mounting bracket to bear the weight. The foot adapter was connected to the snubber ball and fixed with the help of a socket head screw for the foot adapter as shown in Figure 6.14.

Figure 6.14: Prosthetic foot with foot adapter

Even an amputee can walk/ambulate without a foot shell and participate in aquatic activities like beach /swimming by pasting the sole treaded on the bottom side of the prosthetic foot as shown in Figure 6.15.

Figure 6.15: Sole treaded on the bottom side of the prosthetic foot

The pylon adapter was mounted on the foot adapter and tightened with the socket head screw for the pylon adapter at four points as shown in Figure 6.16. The socket adapter was mounted on the pylon and tightened with the socket head screw for the socket adapter at four points. The pylon joins the socket adapter, with the pylon adapter acting as the human femur and/or tibia and fibula, depending on the amount of amputation.

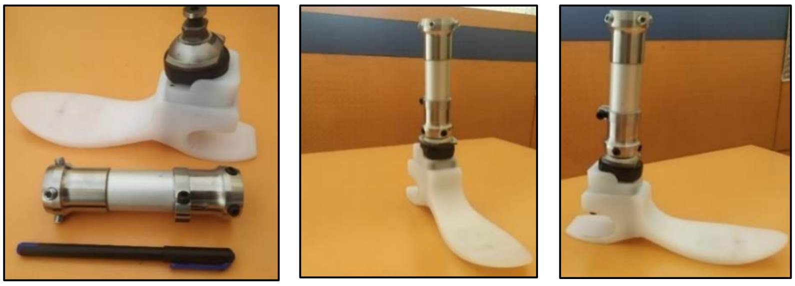


Figure 6.16: Pylon adapter is mounted on the foot adapter

The effects of a non-articulated Solid Ankle Cushion Heel (SACH) and a multiaxial foot-ankle mechanism on the performance of low-activity users are of special interest to professionals in amputee rehabilitation. By comparing these two prosthetic feet, the goal of this study is to evaluate the potential benefits brought about by the increased degrees of freedom afforded by the multiaxial foot. SACH foot has a stiff foot with no ankle articulation, where the heel absorbs stress and the forefoot simulates dorsal flexion. The SACH foot is a basic, robust, low-cost prosthetic foot alternative for persons who need to be restricted mobility and have little fluctuation in pace and terrain. The SACH foot offers adequate shock absorption properties for restricted walkers because of its big heel cushion, but it is not suited for moderate to high-activity prosthetic users who want to perform more than home duties due to its lack of flexibility and inability to tolerate uneven terrain.

According to the following fundamental prosthetic foot features, our studies demonstrate that a multiaxial foot is a substantial alternative option to the typical SACH foot:

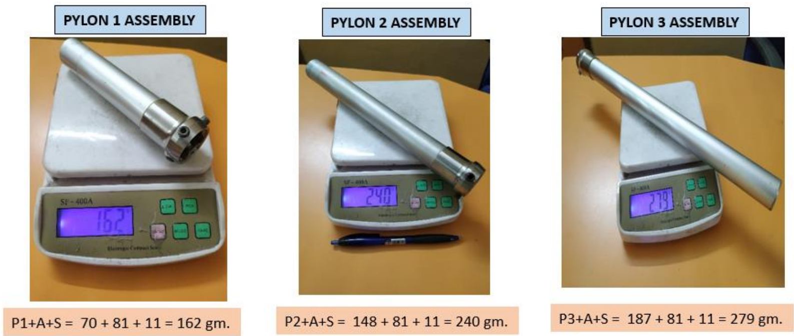
- An amputee can accommodate the foot on uneven terrain easily ascending/ descending on ramps using a multiaxial foot.
- The design of the multiaxial foot structure allows the desired rotation on its axis and offers the freedom to move in a medial-lateral direction.
- Even as per the patient size of the foot one size die can be trimmed to a smaller size foot.
- The innovation is an optimization in the prosthetic foot structure design that resembles the human foot surface.
- The innovation resembles the human foot surface which can absorb the shocks developed during ambulation as well as maintain balance and stability.
- It relates to a high-performance prosthetic foot offering advanced dynamic reaction capabilities.

A detailed examination was performed to assess the weight of SACH and multiaxial foots for this purpose. It is always desirable that the mass will be as least as conceivable without relinquishing strength and stiffness.

Table 6.3: Pylon and adapter size details

Element Name	Length (mm)	Weight (gm.)	Diameter (mm)
Pylon 1	125	70	30
Pylon 2	235	148	30
Pylon 3	380	187	30
Pylon adapter	45	81	32
Socket head screw for pylon adapter (M8*14: Hex Socket Set Screw)	14	11	8

Prosthetic makers have created shock-absorbing pylons to complement the residual capacity of lower limb amputees as well as to reduce the transient stresses of foot-ground contact. Three pylon sizes (Table 6.3) were considered for the comparative analysis and a standard pylon adapter of 45 mm length was used for the assembly process as shown in Figure 6.17.



*Pylon 1= P1 ; Pylon 2= P2; Pylon 3= P3 ; Pylon Adapter= A; Socket head screw for pylon adapter = S

Figure 6.17: Weight of pylon with adapter

The socket aims to offer structural stability to the prosthetic where it meets the residual limb. It may also have suspension features to keep the prosthetic in place. The weight of various required elements for a socket is mentioned in Table 6.4.

Table 6.4: Socket elements for BK patients

Element Name	Weight (gm.)
Socket	378
Socket linear	67
Socket adapter	102
Socket head screw for socket adapter (M8*12: Hex Socket Set Screw)	10
Socket assembly	557

Figure 6.18: Weight of socket elements

As shown in Table 6.5, various prosthetic foot structures (Figure 6.18) were taken into account for weight analysis.

Table 6.5: Weight of various foot structures

Prosthetic Foot Element Name	Weight (gm.)
Novel foot structure	190
3D printed foot structure	112
SACH foot structure	309
NIAGARA foot	364

Figure 6.19: Weight of various prosthetic foot elements

The mass comparison data of SACH and novel foot structure assembly without pylon and socket elements are mentioned in Table 6.6. The mass of the SACH foot structure was discovered to be 309 grams and the mass of the novel foot structure after optimization was found to be **190 grams** (Figure 6.19 & Figure 6.20). The development efforts by considering design optimization in novel prosthetic foot structures show that there was a weight reduction of approximately 61.5 % in comparison with the SACH foot structure.

Table 6.6: Mass comparison of prosthetic foot structure

Elements	SACH foot structure assembly (grams)	Novel foot structure assembly (grams)
Prosthetic foot structure mass	309 (76.5 % of total mass)	**190** (38.46 % of total mass)
Others elements mass	95	304
Total mass	404	494

Figure 6.20: Assembly weight of novel and SACH prosthetic foot elements

The human foot structure was the primary component of the foot-ankle system, serving as the foundation for patient stability and control in all terrains. Elements (Table 6.7) other than the present development like socket elements and pylon mechanism were assembled to get the required functionality (Figure 6.21 to Figure 6.23).

Table 6.7: Novel prosthetic foot structure mechanism details

PYLON SIZE	**PYLON 1**	**PYLON 2**	**PYLON 3**
Element Name	**Weight (gm.)**	**Weight (gm.)**	**Weight (gm.)**
Human foot structure	190	190	190
Socket head screw for human foot structure (M4*30)	15	15	15
Socket head screw for human foot structure (M4*50)	24	24	24
Snubber ball	117	117	117
Mounting bracket	18	18	18
Polyurethane bush	26	26	26
Foot adapter	85	85	85
Socket head screw for foot adapter (M7*25)	19	19	19
Socket head screw for pylon adapter (M8*14: Hex Socket Set Screw)	11	11	11
Pylon adapter	81	81	81
Pylon	70	148	187
Socket	378	378	378
Socket adapter	102	102	102
Socket head screw for socket adapter (M8*12: Hex Socket Set Screw)	10	10	10
Socket linear	67	67	67
Novel prosthetic foot assembly	**1213**	**1291**	**1330**

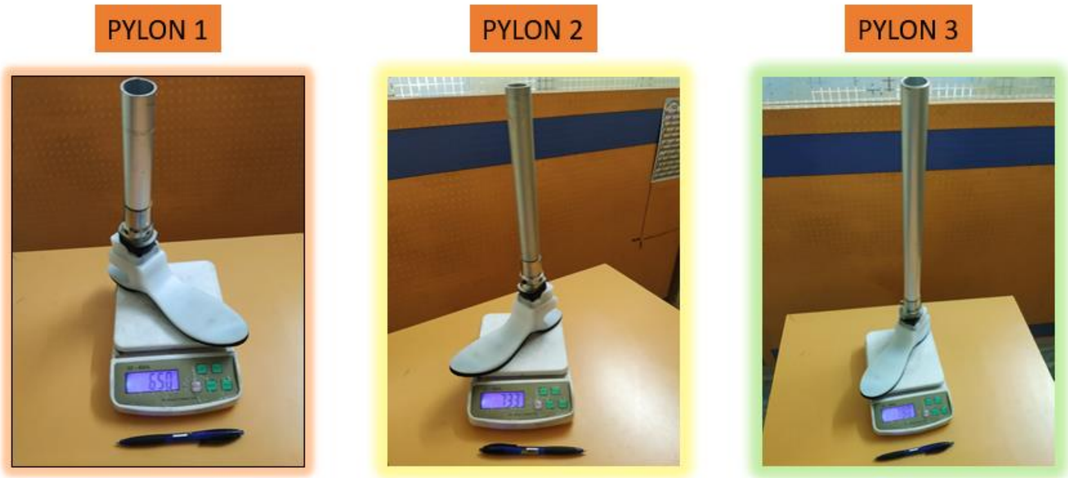


Figure 6.21: Novel prosthetic foot structure with various pylon elements

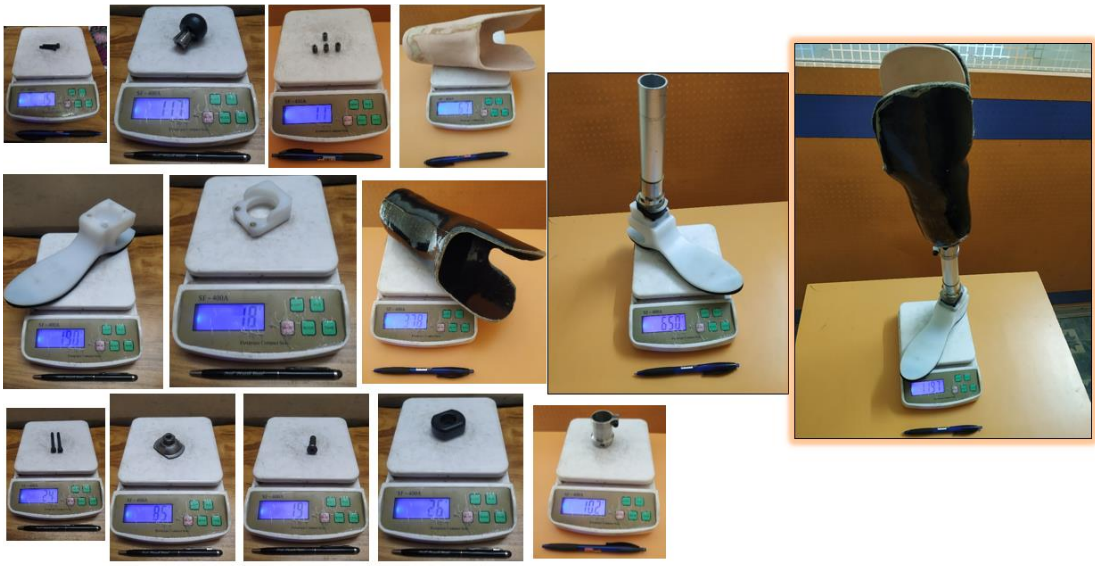


Figure 6.22: Weight for novel prosthetic foot structure using pylon1

Figure 6.23: Weight of novel prosthetic foot structure with various pylon sizes

The most basic type of non-articulated foot is the single-axis foot. The name SACH refers to a soft rubber heel wedge that simulates ankle motion by compressing under pressure during the initial phases of walking's stance phase. The keel is hard, therefore there is no lateral movement but there is midstance stability. The SACH foot (Table 6.8) comes in a variety of heel heights (Figure 6.24 to Figure 6.26).

