Comparison between Weight Activated and Polycentric Knee Joints on the Gait Performance of Transfemoral Amputees

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Abstract: ***Amputation of the lower limb results is a physical change in the body physiology that is often associated with functional limitations, such as an impaired ability to transfer, balance, and/or ambulation. A prosthetic limb acts as a replacing device which helps to restore some of the physical and biomechanical features of the lost foot, ankle, shin, and knee. Prosthetic knee joints have a dual function to perform: to provide stability during the stance phase and to provide controlled motion during the swing phase. Prosthetic knee joint designs have become extremely sophisticated as compared to early constant friction single axis mechanisms. Prosthetists around the world today are spoilt for choice regarding the choice of prosthetic knee joints for their patients. Unfortunately, little quantitative data is available comparing the performance of different types of prosthetic knee joints and prosthetic prescription is often based on clinical knowledge and experience, rather than objective comparison of prosthetic designs. Stance phase stability and swing phase response are both important aspects to consider. The aim of this study was to compare the gait of persons with trans-femoral amputation using two different knee joints by means of a questionnaire, gait analysis measuring temporo-spatial variables and measurement of energy expenditure during walking and to find a relationship among the variables studied.It was found that the polycentric knee joint provides a balance between stability and mobility thereby providing a smooth transition from the stance to the swing phase.***

Keywords: Functional Gait Analysis, Prosthetic Knee Joints, Trans-femoral Amputee Gait, Physiological Cost Index, Safety Knee Joint vs Polycentric Knee Joint

1. Introduction

A prosthetic limb acts as a replacement of the lost body partsand it helps to restore some of the physical and biomechanical features that have been lost including the foot ankle mechanism and the knee joint. The loss of the knee joint compounds the problems for the trans-femoral amputee and may result in patients suffering from instability, loss of control on the prosthesis and increase in the energy cost of walking[28].

The knee joint must remain fully extended during the most unstable phase of the gait cycle, the initial contact phase.Stability of a trans-femoral prosthesis is governed by two factors, 1) the extension moment generated by the remaining hip musculature on the amputated side leading to voluntary control and 2) the alignment of various components of the prosthesis leading to involuntary control also known as alignment stability. Knee instability occurs when the prosthetic knee joint buckles during the stance phase of the gait cycle[4].

Alignment stability is achieved by different methods with respect to different knee joints by determining where the weight line or ground reaction force (GRF) falls with respect to the knee center. If the prosthesis is aligned in such a manner that the weight line remains in front of the knee centre in the single axis knee joint or the ICR of the polycentric knee , the prosthesis will achieve stability by means of alignment[6]. The prosthetic knee joint has to accomplish the dual function of providing stability and helping the amputee to make the transition from the stance phase to the swing phase of the gait in a smooth controlled manner[11].

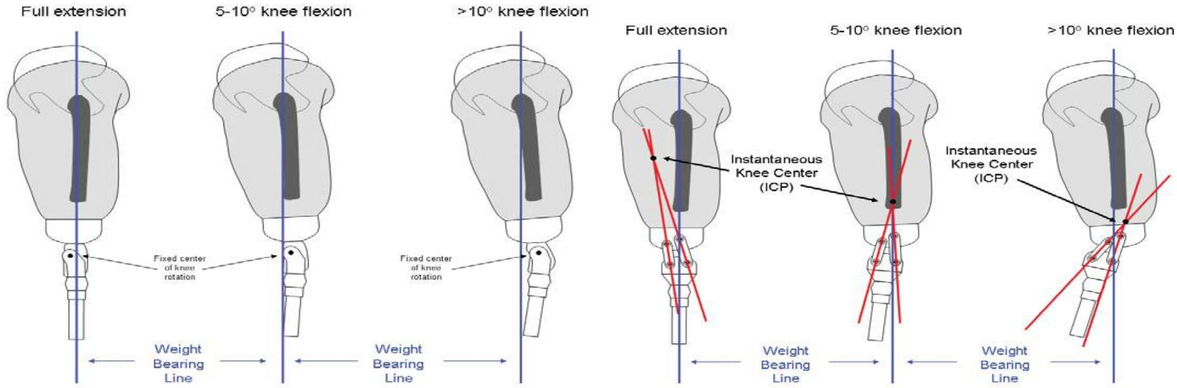

Figure 1: Stability in Single-Axis and Polycentric knees

A properly aligned prosthesis with a properly adjusted swing phase mechanism will result in a stable prosthesis. Improper adjustment of the swing phase mechanism can result in gait deviations and an increase in the energy consumed during the process of ambulation. Instability of the prosthesis will result in improper gait for the patient leading to gait deviations, increase in the consumption of energy during ambulation and may also lead to buckling of the prosthetic knee during the stance phase of gait[2].

Our study considers two most commonly used prosthetic knee designs (polycentric and weight activated) in developing countries used for subjects with fair muscular power (mean age 40.7±8.3) who rely partially on different stability mechanisms to determine whether the same trade-offs between stance stability and swing phase initiation effort are valid for different degrees of inherent knee component stability.

Polycentric Knee Joints: The polycentric knee joint usually consists of a four-bar linkage with four joint axes that provide more than one point of rotation. The two upper axes are located within the proximal knee component, the two lower axes in the distal, tibial part. They are connected by two linkage bars at the medial and two at the lateral side of the knee joint. Thus, a four-bar linkage is formed which crosses during knee flexion. When the knee joint is extended the Instantaneous Centre of Rotation (ICR) is situated far behind and above the knee joint. During flexion the ICR constantly changes its position and moves on a centrode forward and downward. When extended polycentric knee joints are highly stable against undesired flexion[10,11].