Table 6.8: SACH prosthetic foot structure mechanism details

PYLON TYPE	PYLON 1	PYLON 2	PYLON 3
Element Name	**Weight (gm.)**	**Weight (gm.)**	**Weight (gm.)**
SACH foot structure	309	309	309
Foot adapter	85	85	85
Socket head screw for foot adapter	10	10	10
Pylon	70	148	187
Pylon adapter	81	81	81
Socket head screw for pylon adapter (M8*14: Hex Socket Set Screw)	11	11	11
Socket	378	378	378
Socket adapter	102	102	102
Socket head screw for socket adapter (M8*12: Hex Socket Set Screw)	10	10	10
Socket Linear	67	67	67
SACH prosthetic foot structure assembly	**1123**	**1201**	**1240**

Figure 6.24: SACH prosthetic foot structure with various pylon elements

Figure 6.25: Weight for novel prosthetic foot structure using pylon 2

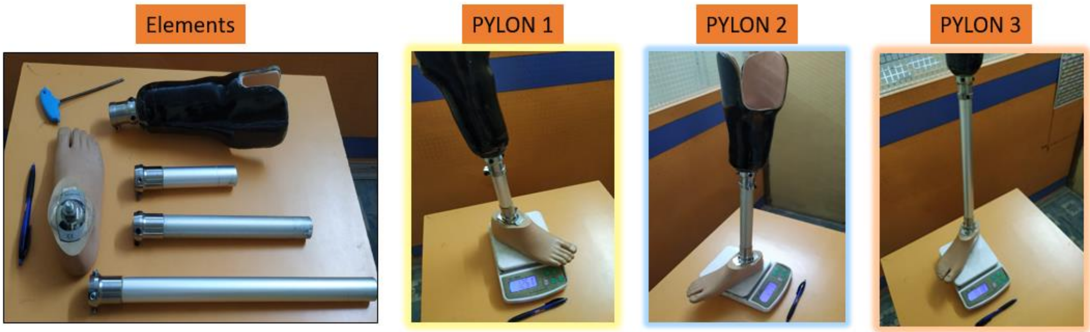


Figure 6.26: Weight of SACH prosthetic foot structure with various pylon sizes

The development efforts including design optimization in the novel prosthetic foot structure reveal a weight decrease of around 61.5% when compared to the SACH foot structure. So finally novel prosthetic foot elements were considered for the evaluation of the patient.

6.2 THE GAIT CYCLE'S PHASES

Gait analysis is an assessment of gait style by observing a patient walking in a straight line. The kinematic system was used to capture the position and angle of joints in gait analysis. The novel prosthetic foot model was connected with the socket and then with the help of the prosthetist as per the comfort of the patients it was fitted properly as shown in Figure 6.27.

Figure 6.27: Socket fitting process on patients

During lower limb prosthetics, patients often return to the clinic for some alterations and adjustments. This iterative process and the ongoing changes in prosthetic socket comfort and function can be a major cause of frustration for both the amputee and the rehabilitation team.

Minimizing adjustment changes is important for maintaining good socket fit, as poor socket fit can cause friction, discomfort, and even skin damage.

Gait has been divided into sections that help us to describe, understand, and evaluate the events that are occurring. Within a gait cycle, each extremity passes through two fundamental phases: stance, when some portion of the feet is near the floor, it accounts for about 60% of the gait cycle, and swing, when the feet aren't in contact with the ground which accounting for the rest 40% (Figure 6.28).

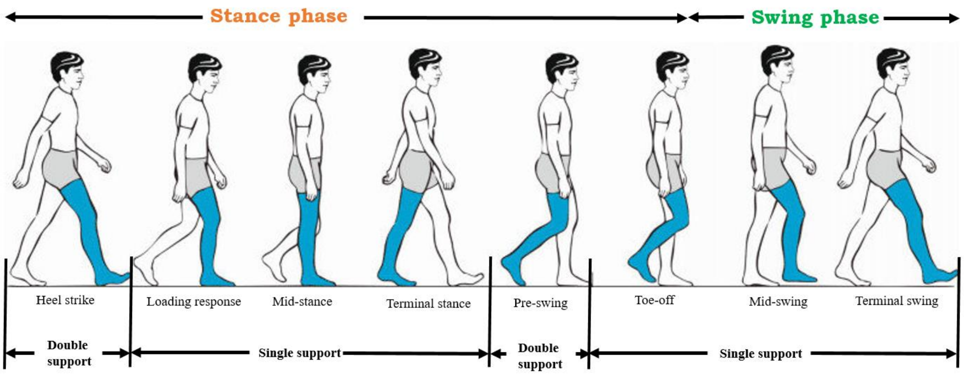


Figure 6.28: Gait cycle's phases

The feet make touch with the ground during the stance phase, the body's mass is supported, and the body is driven forward in the latter phases of the stance. Figure 6.29 depicts the events that occur during the stance phase: (i) heel strike, (ii) midstance, (iii) flat foot, and (iv) toe-off.

- Heel-strike: The first impact of one foot with the floor, known as foot-strike, is the first instant of the gait cycle.
- Foot-flat: When the remainder of the foot makes contact with the ground, and the leg normally sustains the full body weight.
- Midstance is defined as the center of mass being squarely above the center of the ankle joint. When the hip joint center is above the ankle joint, this is likewise utilized as the instant.
- Heel-off happens when the heel begins to lift off the ground in preparation for the body's forward motion.
- Toe-off occurs as the final point of contact during the stance phase.

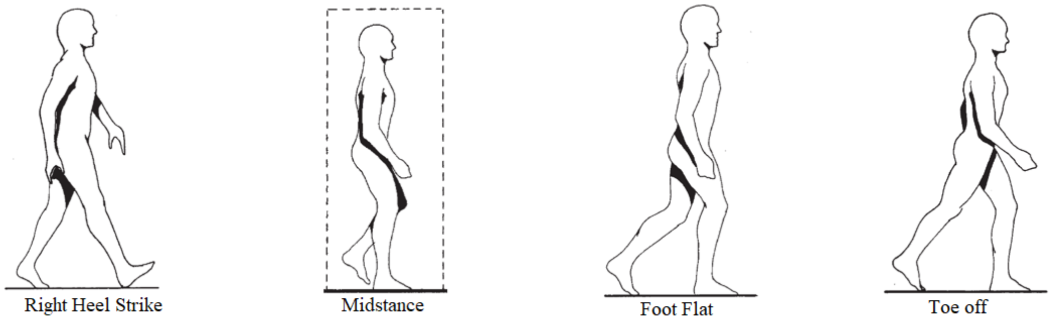


Figure 6.29: The stance phase of the right lower limb's gait cycle

A standardized physical examination of the lower limbs was done throughout the session to determine anthropometry and passive range of motion, and standardized clinical films were captured.

As indicated in Figure 6.30, the foot and ankle have a variety of joints that move during walking. During regular walking, these joints perform vital roles.

The ankle joint permits the foot to move up and down (dorsiflexion and plantarflexion), with the muscles at the front of the leg (the anterior muscle compartment) pulling the foot up and the muscles in the rear of the leg (the posterior compartment) pulling the foot down.

The gait cycle's knee angles are important in terms of the energy consumed during walking and are frequently influenced by pathological conditions.

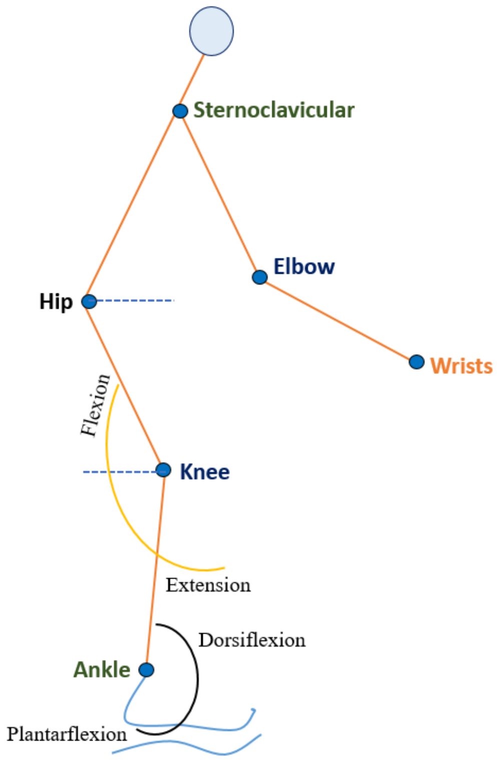


Figure 6.30: Human body stick diagram for pointing movement

The various body movements' data analysis (Figure 6.31 & Figure 6.32) are described below;

- **Plantar flexion** is the movement of the top of your foot away from your leg.
- **Dorsiflexion** is the backward bending and contracting of your hand or foot.
- **Flexion:** It is a type of movement in which an angle between two body segments decreases. Flexion is a type of bending movement that occurs within the sagittal plane. These are referred to as anterior direction body motions.
- **Extension:** These types of body movements cause augmented angles between the two joints. It is a straightening motion of a sagittal plane that involves posterior angled movements of the joints.

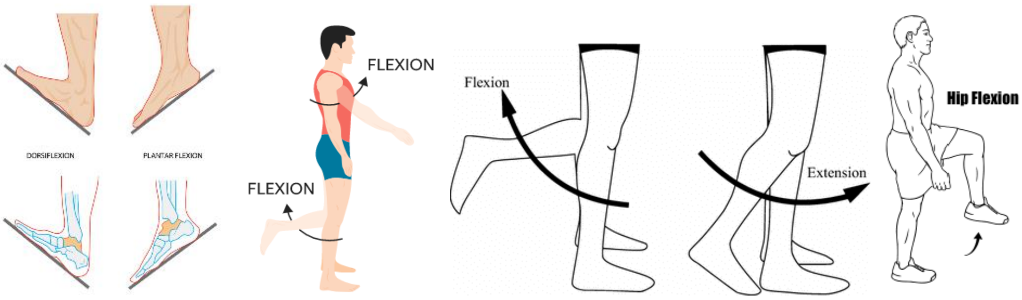


Figure 6.31: Body movement types

- **Eversion:** Foot eversion occurs when your foot falls inward, frequently accompanied by your feet flattening.
- **Inversion** is a movement of the foot which causes the soles of the feet to face inward.
- **Hyperextension** refers to extending the joints in your toe beyond their natural range of motion.
- **Abduction and adduction** are activities of the legs or hand in the coronal (medial-lateral) plane. Abduction is the movement of a leg or arm across from the body or the spreading of the fingers or toes.
- **Adduction** is the motion of a leg or arm along the center of the body.