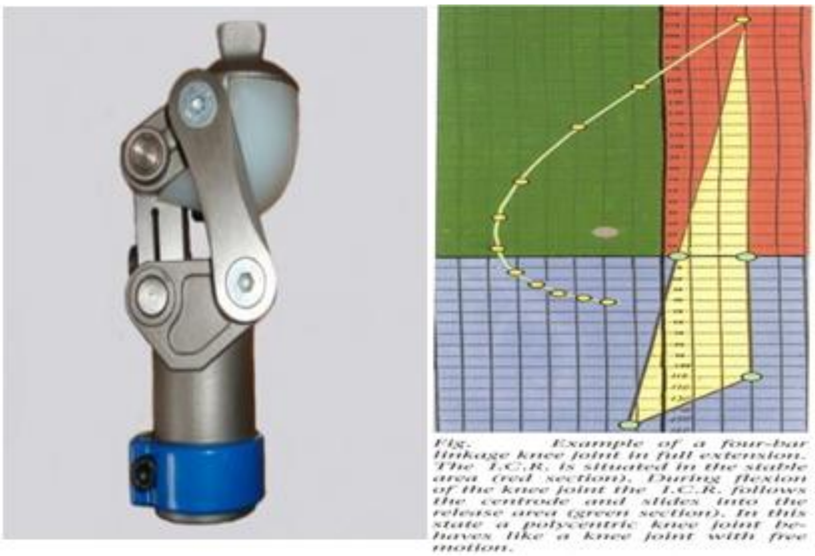

Figure 2: Four - Bar Polycentric Knee Joint

The Weight Activated Friction Brake Safety Knee:
A single axis prosthetic knee joint achieves stability with a weight-activated knee brake. A knee brake resists and can block knee flexion during weight acceptance. This prevents the knee joint from buckling from initial contact till mid stance. For the brake to work satisfactorily, it requires action of the body weight acting on it. A weight-activated knee brake resembles the action of a drum brake in a car. When the body weight acts on it, a brake block contacts a brake drum and thus blocks the knee joint. By means of a spring counteracting against the body weight impact forces, the brake timing and/or moment can be adjusted. As long as the weight acts on the joint, the braking effect is maintained. The higher the pre-compression of the counter spring, the higher is the force needed to trigger the brake[10, 11].

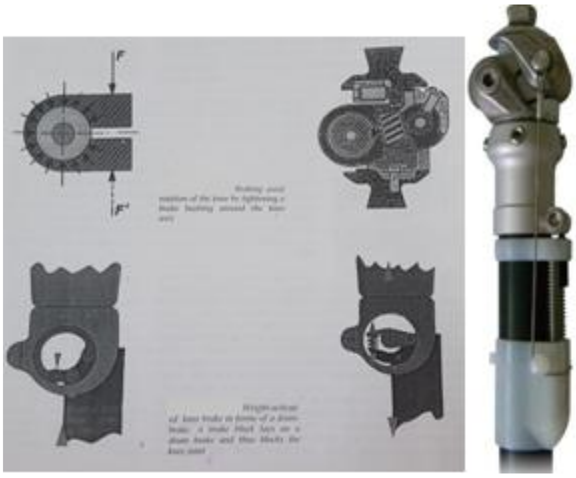

Figure 3: Weight Activated Safety Knee

Both the knee joints considered in this study have different designs by which they obtain stability for the trans-femoral amputee. The weight activated knee joint uses the action of body weight to activate a drum brake to achieve stability whereas the polycentric knee joint employs an instantaneous centre of rotation to mimic the anatomical knee and achieve stability.

The purpose of this study was to analyze and compare the performances of the patients with respect to the temporo-spatial parameters, physiological cost of walking and perceived satisfaction using the Prosthetic Evaluation Questionnaire in unilateral trans-femoral amputees using weight activated friction brake and 4-bar linkage polycentric knee joint on level surface. It was hypothesized that, there may be significant difference in temporo-spatial parameters and energy expenditure between polycentric and weight-activated knee joints.

2. Literature Survey

AliReza Taheri and Mohammad Taghi Karimi (2012) evaluated the gait performance of above-knee amputees while walking with 3R20 and 3R15 knee joints. The authors conducted this study with 7 unilateral trans-femoral amputees. The amputees were asked to walk with a comfortable speed to investigate their gait function with 3 cameras using 3D motion analysis systems.

M. Barbara Silver-Thorn and Christine L. Glaister (2009) evaluated the Functional Stability of Transfemoral Amputee Gait Using the 3R80 and Total Knee 2000 Prosthetic Knee Units. Five healthy, active unilateral transfemoral amputees were recruited to participate in this study. Gait analysis was performed to objectively evaluate the stability characteristics of two types of prosthetic knee designs, the polycentric Total knee 2000 and the single axis 3R80 stance control knee study by completing two gait analysis sessions, one with the total knee 2000 and one with the 3R80.

Jeffrey Sutherland (1997) and others conducted a study comparing the gait of an individual trans-femoral amputee while using two different prosthetic knee joints viz. the Total knee and the DAW 4 bar pneumatic knee.

Problem Definition

There are a variety of prosthetic knee joints available for trans-femoral amputees from different manufacturers around the world. Prosthetic Knee joints are probably the most researched components in the entire domain of Prosthetics and Orthotics. Very few studies have been carried out to understand the differences in performance of patients while using these knee joints and studies on basic knee joints used more commonly in the developing countries are very few. Hence the prescription of prosthetic knees to a particular patient is based more on clinical experience rather than comparison of the performance of the short-listed knee joints. Selecting the most suitable knee joint for the patient in question is a very important task that the Prosthetist has to carry out.

In our study we have made an attempt to compare the performance of trans-femoral amputees with two knee joints which are very commonly used in the developing countries viz the polycentric knee joint and the weight activated knee joint.