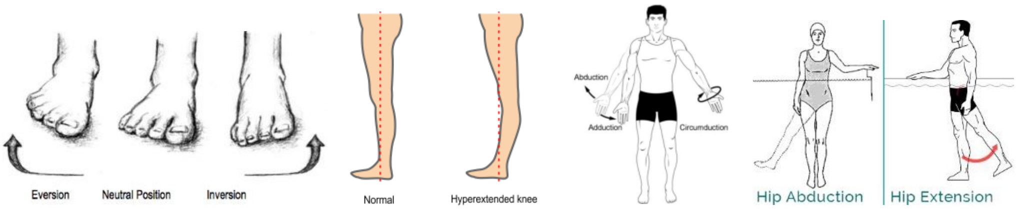


Figure 6.32: Movements of the body

- An ankle angle > 90° denotes plantarflexion while an ankle angle < 90° denotes dorsiflexion.
- A knee angle > 180° denotes hyperextension while a knee angle < 180° denotes flexion.
- Hip flexion is shown as (+) and hip extension is shown as (-).
- Rear foot eversion is denoted as (+) and Rear foot inversion is denoted as (-).
- The contralateral pelvic drop is shown as (+) while the ipsilateral pelvic drop is shown as (-).
- Knee Ab/Adduction is (+) when the patella is medial to the 2nd toe and (-) when the patella is lateral to the 2nd toe.
- All values are free gait speed and phase ending.

6.3 TESTING OF NOVEL PROSTHETIC FOOT ELEMENT BELOW KNEE AMPUTATION LEVEL PATIENTS

Gait analysis is an assessment of gait style by observing a patient walking in a straight line. There are various evaluation methods for human motion, such as video recording, visual inspection, wearable sensors, physical measurements, and questionnaires.

In gait analysis, the kinematic system is utilized to capture the position and angle of joints. Gait analysis (Toro, Nester, & Farren, 2003) includes the measurement, analysis, and evaluation of biomechanical properties associated with gait tasks (Palm-Vlasak, 2022).

As measuring and recording techniques (Viswakumar, Rajagopalan, Ray, Gottipati, & Parimi, 2021) for obtaining gait pictures have improved dramatically over the last few decades, gait analysis is now frequently employed in the everyday work of persons interested in human motor rehabilitation. Video gait analysis is increasingly being utilized to evaluate a subject’s motor patterns to aid in the diagnosis of medical issues, improve sports performance, and/or monitor therapeutic measures such as gait retraining and shoe adjustments.

Figure 6.33 depicts Kinovea, a video annotation tool designed to analyze human body movement. It includes utilities for capturing, slowing down, comparing, annotating, and measuring video motion. The tools built into this software allow the observer to calculate the joint angle and obtain other measurements as required.

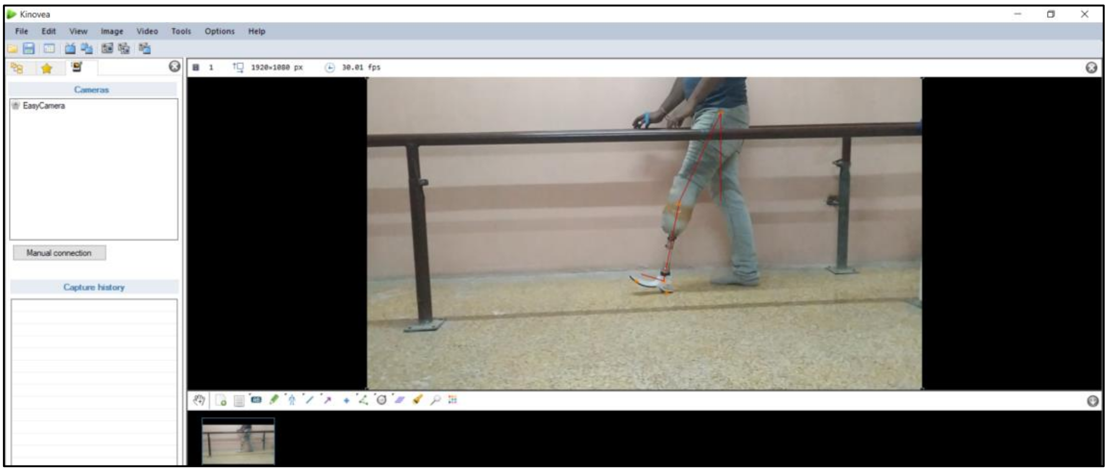


Figure 6.33: GUI of Kinovea for patient motion analysis

6.3.1 Patient's case study

A systematic physical examination of the lower limbs was done throughout the session to determine anthropometry and passive range of motion, and clinical films were recorded.

Different three case studies were performed to get the required data for the evaluation.

1) Patient with a novel prosthetic foot
2) Normal patient without any amputation
3) Patient with prosthetic senator foot

The prosthetic foot model was tailored to the patient, and basic gait analysis data for different viewing angles such as lateral, posterior, and anterior were taken into account. (Mokhtari, Taghizadeh, & Mazare, 2021)

The kinematic data analysis was conducted for different joint angle observation parameters like angles at the ankle, knee, hip, rear foot, pelvic drop, and knee Ab/Adduction. (Cash, van Werkhoven, Cole, & Needle, 2022)

Angular position values were measured for the left and right legs in the patients' lateral views based on the foot contact with the floor surface, as detected during the gait study, such as first contact posture, loaded responses posture, mid-stance location, terminal stance viewpoint, and pre-swing position (Kanthi, 2015). Also, the different measurements of the angular position values were done by considering the mid-stance position of the patient's posterior view and anterior view. The different angular position data were mentioned in the table as well as presented in a graphical view as shown in Figure 6.34.

Case 1: Patient with a novel prosthetic foot

The first case patient's details are mentioned in below Table 6.9;

Table 6.9: Patient with a novel prosthetic foot

Name	Mr. Nikunj Maiskar
Age(Yrs.)	35
Weight (kg)	85
Height (ft)	5' 9"
Gender	Male
Clinician	Dr. Khyati Vansadavala (Prosthetist & Orthotist , RCI No: A51452)
Date of gait analysis	23-10-2021
Amputation	A person was injured in an accident and his left leg was amputated below the knee in 2013
Type of foot	Patient with Novel prosthetic foot

The different required positions of the patients (novel prosthetic foot) were observed during the gait analysis for the stance phase of a gait cycle.

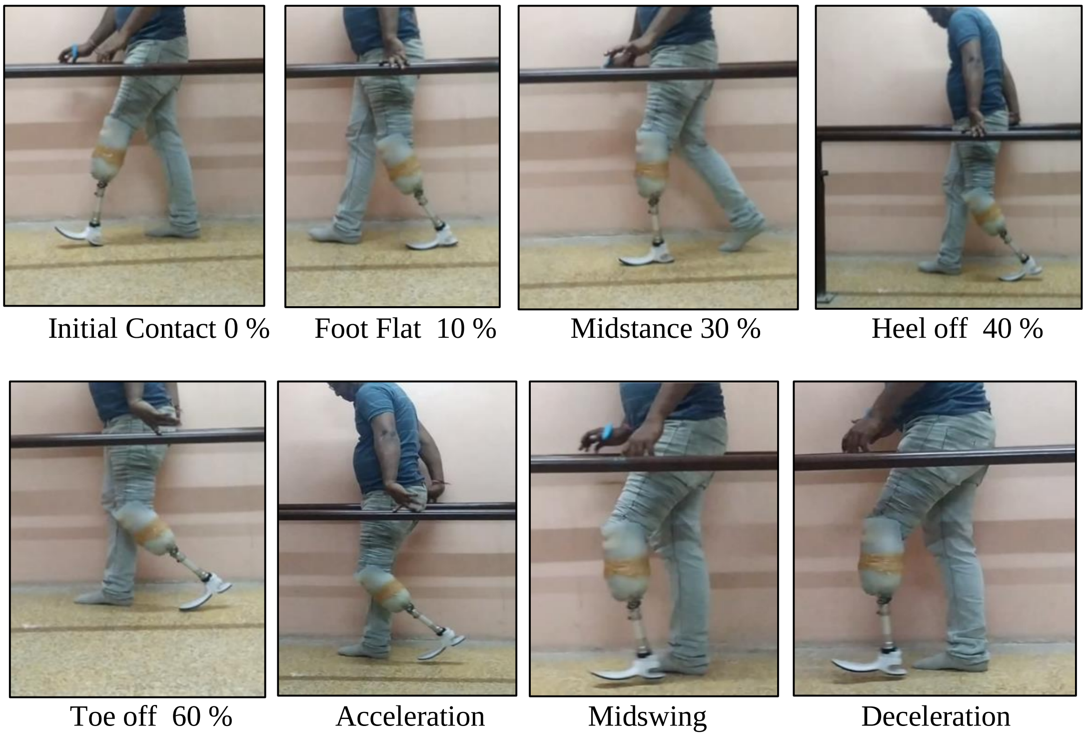


Figure 6.34: The stance phase of the left lower limb's gait cycle (case 1)

- **Kinematic data: lateral view**

Basic left and right foot observations for initial contact positions are shown in the following Table 6.10.

Table 6.10: Patient lateral view initial contact position observation data

Initial Contact	**Left**	**Right**	**Reference Value**	**Left leg observation**	**Right leg observation**
Ankle Angle[a]	91°	90°	90° to 95°	The ankle angle was normal	The ankle angle was normal
Knee Angle[b]	168°	170°	168° to 178°	The knee angle was normal	The knee angle was normal
Hip Angle[c]	(+) 26°	(+) 21°	(+) 20° to (+) 27°	The hip angle was normal	The hip angle was normal

Figure 6.35 shows a graphical depiction of the angles at the ankle, knee, and hip of the right and left legs. The angles at the ankle, knee, and hip readings in the left and right legs were all within the usual range.

(a) Left leg (b) Right leg

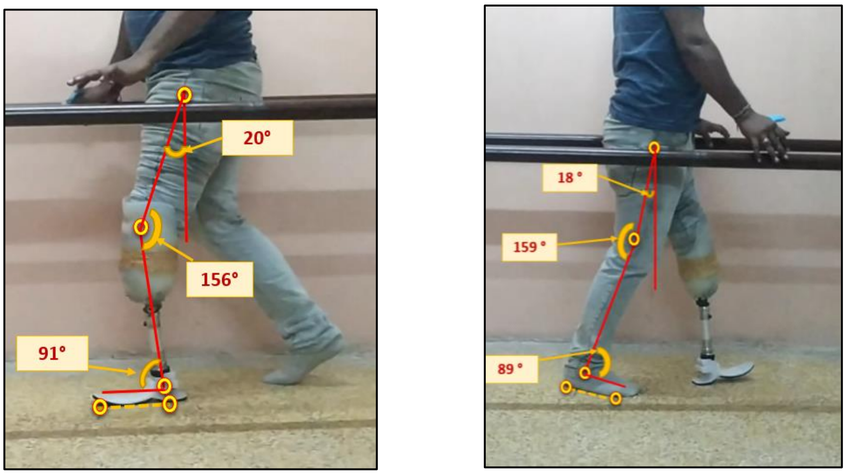
Figure 6.35: Patient lateral view initial contact position (case 1)

The basic observation data for the left leg and right leg for the loading response position is mentioned below in Table 6.11.