3. Methods/Approach

The study included 10 unilateral transfemoral amputees in the age group of 18-55 years with their mean age in the range of 40.7±**8.3** years. (Table 1 & Table 2). The main inclusion criteria were transfemoral amputees with full range of motion at hip, absence of any contracture and deformity and ability to use prosthesis for at least 8 hours per day with ability to walk without aids and in the activity levels of K2 (ability or potential for ambulation with the ability to traverse low-level environmental barriers such as curbs, stairs, or uneven surfaces and is considered a typical community ambulator) and K3 (ability or potential for ambulation with variable cadence, typical of the community ambulator who has the ability to traverse most environmental barriers & may have vocational, therapeutic, or exercise activity that demands prosthetic use beyond simple locomotion). The subjects having contra lateral lower limb joint instability, diabetic and neurological problems were excluded.

After the approval of synopsis by the ethics committee of this Institute and the Maharashtra University of Health Sciences (MUHS), Nashik, Maharashtra, India, subjects fulfilling inclusion criteria were recruited for the study. All the participants were explained about the research protocol and their signed consents were obtained.

Table 1: Data Relating to Patients Recruited in the Study

Subjects	Age (Years)	Height (Cm)	Weight (kg)	Gender	Cause of Amputation	Side of Amputation
1	53	162	65	Male	Trauma	Right
2	53	167	60	Male	Trauma	Right
3	26	159	52	Male	Trauma	Right
4	32	160	50	Male	Trauma	Right
5	38	156	58	Male	Trauma	Left
6	54	170	60	Male	Trauma	Right
7	40	167	56	Male	Trauma	Right
8	35	169	62	Male	Trauma	Right
9	40	167	52	Male	Tumour	Right
10	50	157	53	Male	Trauma	Left

Table 2: Demographic Characteristics of the Amputees

Demographic Data	Mean ± Standard Deviation
Age (years)	40.7±8.3
Height (cm)	168.7±7.2
Body weight (kg)	58.7±4.2
Residual limb length(cm)	22.8±3.32
Time from the amputation (years)	3.2±0.7

All the subjects underwent pre-prosthetic management and gait training in the Department of Physiotherapy after fitting of prosthesis. All subjects were fitted with Quadrilateral sockets and SACH foot whereas 4-bar linkage polycentric knee and weight-activated safety knee joints were used for comparison while keeping all the other components of the prosthesis the same.

4. Protocol

After assessment and evaluation of the patient, fabrication and fitment of the prosthesis was done in the Prosthetic department of the Institute. A period of 15 days was given to each patient to get acclimatized to each joint used. The patients were first fitted with a transfemoral Endoskeletal prosthesis with a polycentric knee joint and SACH foot.
The following data was obtained with respect to the polycentric knee joint:

1) Step Length
2) Stride Length
3) Cadence
4) Step Width
5) Stance Phase Percentage
6) Swing Phase Percentage
7) Stance Phase Time
8) Swing Phase Time
9) Velocity
10) Stride Time.
11) Double Support Percentage
12) Physiological Cost Index (Heart Rate -Resting & Walking)
13) Prosthetic Evaluation Questionnaire (PEQ)

The same readings were then obtained with the Weight activated knee joint after an acclimatization period of 15 days with the joint, all other components remaining the same.

Gait analysis was performed using BTS-Smart-D joint and motion analysis system, Italy (BTS Bioengineering BTS, S. p .A, Italy)

The Temporo-Spatial parameters were evaluated in the gait lab using 3 cameras, 3D gait analysis system (BTS Smart analyzer). Retro-reflective markers were placed on the body as per the Davis protocol.

After the clinical evaluation, the subjects were prepared for the study. The subjects were instructed to use minimal clothing for accurate marker placement. Data was acquired using BTS Smart Capture Software and analysis was done using BTS Smart Analyser software. Davis protocol marker placement procedure was used for all the subjects included in this study.

Figure 4: Plinth with Pillow,Measuring Tape,Markers, Adhesive tape, Pelvimeter,Goniometer

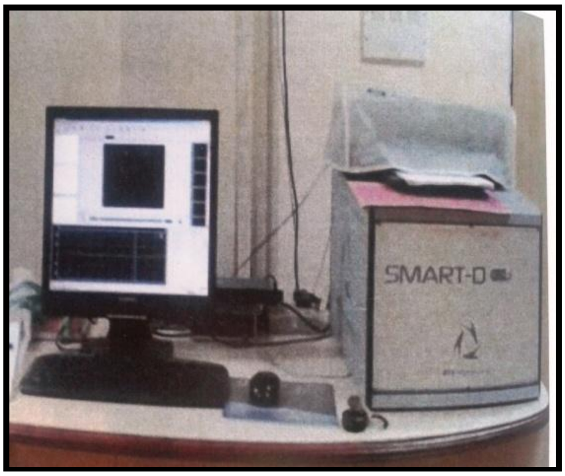

Figure 5: Computer System

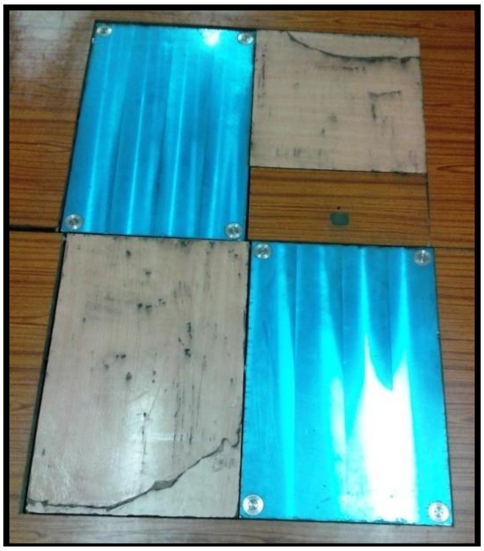

Figure 6: Force Plates

Figure 7: Infrared Cameras

Figure 8: A Patient Walking in the Gait Laboratory of the Institute

Energy consumption was calculated using a 10-meter walk test and was expressed as Physiological Cost Index (PCI) (beats/min) [(Resting Heart Rate) - (Walking Heart Rate) / (Walking Speed (m/min)] [11]. The Physiological Cost Index (PCI) has been shown to correlate well with measurements of oxygen uptake in amputees and is therefore useful in ascertaining the efficiency of walking [15, 18, 19]. Energy cost of walking can be calculated by relating the rate of oxygen consumption to the gait speed. This is considered to be the most appropriate measurement to compare gait efficiency between individuals (Bard and Ralston, 1959; Waters et al., 1976; Fisher and Gullickson, 1978; Waters and Mulroy, 1999.