Table 6.11: Patient lateral view loading response position observation data

Loading response	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	91°	89°	90° to 96°	The ankle angle was normal	The ankle angle was dorsiflexion
Knee angle[b]	156°	159°	156° to 165°	The knee angle was normal	The knee angle was normal
Hip angle[c]	(+) 20°	(+) 18°	(+) 19° to (+) 26°	The hip angle was normal	The hip angle was more extension

Figure 6.36 shows the angles at the ankle, knee, and hip for the right and left legs, respectively. In the left leg observation angle values at the ankle, knee, and hip were in the normal range but for the right leg observation ankle angle was dorsiflexion, the knee angle was normal and the hip angle was more extended.



(a) Left leg (b) Right leg

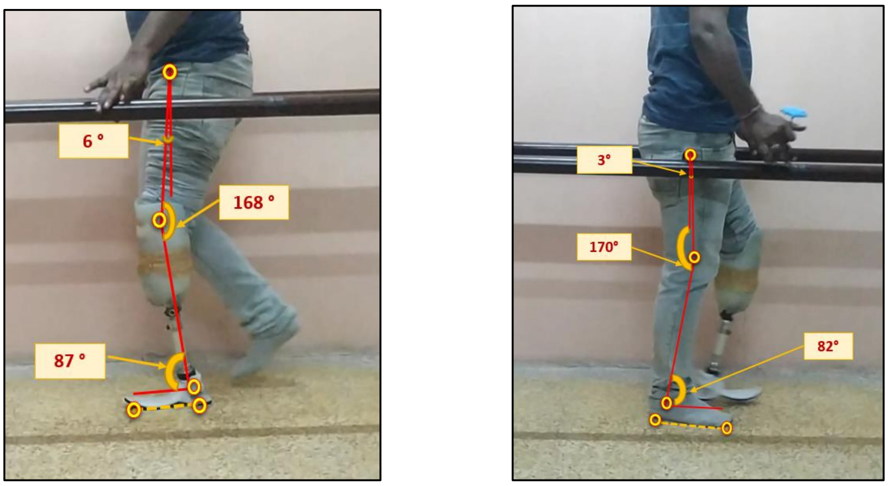
Figure 6.36: Patient lateral view loading response position (case 1)

The basic observation data for the left leg and right leg for the midstance position is mentioned below in Table 6.12.

Table 6.12: Patient lateral view mid stance position observation data

Mid stance	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	87°	82°	78° to 86°	The ankle angle was dorsiflexion	The ankle angle was normal
Knee angle[b]	168°	170°	168° to 177°	The knee angle was normal	The knee angle was normal
Hip angle[c]	6°	3°	0° to (-) 6°	The hip angle was normal	The hip angle was normal

Figure 6.37 shows a graphical depiction of the angles at the ankle, knee, and hip of the right and left legs. The ankle angle in the left leg was dorsiflexion; the knee and hip angle readings were within the usual range. The ankle, knee, and hip angle readings for the right leg were within the usual range.



(a) Left leg (b) Right leg

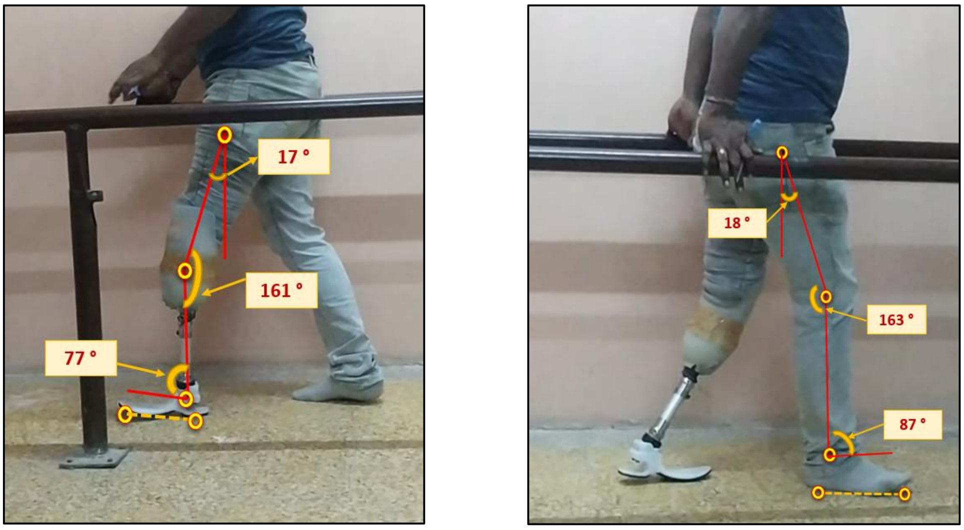
Figure 6.37: Patient lateral view mid stance position (case 1)

The basic observation data for the left leg and right leg for the terminal stance position is mentioned below in Table 6.13.

Table 6.13: Patient lateral view terminal stance position observation data

Terminal stance	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	77°	87°	76° to 84°	The ankle angle was normal	The ankle angle was dorsiflexion
Knee angle[b]	161°	163°	163° to 171°	The knee angle was flexion	The knee angle was normal
Hip angle[c]	(-) 17°	(-) 18°	(-) 15° to (-) 23°	The hip angle was normal	The hip angle was normal

Figure 6.38 depicts the graphical depiction of the angles at the ankle, knee, and hip of the right and left legs, respectively. In the left leg observation ankle angle and hip angle values were in the normal range; knee angle was flexion. For the right leg observation ankle angle was dorsiflexion, knee and hip angle values were in the normal range.



(a) Left leg (b) Right leg

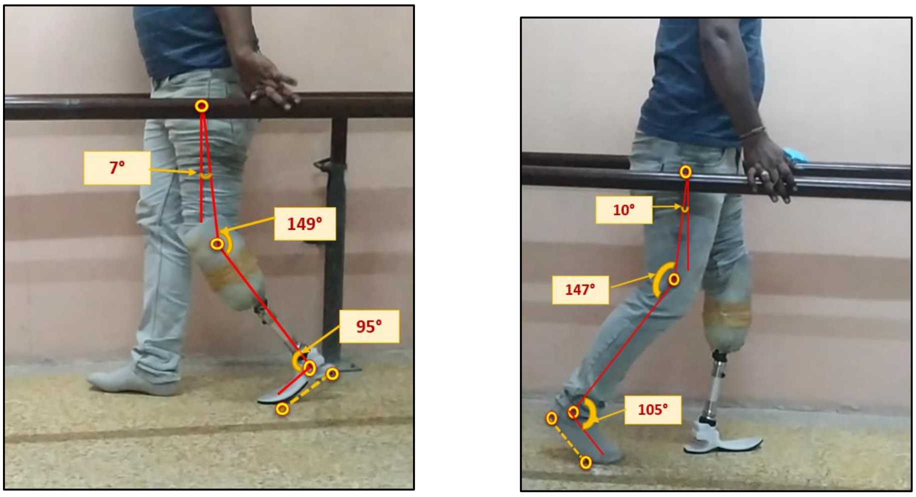
Figure 6.38: Patient lateral view terminal stance position (case 1)

The basic observation data for the left leg and right leg for the pre-swing position was mentioned in Table 6.14.

Table 6.14: Patient lateral view pre swing position observation data

Pre swing	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	95°	105°	99° to 109°	The ankle angle was plantarflexion	The ankle angle was normal
Knee angle[b]	149°	147°	136° to 147°	The knee angle was flexion	The knee angle was normal
Hip angle[c]	(-)7°	(-)10°	(-)7° to (-)15°	The hip angle was normal	The hip angle was normal

Figure 6.39 shows the angles at the ankle, knee, and hip for the right and left legs, respectively. In the left leg observation, the hip angle was within the usual range, the knee angle was flexion, and the ankle angle was plantar flexion. For the right leg observation ankle angle, knee angle and hip angle were normal.



(a) Left leg (b) Right leg

Figure 6.39: Patient lateral view pre swing position (case 1)

In the graphical representation data for the patient's lateral view of the gait cycle, the different measured parameter values by considering ankle, knee, and hip angles were mentioned in Figure 6.40 to Figure 6.42 respectively. The graphic displays the values of the various measured characteristics at the precise contact position, including first contact, loading response, midstance, terminal stance, and pre-swing. The reference value points were marked with a green color line and the left & right assessed values were marked with a blue and orange color line as shown in the figures.

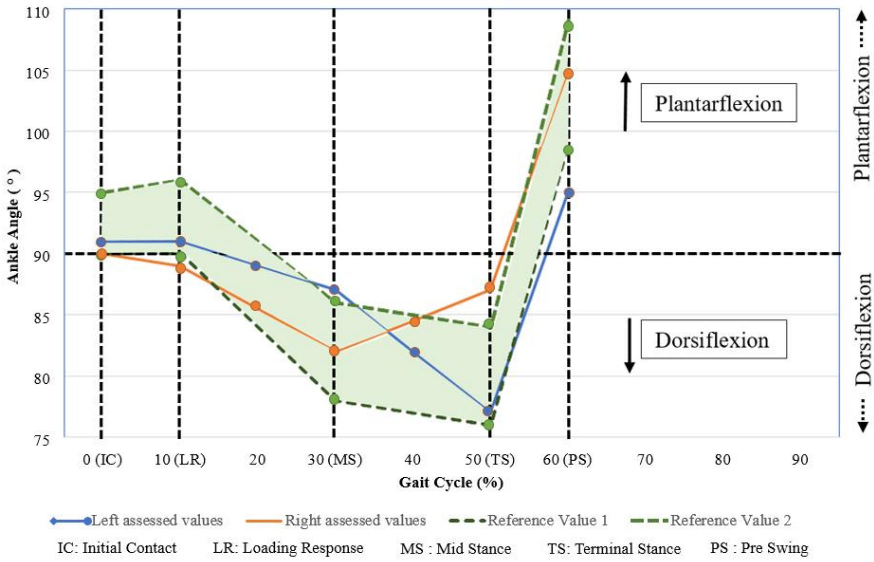


Figure 6.40: Graphs for the lateral views of the gait cycle: Ankle angle (Novel prosthetic foot)

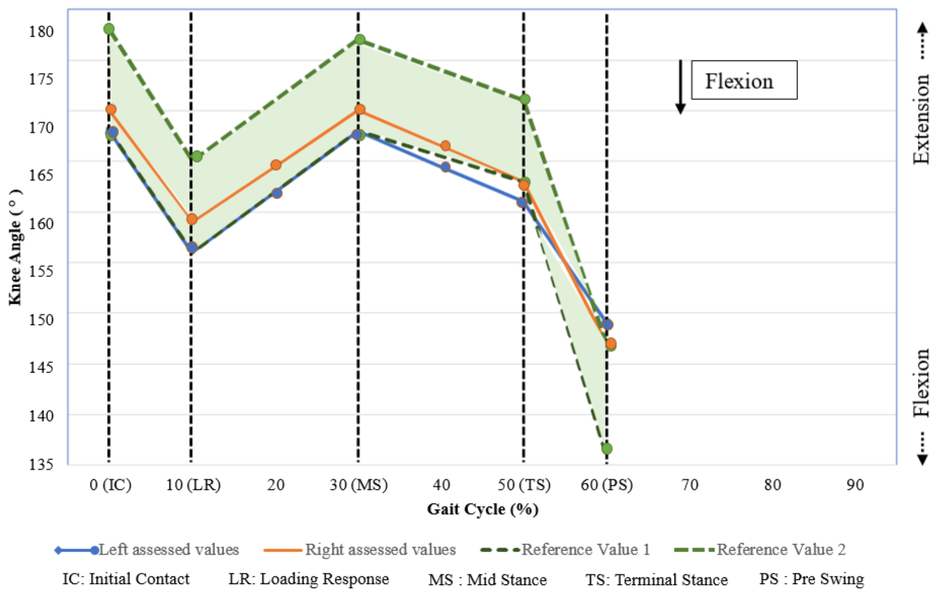


Figure 6.41: Graphs for the lateral views of the gait cycle: Knee angle (Novel prosthetic foot)

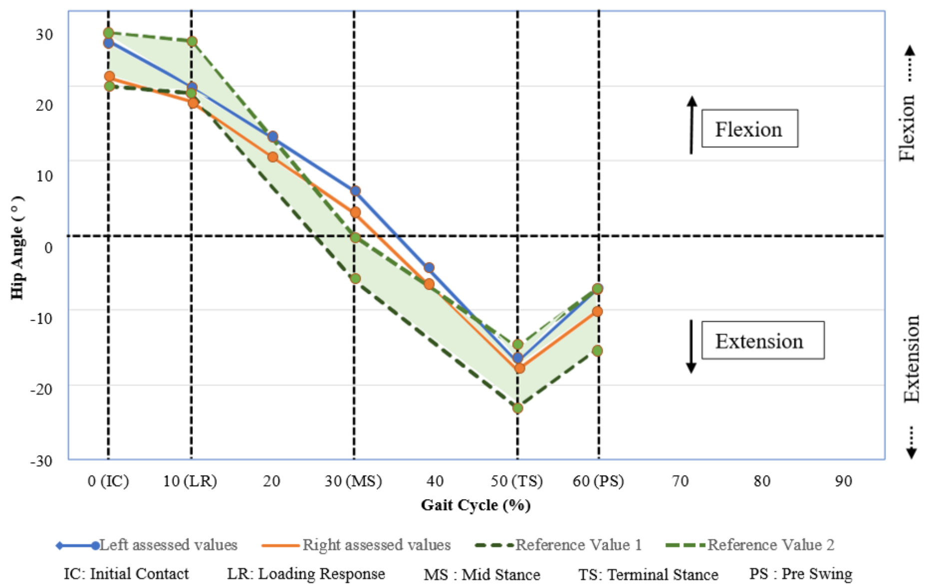


Figure 6.42: Graphs for the lateral views of the gait cycle: Hip angle (Novel prosthetic foot)

- **Kinematic data: posterior view**

The basic observation data for the left leg and right leg for the midstance position is mentioned below in Table 6.15.

Table 6.15: Patient posterior view mid stance position observation data

Mid stance	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Rear foot angle[d]	11°	3°	(+) 2° to (+) 6°	The rear foot angle was in eversion	The rear foot angle was in eversion
Pelvic drop[e]	2°	3°	0° to (+) 5°	Contralateral pelvic descent was possible	The range of contralateral pelvic descent was present

Figure 6.43 shows the graphical representations of the angles at the ankle, knee, and hip of the right and left legs, respectively. In the left leg observation rear foot angle was in eversion and contra lateral pelvic drop was within range. For the right leg observation rear foot angle was in eversion and the contra lateral pelvic drop was within range.

a) Left leg (b) Right leg

Figure 6.43: Patient posterior view midstance position (case 1)

- **Kinematic data: Anterior view**

The basic observation data for the left leg and right leg for the midstance position is mentioned below in Table 6.16.

Table 6.16: Patient anterior view mid stance position observation data

Midstance	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Knee Ab/Adduction[f]	(-) 0.5°	(-) 1°	0°	The knee was abducted as the patella was lateral to 2nd toe	The knee angle was considered to be normal

Figure 6.44 shows the knee Ab/Adduction angle for the right and left legs, respectively. For the left leg observation, the knee was abducted since the patella was lateral to the second toe, but for the right leg observation, the knee angle was seen to be normal.

(a) Left leg (b) Right leg

Figure 6.44: Patient anterior view midstance position (case 1)

Case 2: Normal patient without amputation

The second case patient's details are mentioned in below Table 6.17;

Table 6.17: Normal patient without amputation

Name	Ruju
Age(Yrs.)	27
Weight (kg)	65
Height (ft)	5' 4"
Gender	Male
Clinician	Dr. Mitul Darji (Sports PT)
Date of gait analysis	21-06-2019
Type of foot	Normal patients without Amputation

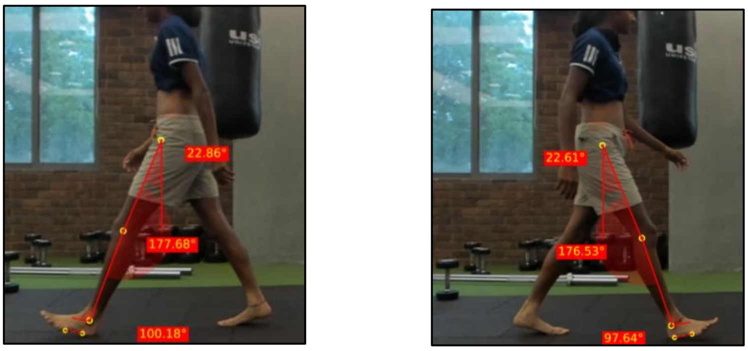
- **Kinematic data: lateral view**

The basic observation data (Siddharth, 2019) for the left leg and right leg for the initial contact position is mentioned in below Table 6.18.

Table 6.18: Patient posterior view mid stance position observation data

Initial contact	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	100.18°	97.64°	90° to 95°	Ankle angle in plantarflexion	The ankle angle was near normal
Knee angle[b]	177.68°	176.53°	168° to 178°	The knee angle was normal	The knee angle was normal
Hip angle[c]	22.86°	22.61°	(+) 20° to (+) 27°	The hip angle was normal	The hip angle was normal

Figure 6.45 shows the graphical representations of the angles at the ankle, knee, and hip of the right and left legs, respectively. In the left leg observation ankle angle in plantarflexion, it was due to either claf tightness or dorsiflexion weakness; knee and hip angle values were in the normal range. For the right leg observation, the ankle angle was near normal but can improve by 10° to make efficient absorption of ground reaction force; knee and hip angle values were in the normal range.



(a) Left leg (b) Right leg

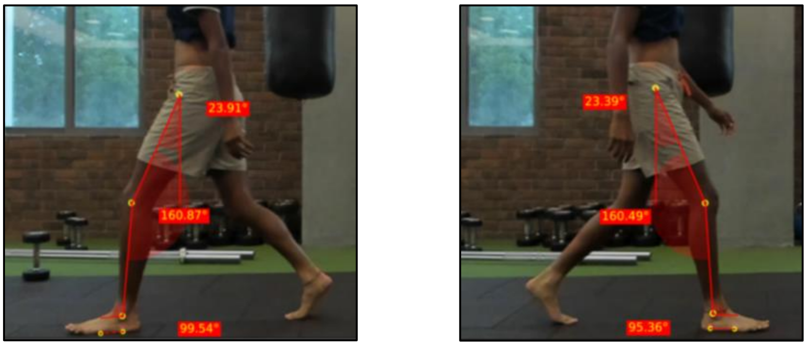
Figure 6.45: Patient lateral view initial contact position (case 2)

The basic observation data for the left leg and right leg for the loading response position is mentioned below in Table 6.19.

Table 6.19: Patient lateral view loading response position observation data

Loading response	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	99.54°	95.36°	90° to 96°	The ankle angle was in Plantarflexion	The ankle angle was normal
Knee angle[b]	160.87°	160.49°	156° to 165°	The knee angle was normal	The knee angle was normal
Hip angle[c]	23.91°	23.39°	(+) 19° to (+) 26°	The hip angle was normal	The hip angle was normal

The graphical representation of the angles at the ankle, knee, and hip of the right and left legs for a lateral view of the patients were given in Figure 6.46 respectively. In the left leg observation, the ankle angle was in plantarflexion; the knee and hip angles were normal. For the right leg observation ankle, knee, and hip angles were normal.



(a) Left leg (b) Right leg

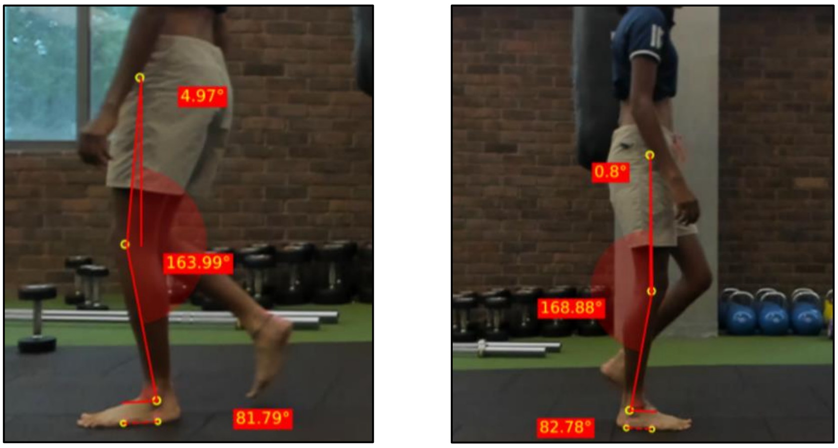
Figure 6.46: Patient lateral view loading response position (case 2)

The baseline observation data for the left and right leg for the lateral view of the patient in the midstance position was mentioned in Table 6.20.

Table 6.20: Patient lateral view mid stance position observation data

Mid stance	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	81.79°	82.78°	78° to 86°	The ankle angle was normal	The ankle angle was normal
Knee angle[b]	163.99°	168.88°	168° to 177°	The knee angle was near normal	The knee angle was normal
Hip angle[c]	4.97°	0.8°	0° to (-) 6°	The hip angle was normal	The hip angle was normal

Figure 6.47 shows, for the right and left legs, the graphical representations of angles at the ankle, knee, and hip. In the left leg and right leg observation angle values at the ankle, knee, and hip were in the normal range.



(a) Left leg (b) Right leg

Figure 6.47: Patient lateral view mid stance position (case 2)

The baseline observation data for the left and right leg for the lateral view of the patient in the terminal stance position was mentioned in Table 6.21.

Table 6.21: Patient lateral view terminal stance position observation data

Terminal stance	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	79.92°	82.77°	76° to 84°	The ankle angle was near normal	The ankle angle was normal
Knee angle[b]	167.13°	167.8°	163° to 171°	The knee angle was normal	The knee angle was normal
Hip angle[c]	(-) 24.02°	(-) 19.69°	(-) 15° to (-) 23°	The hip angle was normal	The hip angle was normal

Figure 6.48 shows, for the right and left legs, the graphical representations of the angles at the ankle, knee, and hip. In the left leg observation, the ankle angle was near normal; knee and hip angle values were in the normal range. For the right leg observation ankle angle, knee, and hip angle values were in the normal range.