Prosthesis Evaluation Questionnaire (PEQ) was completed as per amputees' perception about walking with the prosthesis.The PEQ is composed of 9 validated scales that are each comprised of multiple questions, and there are a number of additional individual questions, which should not be combined into scale scores. These individual questions are on satisfaction, pain, transfer, prosthetic care and on self-efficacy. Most questions in the PEQ use a visual analog scale (VAS) format.These questions were scored on a numerical scale from 0 to 100, with a rating of 0 corresponding to the least confidence and comfort with the prosthetic knee joint and 100 being the most confident and comfortable with the said prosthetic knee joint.

Out of 9 validated scales 2 scales and 2 individual satisfaction questions were used in this study as the acclimatization period was two weeks for each, prosthesis. The two scales Utility Scale (6 questions), Ambulation Scale (7 questions), and Individual questions on Satisfaction (2 questions) were listed. These questions were used to provide the patient's perceived data for comparison with the data obtained through other parameters. All the answers were scored based on visual analog scale (VAS) format. All the 10 subjects completed the PEQ programme after end of procedure.

Table 3: Prosthetic Evaluation Questionnaire Questions

Item	Scale	Question	Scoring Scale	Response to the Questionnaire	
				Polycentric Knee Joint	Weight Activated Knee Joint
01	Utility scale	Rate the fit of prosthesis	0-100		
	Utility scale	Weight of prosthesis	0-100		
	Utility scale	Rate the comfort while sitting	0-100		
	Utility scale	Rate the balance while using prosthesis	0-100		
	Utility scale	Rate how much energy it took to use prosthesis	0-100		
	Utility scale	Rate the ease of putting on your prosthesis	0-100		
02	Ambulation scale	Rate your ability to walk when using prosthesis	0-100		
	Ambulation scale	Rate your ability to walk in close spaces when using prosthesis	0-100		
	Ambulation scale	Rate your ability to walk up stairs	0-100		
	Ambulation scale	Rate your ability to walk down stairs	0-100		
	Ambulation scale	Rate your ability to walk up ramp	0-100		

	Ambulation scale	Rate your ability to walk down ramp	0-100		
	Ambulation scale	Rate your ability to walk on side walks	0-100		
03	Satisfaction questions	Rate how happy you have been with your current prosthesis	0-100		
	Satisfaction questions	Rate how satisfied you have been with how you are walking	0-100		

5. Results and Discussion

Though the prosthetic knee joint has come a long way from the basic single axis knee joint of the earlier days to the modern-day microprocessor controlled hydraulic or pneumatic prosthetic knee joint, there is relatively lesser amount of quantitative data available which enumerates the performances of patients with different types of knee joints [2,3,12]. Many prosthetic knees have been developed to achieve stability during the stance phase by avoiding any uncontrolled flexion, such as mechanical knee brakes, hydraulic stance phase control, and polycentric knees.

In our study we have attempted to quantitatively assess the performances of two commonly used prosthetic knee joints in the developing countries. The temporo-spatial parameters were calculated with the help of gait and motion analysis laboratory of the Institute. The Physiological Cost Index was calculated manually on a 10-meter walkway test and using the methodology enumerated above. The Prosthesis Evaluation Questionnaire (PEQ) was used to compare the subjective measures of participants' feelings while using both the prosthetic knee joints. The PEQ is a clinically validated tool used by many researchers to assess the perceptions of patients while using their prosthesis on different types of surfaces, conditions and to evaluate their relative ease of use and comfort with respect to various crucial components of the prosthesis.

Stability of the prosthetic knee joint is extremely important during the stance phase of the gait cycle to prevent the sudden or undesired flexion of the prosthetic knee joint. Stability of the prosthesis is dependent the design and alignment of the prosthetic knee and the hip extension moment generated by the amputee using his hip musculature. It is imperative for the prosthetic knee to provide stability in the stance phase and allow a smooth transition to the swing phase for a smooth gait pattern[11.]

Stance, swing and double support durations, velocity, cadence, step length, stride length have been measured and used in this study as indicators of prosthetic stability. *M. Barbara & Christine* [2] et al and Zuniga[24] et al have found that velocity and step length have been found to be correlated with the degree of lower limb impairment, with slower velocities and shorter steps indicating greater disability [6, 24].

In trans-femoral amputees, decreased velocity and step length may be due to decreased stability on the prosthetic limb. *Murray et al1980, 1983* have found that decreased stability of the prosthesis has also been seen to lead to longer sound side stance phase durations than prosthetic stance phase durations [25, 26.]

The following observations were made during the course of the study:

There were some differences observed between the performances of the patients while using the weight activated knee joint and the polycentric knee joints.

Table 4: Differences in Parametric Measures with Both Knee Joints

Parameters	Polycentric Knee Joint	Weight activated Knee Joint
Stance Phase%	56.49±6.65	61.05±5.39
Swing Phase%	49.76±6.74	45.1±4.71
Double Support%	14.08±3.35	15.95±4.41
Stance Phase Time (Seconds)	0.87±0.19	1.03±0.27
Swing Phase Time (Seconds)	0.82±0.07	0.70±0.12
Stride Time	1.56±0.33	1.89±0.18
Cadence (Steps/Min)	80.74±12.05	68.50±7.08
Step Length (Meters)	0.57±0.12	0.47±0.13
Stride Length (Meters)	1.11±0.16	0.92±0.18
Step Width (Meters)	0.23±0.05	0.27±0.06
Velocity (Meters / Second)	0.66±0.15	0.60±0.16
Swing Velocity (Meters/Second)	1.31±0.23	1.15±0.18
Physiological Cost Index (PCI) Values	0.17±0.05	0.25±0.09

Statistical Analysis of Quantitative Data and Graphical Presentation of **Temporo-spatial parameters.**

The mean and standard deviation of the following parameters -Temporo-Spatial gait parameters, Physiological Cost Index and Prosthetic Evaluation Questionnaire were determined. The statistical difference between the gait performance of the subjects while walking with polycentric and weight activated knees was determined by the use of ***Paired t-test***. Data was analyzed by SPSS software 22. The level of significance was set as $p<0.05$. The calculated t was compared against the table t reading, which is a standard table of t values corresponding to the various degrees of freedom.

The temporo-spatial parameters examined in this study demonstrate that there is a difference in the stability characteristics of the polycentric knee joint and the weight activated knee joints.

Table 5: Stance Phase Percentage values: Mean (M), Standard Deviation (SD), Number of Population (N) and t-value with both the knee joints

Type of Knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	56.49	6.65	10	**2.956**	p<0.05*
Weight-Activated Knee joint	61.05	5.39			

*0.05% Level of Significance

From the above table it can be seen that the t value is **2.956** which is significant at 0.05 level with degree of freedom 9.It indicates that the mean values of (stance phase %) of polycentric and weight-activated joints differs significantly. Further the mean values of stance phase (%) with the weight activated knee joint is 61.05 which is higher than with the polycentric knee joint whose mean value of stance phase (%) is 56.49. It can therefore be said that subjects were spending more time in the stance phase with the weight-activated knee joint than with the polycentric knee joint.

Table 6: Swing Phase Percentage Values: Mean (M), Standard Deviation (SD), Number of Population (N) and t-value with both the knee joints

Type of Knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	49.76	6.74	10	**2.321**	p<0.05*
Weight-Activated Knee joint	45.1	4.71			

*0.05% Level of Significance

From the above table it can be seen that the t value is 2.321 which is significant at 0.05 level with degree of freedom 9.It indicates that the mean values of (swing phase %) of polycentric and weight-activated joints differs significantly. Further the mean values of swing phase (%) with the polycentric knee joint is 49.76 which is higher than that with the weight-activated knee joint whose mean values of swing phase(%) is 45.1. It can therefore be said that with the polycentric knee joint the subjects were having a longer swing phase than with the weight-activated knee joint.

Table 7: Double support Percentage Values: Mean (M), Standard Deviation(SD), Number of Population (N) and t-value with both the knee joints

Type of Knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	14.08	3.53	10	**3.495**	p<0.05*
Weight-Activated Knee joint	15.95	4.41			

*0.05 Level of Significance

From the above table it can be seen that the **t value is 3.495 which is significant** at 0.05 levels with degree of freedom 9.It indicates that the mean values of (double support phase %) of polycentric and weight-activated groups differs significantly. Further the mean values of double support phase (%) with the weight-activated knee joint is 15.95 which is higher than that of polycentric knee joint whose mean values of double support phase (%) is 14.08.It can therefore be said that the subjects were spending more time in the double support phase with the weight-activated knee joint than with the polycentric knee joint.

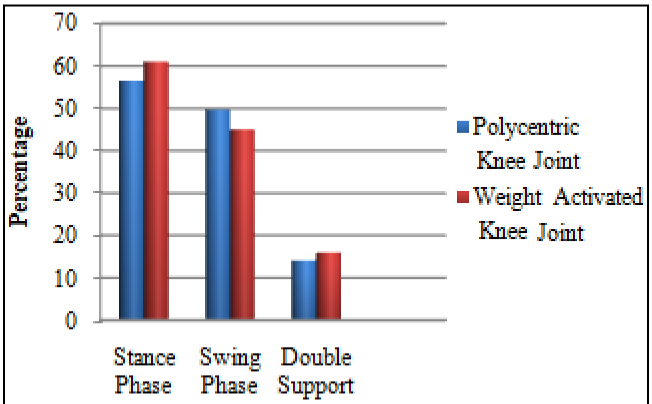

Figure 9: Comparison of Mean Values of Temporo-Spatial Parameters of Stance Phase, Swing Phase and Double Support Percentage of Prosthetic limbs with both knee joints

From the figures and the tables it can be seen that the mean Stance phase percentage is for a longer duration with the weight-activated knee joint as compared with polycentric knee joint at a comfortable walking speed in the 10 meter walkway test (p<0.05).

It was seen that the mean stance phase percentage (61.05±5.39) was slightly more with the weight-activated knee joint as compared to (56.49% ±6.65) with the polycentric knee joint at a comfortable walking speed in 10 meter walkway test. This can be seen in the tables 5 and figure 9 above.

The swing phase percentage with the weight activated knee joint (45.1±4.71)was slightly lesser as compared with the value for the polycentric knee (49.76±6.74)as can be seen in the tables 6 and the figure 9.

The period of Double Support was more with the weight activated knee joint (15.95 ±4.41) as compared with the polycentric knee joint (14.08 ±3.53).

Table 8: Stance Phase Time Values: Mean (M), Standard Deviation (SD), Number of Population (N) and t-value with both the knee joints

Types of knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	0.87	0.197	10	**3.876**	p<0.05*
Weight-Activated Knee joint	1.031	0.271			

*0.05 Level of Significance

From the above tableit can be seen that the **t value is 3.876** which issignificant at 0.05 level with degree of freedom 9.It indicates that the mean values of (stance phase timing) of polycentric and weight-activated joints differs significantly. Further the mean values of stance phase timing (s) with the weight-activated knee joint is 1.031 which is significantly higher than that with the polycentric knee joint whose mean values of stance phase (s) is 0.87(Table No. 8).It can therefore be said that the patients were spending more time in the stance phase with the weight-activated knee joint than with the polycentric knee joint.