(a) Left leg (b) Right leg

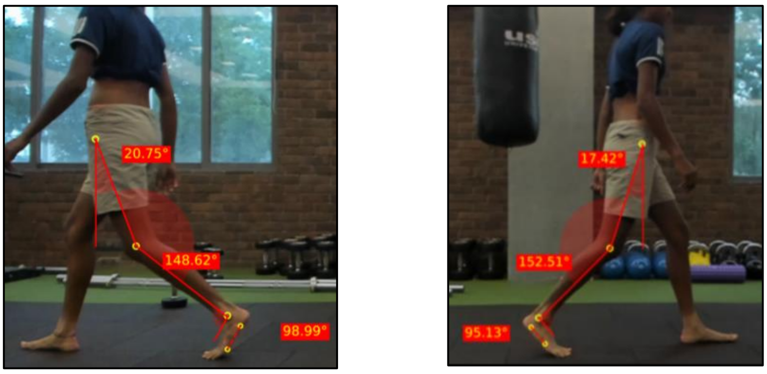
Figure 6.48: Patient lateral view terminal stance position (case 2)

The baseline observation data for the left and right leg for the lateral view of the patient in the pre-swing position was mentioned in Table 6.22.

Table 6.22: Patient lateral view pre swing position observation data

Pre swing	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	98.99°	95.13°	99° to 109°	The ankle angle was normal	The ankle angle was normal
Knee angle[b]	148.62°	152.51°	136° to 147°	The knee angle was normal	The knee angle was near normal
Hip angle[c]	(-)20.75°	(-)17.42°	(-)7° to (-)15°	The hip angle was more extension	The hip angle was normal

Figure 6.49 shows the angles at the ankle, knee, and hip for the right and left legs, respectively. In the left leg observation, an angle at the ankle and knee was normal; the hip angle was more extended due to overstriding. For the right leg observation ankle angle, and hip angle values were in the normal range but the knee angle was near normal.



(a) Left leg (b) Right leg

Figure 6.49: Patient lateral view pre swing position (case 2)

In the graphical representation data for the normal patient's lateral view of the gait cycle, the different measured parameter values by considering ankle, knee, and hip angles were mentioned in Figure 6.50 to Figure 6.52 respectively.

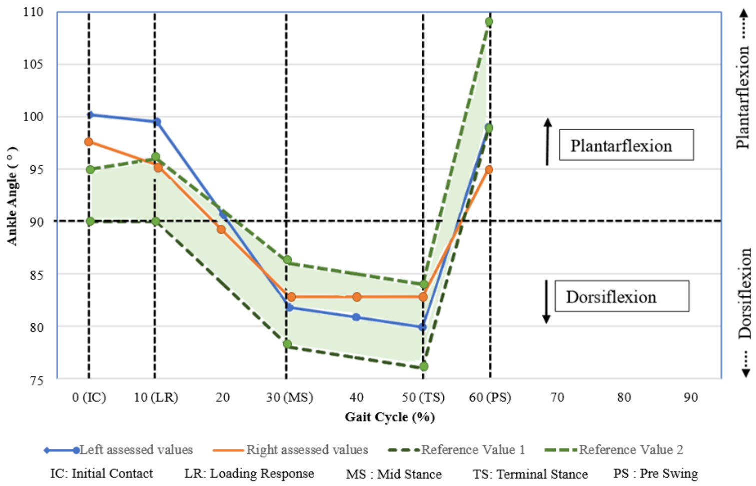


Figure 6.50: Graphs for the lateral views of the gait cycle: Ankle angle (Normal patient)

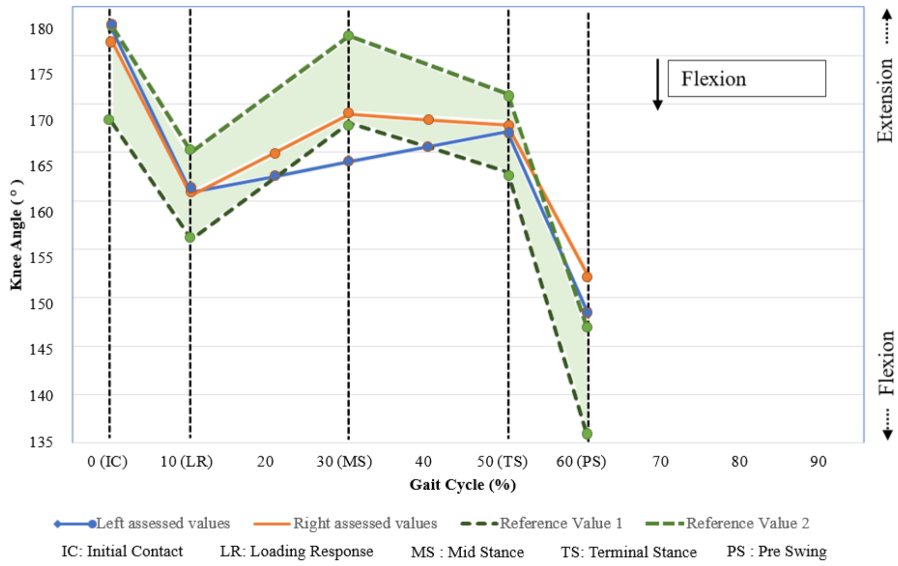


Figure 6.51: Graphs for the lateral views of the gait cycle: Knee angle (Normal patient)

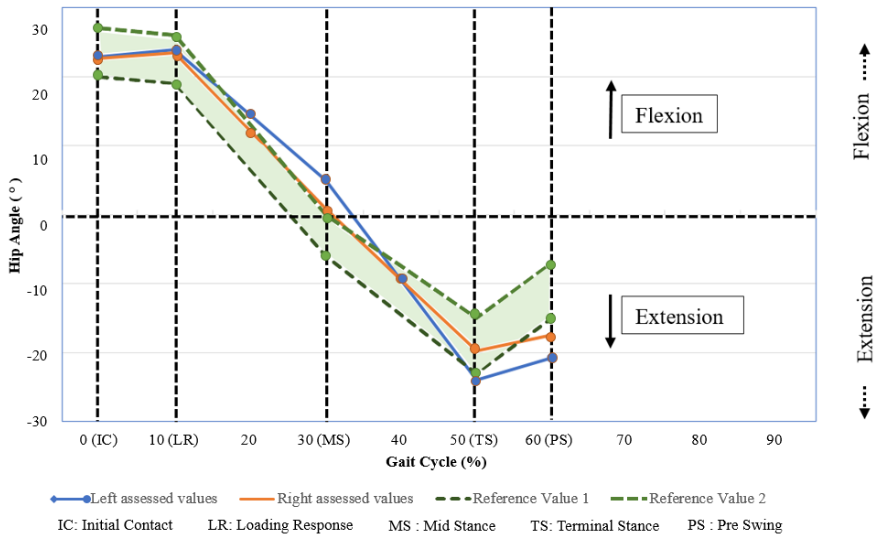


Figure 6.52: Graphs for the lateral views of the gait cycle: Hip angle (Normal patient)

- **Kinematic data: posterior view**

The baseline observation data for the left and right leg for the posterior view of the patient in the midstance position was mentioned in Table 6.23.

Table 6.23: Patient posterior view mid stance position observation data

Mid stance	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Rear foot angle[d]	15.63°	15.01°	(+) 2° to (+) 6°	The rear foot angle was in eversion	The rear foot angle was in eversion
Pelvic drop[e]	2.75°	8.53°	0° to (+) 5°	The range of contralateral pelvic descent was present	There was a contralateral pelvic descent

Figure 6.53 depicts the graphical depiction of the right and left legs' rear foot angle and pelvic drop angle. In the left leg observation rear foot angle was in eversion and contra lateral pelvic drop was within range. For the right leg observation rear foot angle was in eversion and contra lateral pelvic drop was present due to right hip abductor weakness.

(a) Left leg (b) Right leg

Figure 6.53: Patient posterior view mid stance position (case 2)

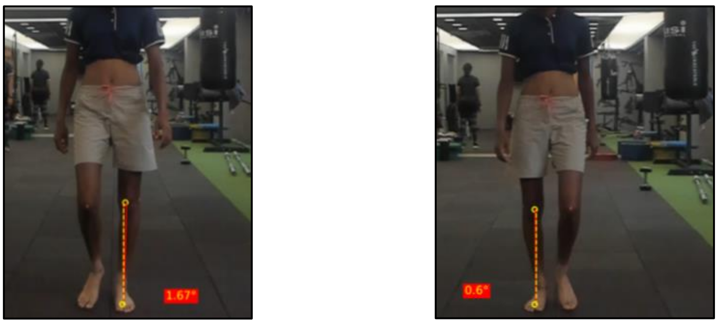
- **Kinematic data: anterior view**

The baseline observation data for the left and right leg for the anterior view of the patient in the midstance position was mentioned in Table 6.24.

Table 6.24: Patient anterior view mid stance position observation data

Mid Stance	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Knee Ab/Adduction[f]	(-) 1.67°	(-) 0.6°	0°	The knee was Abducted as the patella was lateral to 2nd toe.	The knee angle was considered to be normal

Figure 6.54 shows the Knee Ab/Adduction angle for the right and left legs, respectively. In the left leg observation knee was abducted as the patella is lateral to the 2nd toe. This can cause knee discomfort as a result of an over-pronated foot, an over-supinated foot, and/or core muscular weakness. Abnormal knee adduction was frequently associated with patellofemoral discomfort, iliotibial band syndrome, and Achilles tendinitis. For the right leg observation, the knee angle was considered to be normal.



(a) Left leg (b) Right leg

Figure 6.54: Patient anterior view mid stance position (case 2)

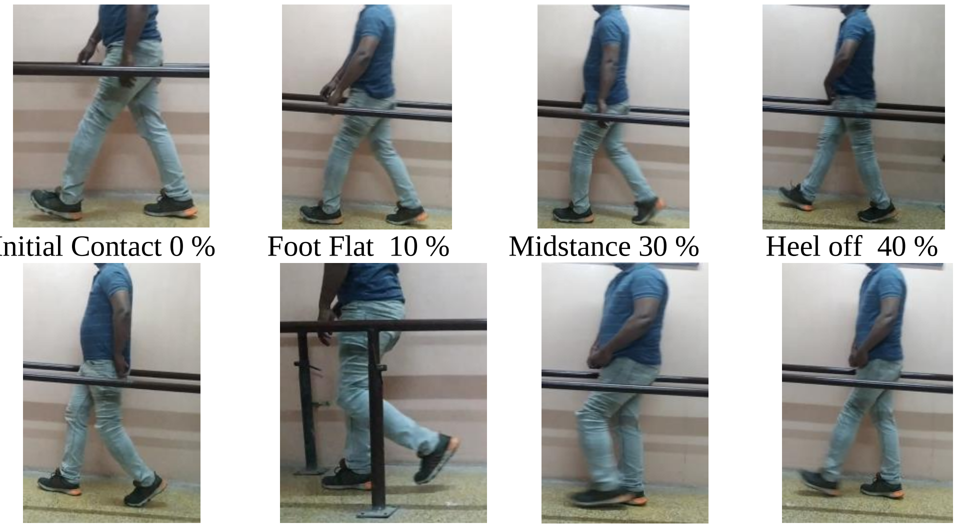
Case 3: Patient with prosthetic senator foot

The third patient's case details are mentioned in below Table 6.25;

Table 6.25: Patient with prosthetic senator foot

Name	Mr. Nikunj Maiskar
Age(Yrs.)	35
Weight (kg)	85
Height (ft)	5' 9"
Gender	Male
Clinician	Dr. Khyati Vansadavala (Prosthetist & Orthotist , RCI No: A51452)
Date of gait analysis	23-10-2021
Amputation	A person was injured in an accident and his left leg was amputated below the knee in 2013
Type of foot	Patient with Prosthetic senator foot

The different required positions of the patients (prosthetic senator foot) were observed during the gait analysis for the stance phase of a gait cycle as shown in Figure 6.55.