Table 9: Swing Phase Time Values: Mean (M), Standard Deviation (SD), Number of Population (N) and t-value with both the knee joints

Types of knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	0.825	0.079	10	**3.268**	p<0.05*
Weight-Activated Knee joint	0.707	0.122			

*0.05 Level of Significance

From the table above it can be seen that the **t value is 3.268** which is significant at 0.05 levels with 9 degree of freedom. It indicates that the mean values of (swing phase timing) of polycentric and weight-activated joints differs significantly. Further the mean values of swing phase timing (s) with the polycentric knee joint is 0.825 which is higher than that with the weight-activated knee joint whose mean values of swing phase (s) is 0.707.It may therefore be said that the subjects were able to spend more time in the swing phase with the polycentric knee joint as compared with the weight-activated knee joint.

Table 10: Stride Time Values: Mean (M), Standard Deviation (SD), Number of Population (N) and t-value with both the knee joints

Types of knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	1.55	0.338	10	**2.905**	p<0.05*
Weight-Activated Knee joint	1.89	0.188			

*0.05 Level of Significance

From the above table **it** can be seen that **the t value is 2.905** which issignificant at 0.05 levels with 9 degrees of freedom.It indicates that the mean values of (stride time) of polycentric and weight-activated joints differ significantly. Further the mean values of stride time with the weight-activated knee joint is 1.89 which is significantly higher than that with the polycentric knee joint whose mean values of stride time is 1.55 (Table No. 10).It may therefore be said that the subjects took more time to finish the stride with the weight-activated knee joint as compared to the polycentric knee joint.

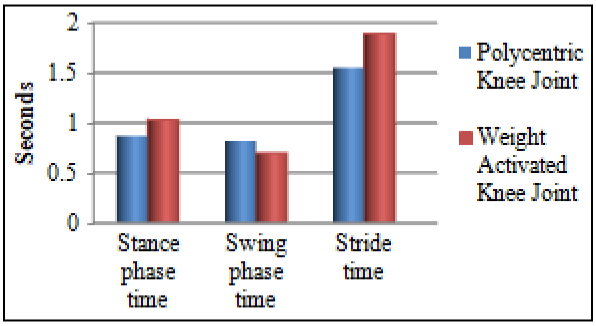

Figure 10: Comparison of Mean Values of Stance Phase Time, Swing Phase Time and Stride Time duration with both the knee joints

It was seen that the mean stance phase time in seconds (1.03±0.27) was slightly more with the weight-activated knee joint as compared to (0.87±0.19) with the polycentric knee joint at a comfortable walking speed in 10 meter walkway test. This can be seen in the table 8 and figure 10 above.

The swing phase time in seconds with the weight activated knee joint (0.707±0.122) was slightly lesser as compared with the value for the polycentric knee (0.825±0.079)as can be seen in the table 9 and the figure 10 above..

The stride time value was more with the weight activated knee joint (1.89±0.188) as compared with the polycentric knee joint (1.55±0.338).

Karimi[2]*et al* and Farahmand[9]*et al*. reported similar findings when they studied the performance of trans-femoral amputees with the 3R20 (Polycentric knee joint) and 3R15 (Weight activated knee joint).

It can be seen from the above data that the patients are spending more time in the stance phase with the weight activated knee joint, than with the polycentric knee joint. This may mean that the weight activated knee joint provides more stability as compared with the polycentric knee and for a longer period of the stance phase. It has been found that although weight-activated knee joints eliminate gait deviations associated with the stiff-legged gait of a manual locking knee, they result in an unnatural and delayed initiation of swing phase, since weight must be fully removed from the prosthesis for knee flexion to occur [11, 12]. The prosthetic knees which provide increased stance phase stability may require an increased hip flexion moment to initiate knee flexion for transitioning to the swing phase. This may result in trade-offs between stance phase stability and swing phase initiation efforts. This may result in asymmetrical gait which has been seen and assessed quantitatively in transfemoral amputees by a number of authors [6, 20, 21]. Asymmetry in amputee gait usually results in a prolonged stance phase on the sound side revealing fear of the amputee to load the prosthetic side. So to summarize the findings related to the stance phase, we can interpret that this essentially means that there is a delay in the initiation of swing phase while walking with the weight activated knee joint. This will result in an unnatural and energy inefficient gait. It was also observed that with the polycentric knee the patients were spending less time in the stance phase (56.49%) as compared with the weight activated knee (61.05). In case of the polycentric knee joint flexion of the knee joint can only be initiated if the four-bar linkage is displaced by an anterior displacement of the knee joint. During knee flexion, the ICR of the polycentric knee joint leaves the stable area and thus releases the knee. This means that during weight acceptance and mid-stance, when the knee is extended, there is a high safety margin. Once knee flexion is initiated at the end of stance phase the knee joint becomes more dynamic. This provides enhanced stability during heel strike and decreased stability at toe-off thus allowing for easier initiation of swing phase[11]. Our findings reveal that the swing phase percentage and timings with the polycentric knee joint are more as compared with the weight activated knee joint, indicating an early initiation of the swing phase without compromising on the stance phase stability.

Table 11: Cadence (Steps/Min) Values: Mean (M), Standard Deviation (SD), Number of Population (N) and t-value with both the knee joints

Types of knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	80.74	12.05	10	**3.047**	p<0.05*
Weight-Activated Knee joint	68.50	7.18			

*0.05 Level of Significance

From the above table it can be seen that **the t value is 3.047** which is significant at 0.05 levels with 9 degrees of freedom .It indicates that the mean values of (cadence) of polycentric and weight-activated joints differ significantly. Further the mean values of cadence with the polycentric knee joint is 80.74 which is higher than that of weight-activated knee joint whose mean values of cadence is 68.50.It can therefore be said that subjects were able to take more steps per minute with the polycentric knee as compared to the weight-activated knee joint.

Table 12: Stance Velocity (m/s) Values: Mean (M), Standard Deviation (SD), Number of Population (N)and t-value with both the knee joints

Type of knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	0.667	0.153	10	**2.437**	p<0.05*
Weight-Activated Knee joint	0.600	0.164			

*0.05 Level of Significance

From the above table it can be seen that **the t value is 2.437** which is significant at 0.05 levels with 9 degree of freedom. It indicates that the mean values of (stance velocity) of polycentric and weight-activated knee joints differ significantly. Further the mean values of stance velocity with the polycentric joint is 0.667 which is higher than that with the weight-activated joint whose mean value of stance velocity is 0.600.It can therefore be said that the polycentric knee joint was found to be superior to weight-activated knee joint in terms of stance velocity.

Table 13: Swing Velocity (m/s) Values: Mean (M), Standard Deviation (SD), Number of Population (N) and t-value with both the knee joints

Type of knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	1.318	0.238	10	**2.497**	p<0.05*
Weight-Activated Knee joint	1.153	0.181			

*0.05 Level of Significance

From the above table it can be seen that the **t value is 2.497** which is significant at 0.05 levels with 9 degrees of freedom. It indicates that the mean values of (swing velocity) with the polycentric knee joint and the weight-activated knee joints differ significantly. Further the mean values of swing velocity of polycentric group is 1.318 which is significantly higher than that of weight-activated group whose mean values of stance velocity is 1.153.It can therefore be said that the polycentric knee joint was found to be superior to weight-activated knee joint in terms of swing velocity.

The mean values for cadence were (80.74±12.05) with the polycentric knee joint as compared with (68.50±7.08) with the weight activated knee joint. A slower cadence is usually associated with a lower velocity and a faster cadence is usually associated with a higher velocity. Cadence is related to both velocity and step length. Velocity and step length have been found to be co-related with the degree of lower limb impairment with slower velocities and shorter steps indicating greater disability [2,24]. A prosthetic knee with increased stability should allow an amputee to walk faster and with a slower cadence due to longer step and stride lengths in comparison to a less stable knee. The tables 11, 12 and 13show that the patients were able to walk with a higher stance and swing velocity while ambulating with the polycentric knee joint (0.667±0.153) and (1.318± 0.238) as compared to (0.600 ± 0.164) and (1.153 ± 0.181) respectively with the weight activated knee joint.

Table 14: Step Length (m) Values: Mean (M), Standard Deviation (SD),Number of Population (N) and t-value with both the knee joints

Type of knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	0.579	0.126	10	**2.57**	p<0.05*
Weight-Activated Knee joint	0.472	0.133			

*0.05 Level of Significance

From the above table it can be seen that **the t value is 2.57** which is significant at 0.05 levels with 9 degrees of freedom. It indicates that the mean values of (step length) of polycentric and weight-activated joints differ significantly. Further the mean values of step length with the polycentric knee joint is 0.579 which is higher than that with the weight-activated joint whose mean values of step length is 0.472.It can therefore be said that subjects were able to take longer steps with the polycentric knee joint than with the weight-activated knee joint.

Table 15: Stride Length (m) Values: Mean (M), Standard Deviation (SD), Number of Population (N) and t-value with both the knee joints

Type of knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	1.11	0.163	10	**4.84**	p<0.05*
Weight-Activated Knee joint	0.927	0.181			

*0.05 Level of Significance

From the above table it can be seen that **the t value is 4.84** which is significant at 0.05 levels with 9 degree of freedom. It indicates that the mean values of (stride length) of polycentric and weight-activated joints differ significantly. Further the mean values of stride length with the polycentric knee joint is 1.11 which is significantly higher than that of the weight-activated knee joint whose mean values of stride length is 0.927. It can therefore be said that subjects were able to take longer steps with the polycentric knee joint than with the weight-activated knee joint.

Table 16: Step Width (m) Values: Mean (M), Standard Deviation (SD), Number of Population (N) and t-value with both the knee joints

Type of knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	0.237	0.05	10	**2.872**	p<0.05*
Weight-Activated Knee joint	0.275	0.06			

*0.05 Level of Significance

From the above table it can be seen that **the t value is 2.872** which is significant at 0.05 levels with 9 degrees of freedom. It indicates that the mean values of (step width) of polycentric and weight-activated knee joints differ significantly. Further the mean values of step width with the weight-activated joint is 0.275 which is significantly higher than that with the polycentric knee joint whose mean values of step width is 0. 237. It can therefore be said that the step width was closer to the normal values with the polycentric knee joint than with the weight activated knee joint. This effectively means that the patients were able to have a more stable gait with the polycentric knee joint than that with the weight activated knee joint as is evident from the narrow width of walking base with the polycentric knee joint.

The means values of step length, stride length and step width with the polycentric knee joint are **(0.579 ± 0.126),(1.11 ± 0.163) and (0.237 ± 0.05)** as compared to **(0.472±0.133), (0.927 ± 0.181) and (0.275 ± 0.06)** with the weight activated knee joint as can be seen from the tables 14, 15 and 16 above.These findings indicate that the polycentric knee joint is more stable than the weight activated knee joint, allowing the subjects to take longer steps and strides along-with a reduced step width, thus allowing them to walk with a higher velocity and cadence. These findings are also consistent with the findings of *M. Barbara Silver-Thorn and Christine L.Glaister* who studied the functional differences with the 3R80 and the Total Knee 2000 and *AliReza Taheri* *and Mohammad Taghi Karimi* who obtained similar results with the 3R20 (Polycentric knee joint) and 3R15 (Weight activated knee joint) knee joints from Otto Bock[2, 3]

Table 17: PCI Values: Mean (M), Standard Deviation (SD), Number of Population (N) and t-value with both the knee joints

Type of knee joint	Mean(M)	SD	N	t-value	Remarks
Polycentric Knee Joint	0.177	0.054	10	**3.219**	p<0.05*
Weight-Activated Knee joint	0.257	0.095			

*0.05 Level of Significance

From the above table it can be seen that **the t value is 3.219**which is significant at 0.05 levels with 9 degrees of freedom. It indicates that the mean values of (PCI) with the polycentric knee joint and weight-activated knee joint differ significantly. Further the mean values of PCI with the weight-activated knee joint is 0.257 which is significantly higher than that with the polycentric knee joint whose mean values of PCI is 0.177.It can therefore be said that the subjects are able to have an energy efficient gait with the polycentric knee joint than with the weight activated knee joint.