Initial Contact 0 % | Foot Flat 10 % | Midstance 30 % | Heel off 40 %

Toe off 60 % | Acceleration | Midswing | Deceleration

Figure 6.55: The stance phase of the left lower limb's gait cycle (case 3)

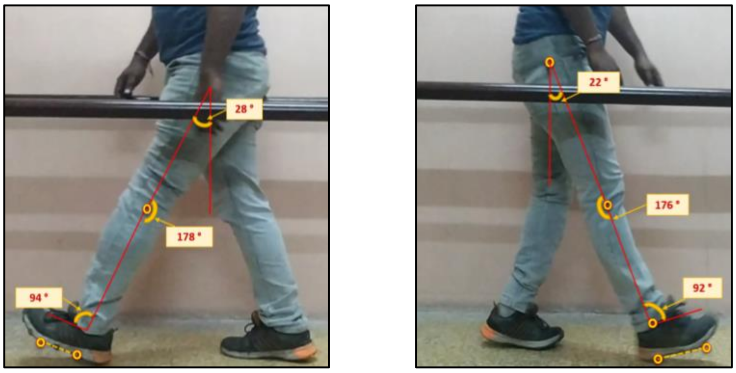
- **Kinematic data: lateral view**

The baseline observation data for the left and right leg for the lateral view of the patient in the initial contact position was mentioned in Table 6.26.

Table 6.26: Patient lateral view initial contact position observation data

Initial Contact	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	94°	92°	90° to 95°	The ankle angle was normal	The ankle angle was normal
Knee angle[b]	178°	176°	168° to 178°	The knee angle was normal	The knee angle was normal
Hip angle[c]	28°	22°	(+) 20° to (+) 27°	The hip angle was normal	The hip angle was normal

Figure 6.56 shows the angles at the ankle, knee, and hip for the right and left legs, respectively. In the left leg observation angles at the ankle and knee were normal; the hip angle was more extended due to overstriding. For the right leg observation ankle angle, knee, and hip angle values were in the normal range.



(a) Left leg (b) Right leg

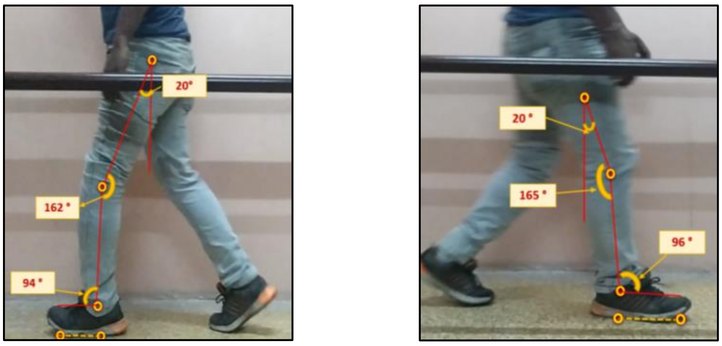
Figure 6.56: Patient lateral view initial contact position (case 3)

The baseline observation data for the left and right leg for the lateral view of the patient in the loading response position was mentioned in Table 6.27.

Table 6.27: Patient lateral view loading response position observation data

Loading response	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	94°	96°	90° to 96°	The ankle angle was normal	The ankle angle was normal
Knee angle[b]	162°	165°	156° to 165°	The knee angle was flexion	The knee angle was flexion
Hip angle[c]	20°	20°	(+) 19° to (+) 26°	The hip angle was normal	The hip angle was normal

Figure 6.57 depicts the graphical depiction of the angles at the ankle, knee, and hip of the right and left legs, respectively. In the left leg observation angle values at the ankle and hip were in the normal range; the knee angle was flexion. For the right leg observation angle values at the ankle and hip were in the normal range; the knee angle was flexion.



(a) Left leg (b) Right leg

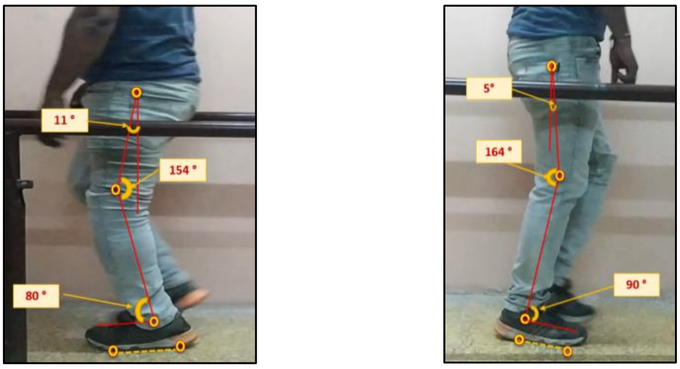
Figure 6.57: Patient lateral view loading response position (case 3)

The baseline observation data for the left and right leg for the lateral view of the patient in the midstance position was mentioned in Table 6.28.

Table 6.28: Patient lateral view mid stance position observation data

Mid stance	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	80°	90°	78° to 86°	The ankle angle was normal	The ankle angle was normal
Knee angle[b]	154°	164°	168° to 177°	The knee angle was flexion	The knee angle was flexion
Hip angle[c]	11°	5°	0° to (-) 6°	The hip angle was normal	The hip angle was normal

Figure 6.58 shows the angles at the ankle, knee, and hip for the right and left legs, respectively. In the left leg observation ankle angle and hip angle were normal; the knee angle was flexion. For the right leg observation ankle angle, and hip angle values were in the normal range but the knee angle was flexion.



(a) Left leg (b) Right leg

Figure 6.58: Patient lateral view mid stance position (case 3)

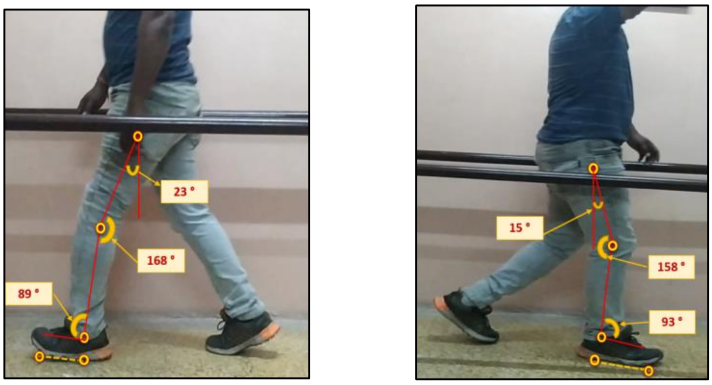
The baseline observation data for the left and right leg for the lateral view of the patient in the terminal stance position was mentioned in Table 6.29.

Table 6.29: Patient lateral view terminal stance position observation data

Terminal stance	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	89°	93°	76° to 84°	The ankle angle was near dorsiflexion	The ankle angle was plantarflexion
Knee angle[b]	168°	158°	163° to 171°	The knee angle was normal	The knee angle was flexion
Hip angle[c]	(-)23°	(-)15°	(-) 15° to (-) 23°	The hip angle was normal	The hip angle was normal

Figure 6.59 depicts the graphical depiction of the angles at the ankle, knee, and hip of the right and left legs, respectively. In the left leg observation knee angle and hip angle values were in the normal range; the ankle angle was near dorsiflexion. For the right

leg observation, the hip angle was in the normal range; the ankle angle was plantarflexion and the knee angle was flexion.



(a) Left leg (b) Right leg

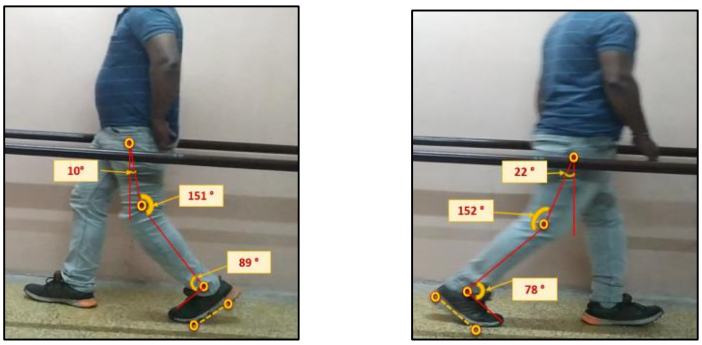
Figure 6.59: Patient lateral view terminal stance position (case 3)

The baseline observation data for the left and right leg for the lateral view of the patient in the pre-swing position was mentioned in Table 6.30.

Table 6.30: Patient lateral view pre swing position observation data

Pre swing	**Left**	**Right**	**Reference value**	**Left leg observation**	**Right leg observation**
Ankle angle[a]	89°	78°	99° to 109°	The ankle angle was dorsiflexion	The ankle angle was dorsiflexion
Knee angle[b]	151°	152°	136° to 147°	The knee angle was flexion	The knee angle was flexion
Hip angle[c]	(-)10°	(-)22°	(-)7° to (-)15°	The hip angle was normal	The hip angle was normal

Figure 6.60 shows the angles at the ankle, knee, and hip for the right and left legs, respectively. In the left leg, the hip angle was normal; the ankle angle was dorsiflexion and the knee angle was flexion. For the right leg observation hip angle value was in the normal range but the ankle angle was dorsiflexion and the knee angle was flexion.



(a) Left leg (b) Right leg

Figure 6.60: Patient lateral view pre swing position (case 3)

In the graphical representation data for the patient's (senator's foot) lateral view of the gait cycle, the different measured parameter values by considering ankle, knee, and hip angles were mentioned in Figure 6.61 to Figure 6.63 respectively.

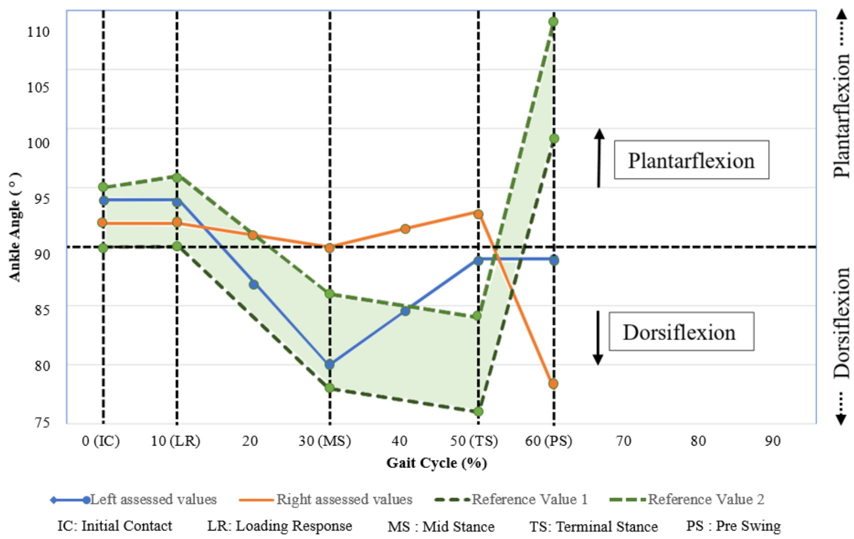


Figure 6.61: Graphs for the lateral views of the gait cycle: Ankle angle (Senator foot)