Table 18: Prosthetic Evaluation Questionnaire with both the knee joints
Values for Both Scales and Questions: Mean (M), Standard Deviation (SD) and t-value with both the knee joints

PEQ Scale and Question	Polycentric Knee Joint		Weight-Activated Knee Joint		N	t-value
	Mean	SD	Mean	S.D.		
Utility Scale	78.26	5.007	77.70	2.602	10	**0.56**
Ambulatory Scale	77.67	4.006	77.44	3.37	10	**0.92**
Satisfactory Question	77.44	3.37	81.50	6.14	10	**3.56**

*0.05 Level of Significance

In response to the Prosthetic Evaluation Questionnaire (PEQ) on the Utility Scale it can be seen from the Table 18that **the t value is 0.56**which is **insignificant** at 0.05 levels with 9 degrees of freedom. It means that the mean values of scores on the **Utility scale** with the polycentric knee joint **(78.26±5.007)** and weight-activated knee joint **(77.70±2.602)**do not differ significantly. So we can conclude that in relation to this scale there is no significant difference in the performance of the patients with both the knee joints.

In response to the Prosthetic Evaluation Questionnaire (PEQ) on the Ambulatory Scale it can be seen from the Table 18that **the t value is 0.92**which is **insignificant** at 0.05 levels with 9 degrees of freedom. It means that the mean values of scores on the **Ambulatory Scale** with the polycentric knee joint **(77.67±4.006)** and weight-activated knee joint **(77.44±3.37)** do not differ significantly. So we can conclude that in relation to this scale there is no significant difference in the performance of the patients with both the knee joints.

In response to the Prosthetic Evaluation Questionnaire (PEQ) on the Satisfactory Question it can be seen from the Table 18that **the t value is 356**which is **significant** at 0.05 levels with 9 degrees of freedom. It means that the mean values of scores on the **Ambulatory Scale** with the polycentric knee joint **(77.44±3.37)** and weight-activated knee joint **(81.50±6.14)** differ significantly. So we can conclude that in relation to this scale there is a significant difference in the performance of the patients with both the knee joints and the patient feels more comfortable with the weight activated knee joint.

It was observed that the patient felt more comfortable while walking up and down stairs using the polycentric knee joint, they also felt that the polycentric knee joint resulted in a more energy efficient gait (this is also co-related with our statistical analysis results) and that they could cover more distances in lesser time with this knee joint. While walking on level ground and ramps they felt comfortable with the weight activated knee joint. The added stability provided by the weight activated knee joint may have to do with the comfort of the patient especially on the ramp.

6. Conclusion

Prosthetic *knee* stability is an important factor in determining which prosthetic *knee* component is most appropriate for a specific individual. An amputee who has particular difficulty establishing stability at heel contact may benefit from a weight activated prosthetic *knee* design which appears to be more stable in early stance phase than the polycentric. However, an amputee who has no trouble establishing stability in early stance phase, but who encounters stability problems in mid and late stance, when their full body weight is supported on the prosthetic limb, may benefit from a polycentric prosthetic *knee*. For this study polycentric and weight-activated knee joints were selected because they are most commonly used amongst the developing countries and there is a lack of enough data/research as regards the gait performance of the amputee with these two knee joints.

This study compared the effectiveness of unilateral trans-femoral amputees with polycentric knee joint and weight-activated knee joint, in the areas of temporo-spatial parameters. Prosthetic evaluation questionnaire was used to measure self-assessment outcomes.

The results of study show similar findings as observed by previous researchers AliReza Tahiri[3] and Barbara Silver Thorn[2]and other researchers. The results show that the weight-activated knee joint seems to provide more stability during stance phase, whereas polycentric knee joint provides better swing phase clearance and an energy efficient gait. However with the weight activated knee joint the patients had a longer stance phase, implying that there was a delay in the transition of the patient from the stance to the swing phase resulting in an energy inefficient gait, which was also validated by the statistical analysis tests.

The patients showed a leaning towards the weight activated knee joint while walking up and down ramps because of the additional stability it provided. The results of this research study showed that the performance of the trans-femoral amputees was found to be better with the polycentric knee joint by allowing them to spend less time in the stance phase and therefore it was able to provide a better and smoother transition from the stance phase to the swing phase, which was also validated by the results of the statistical analysis tests.

The polycentric knee also provided better cadence and velocity values as is evident from the results of the statistical analysis tests conducted for these parameters. The study showed an increase in the walking speed with the polycentric knee joint than that with the weight activated knee joint. It also provided a more energy efficient gait as was seen with the results of the statistical tests conducted for the Physiological Cost Index.

The overall conclusion that can be drawn from this study, is that the weight activated knee joint provides a high degree of stability at the cost of mobility, which is necessaryfor amputees who have short stumps, weak hip musculature and are geriatric patients, whereas the polycentric knee joint provides a balance between stability and mobility thereby providing a smooth transition from the stance to the swing phase. It also provides an energy efficient gait and it also provides a higher cadence and velocity, which is necessary for younger and more active amputees with strong hip musculature [1, 11.]

7. Future Scope

This paper is not without its limitations. First of all the number of patients included in this study is only 10, we plan to further include at least 30 patients in the next phase of this study. The hip extension angles and hip flexion angles that the patients could achieve with these prosthetic knee joints were not compared, we would like to compare this and other relevant parameters like pelvic motion etc. in the next stage of the study.

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