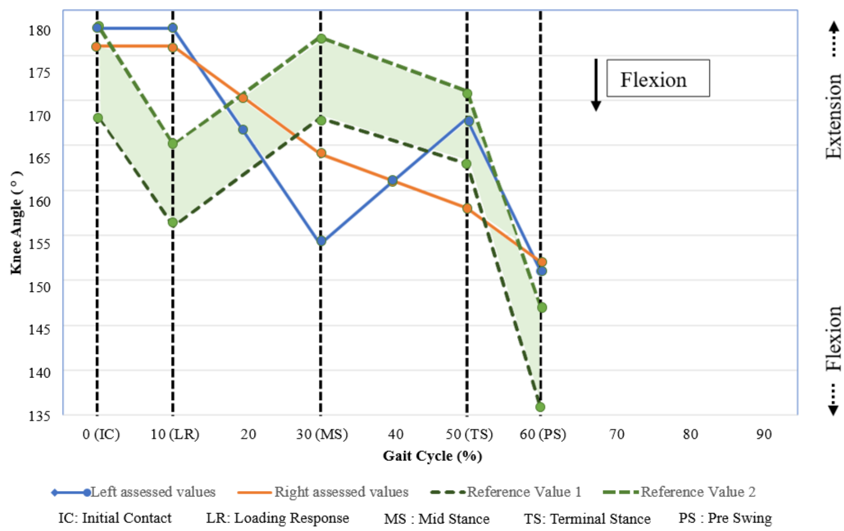


Figure 6.62: Graphs for the lateral views of the gait cycle: Knee angle (Senator foot)

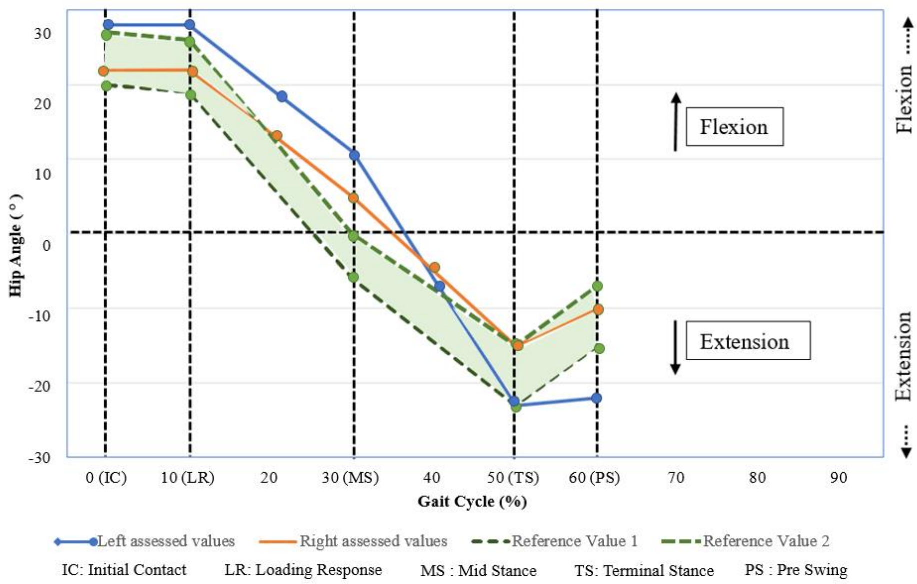


Figure 6.63: Graphs for the lateral views of the gait cycle: Hip angle (Senator foot)

According to data analysis from three different case study reports, the final comparative data for normal patients, patients with below-knee amputation wearing Senator's foot, and new prosthetics were summarized in the following Table 6.31.

Table 6.31: Patient gait analysis comparison data

Normal Patient

LATERAL VIEW

Ankle Angle[a]	Right	Left	Reference Value
Initial Contact	90°	91°	90° to 95°
Loading Response	89°	91°	90° to 96°
Mid Stance	82°	87°	78° to 86°
Terminal Stance	87°	77°	76° to 84°
Pre Swing	105°	95°	99° to 109°

Knee Angle[b]	Right	Left	Reference Value
Initial Contact	170°	168°	168° to 178°
Loading Response	159°	156°	156° to 165°
Mid Stance	170°	168°	168° to 177°
Terminal Stance	163°	161°	163° to 171°
Pre Swing	147°	149°	136° to 147°

Hip Angle[c]	Right	Left	Reference Value
Initial Contact	21°	26°	(+) 20° to (+) 27°
Loading Response	20°	18°	(+) 19° to (+) 26°
Mid Stance	6°	3°	0° to (-) 6°
Terminal Stance	(-)18°	(-)17°	(-) 15° to (-) 23°
Pre Swing	(-)10°	(-)7°	(-)7° to (-)15°

POSTERIOR VIEW

Rear Foot Angle[d]	Right	Left	Reference Value
Mid Stance	3°	11°	(+) 2° to (+) 6°

Pelvic drop[e]	Right	Left	Reference Value
Mid Stance	3°	2°	0° to (+) 5°

ANTERIOR VIEW

Knee Ab/Adduction[f]	Right	Left	Reference Value
Mid Stance	(-) 1°	(-) 0.5°	0°

Patient with Senator Foot

LATERAL VIEW

Ankle Angle[a]	Right	Left	Reference Value
Initial Contact	92°	94°	90° to 95°
Loading Response	96°	94°	90° to 96°
Mid Stance	90°	80°	78° to 86°
Terminal Stance	93°	89°	76° to 84°
Pre Swing	78°	89°	99° to 109°

Knee Angle[b]	Right	Left	Reference Value
Initial Contact	176°	178°	168° to 178°
Loading Response	165°	162°	156° to 165°
Mid Stance	164°	154°	168° to 177°
Terminal Stance	158°	168°	163° to 171°
Pre Swing	152°	151°	136° to 147°

Hip Angle[c]	Right	Left	Reference Value
Initial Contact	(+) 22°	(+) 28°	(+) 20° to (+) 27°
Loading Response	(+) 20°	(+) 20°	(+) 19° to (+) 26°
Mid Stance	(+) 5°	(+) 11°	0° to (-) 6°
Terminal Stance	(-)15°	(-)23°	(-) 15° to (-) 23°
Pre Swing	(-)10°	(-)22°	(-)7° to (-)15°

Patient with Novel prosthetic foot

LATERAL VIEW

Ankle Angle[a]	Right	Left	Reference Value
Initial Contact	97.64°	100.18°	90° to 95°
Loading Response	95.36°	99.54°	90° to 96°
Mid Stance	82.78°	81.79°	78° to 86°
Terminal Stance	82.77°	79.92°	76° to 84°
Pre Swing	95.13°	98.99°	99° to 109°

Knee Angle[b]	Right	Left	Reference Value
Initial Contact	176.53°	177.68°	168° to 178°
Loading Response	160.49°	160.87°	156° to 165°
Mid Stance	168.88°	163.99°	168° to 177°
Terminal Stance	167.8°	167.13°	163° to 171°
Pre Swing	152.51°	148.62°	136° to 147°

Hip Angle[c]	Right	Left	Reference Value
Initial Contact	(+) 22.61°	(+) 22.86°	(+) 20° to (+) 27°
Loading Response	(+) 23.39°	(+) 23.91°	(+) 19° to (+) 26°
Mid Stance	(+) 0.8°	(+) 4.97°	0° to (-) 6°
Terminal Stance	(-) 19.69°	(-) 24.02°	(-) 15° to (-) 23°
Pre Swing	(-) 17.42°	(-) 20.75°	(-)7° to (-)15°

POSTERIOR VIEW

Rear Foot Angle[d]	Right	Left	Reference Value
Mid Stance	(+) 15.01°	(+) 15.63°	(+) 2° to (+) 6°

Pelvic drop[e]	Right	Left	Reference Value
Mid Stance	(+) 8.53°	(+) 2.75°	0° to (+) 5°

ANTERIOR VIEW

Knee Ab/Adduction[f]	Right	Left	Reference Value
Mid Stance	(-) 0.6°	(-) 1.67°	0°

A graphical representation of various measured parameter values for angles at the ankle, knee, and hip shows that the data were within the allowable range of the standard reference data for the patient's lateral view position when wearing the new prosthetic as shown below in Figure 6.64.

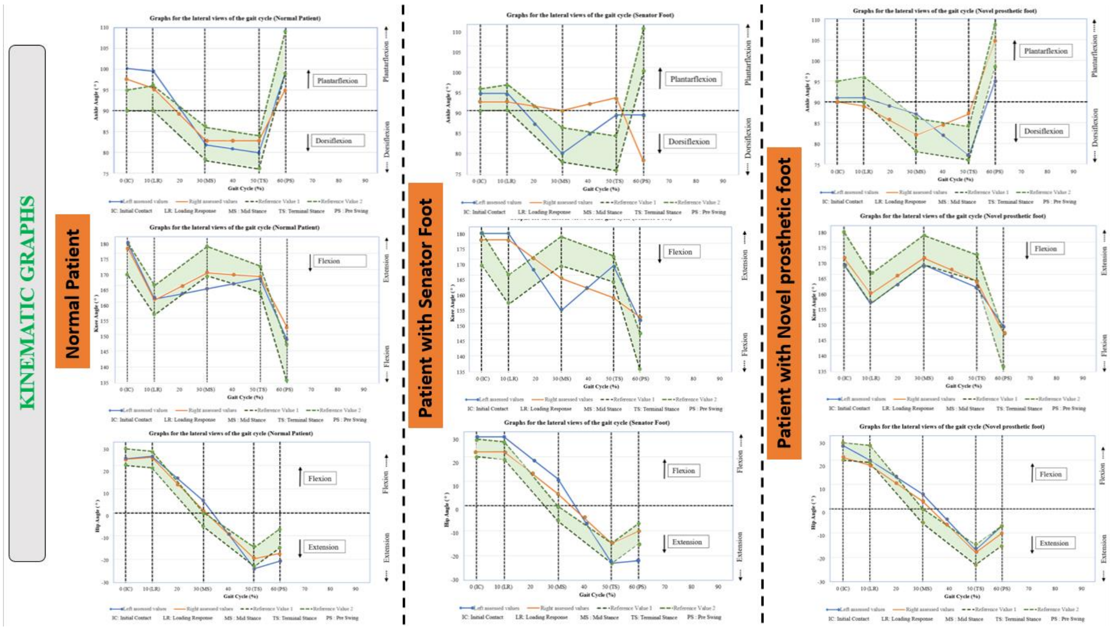


Figure 6.64: Kinematic graph for patient's lateral view position

6.4 RESULT AND DISCUSSION OF PATIENT'S TEST

This study presents the physical design, mechanical properties, and initial gait test of a prosthetic to evaluate the effectiveness of the prosthetic as a design goal. The special feature of this foot is that it allows testing of ankle stiffness over a wide range of motion, similar to physiological ankle stiffness and range of motion. The prosthetic foot element design shows a reduction in weight compared to previous prototypes, maintaining structural integrity, and allowing proper operation according to the patient's requirements.

Table 6.6 shows the mass comparison statistics of SACH and novel foot structure assemblies without pylon and socket parts. The SACH foot structure has a mass of 309 grams, while the novel foot structure has a mass of 190 grams after optimization. The research efforts including design optimization in novel prosthetic foot structure reveal a weight decrease of around 61.5% when compared to the SACH foot structure.

The current approach pertains to a revolutionary single-unit prosthetic foot that may absorb shocks during ambulation while also transferring energy efficiently between heel strike and toe-off and improving stability.