Original Article

Comparative Study between Jaipur Foot and Polyurethane Foot

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Abstract

Objective: To draw a comparison between Jaipur foot and polyurethane (PU) foot in terms of breakage and functional capabilities.

Study Design: Cross sectional, observational study.

Setting and Participants: Outpatient door of Department of Physical Medicine and Rehabilitation, SMS Medical College and Hospital, Jaipur, Rajasthan. A total of 136 individuals were evaluated at the start of the study, and a total number of 88 could be followed up to 6 months.

Results: 13 patients reported dissatisfaction for reasons other than that of prosthetic foot, 11 (23.40%) out of 47 using Jaipur foot had loose fitting socket and 2(4.87%) of PU foot were dissatisfied because of cosmesis. Breakage was responsible for dissatisfaction in 6.38% of Jaipur foot users as against 18 (43.90%) in PU foot users. Forty-six (97.87%) of Jaipur foot users had an locomotor capability index (LCI) score of 21 while only 1 had less than 1 in basic activity as against 100% of PU foot users having scores 21. On advanced activity, 38 (80.85%) of Jaipur foot and 31 (75.60%) of PU foot users had scores less than 21. On Houghton scale, 29 (61.70%) of Jaipur foot and 27 (65.85%) of PU foot had scores of 11-12.

Conclusion: Jaipur foot has been more cosmetically and functionally acceptable but PU foot has also shown fare cosmetic acceptance and shock absorption quality, with comparable mobility and functional use but because of greater and early breakage, its improvisation and redesigning is required for greater acceptance.

Key words: **Jaipur foot, polyurethane foot (PU foot), locomotor capability index (LCI), Houghton scale, timed up and go test (TUG), timed walk test (TWT).**

Introduction:

Amputation is an acquired condition that results in the loss of a limb, secondary to injury or diseases. Loss of a limb causes permanent disability that can affect a patient's self image, and activities of daily living. To rehabilitate such amputees, artificial limbs are necessary. The basic purpose of an artificial limb is to enable the amputee to perform essential daily activities in an easy, natural and more comfortable manner[1].

History of an artificial limb is not new in India. The earliest mention of an artificial limb was in Rig Veda (1500 to 800 BC). The artificial limbs in earlier times were simpler, but not suitable for amputees living in rural areas of India. As time passed, various field trials and testing were done with different types of prosthesis, and subsequently; the modifications were also done according to the needs.

For a prosthesis to be appropriate for use in Indian conditions, it should be low cost, made from locally available raw material, durable, simple to repair, light weight and culturally acceptable[2]. Thus came into existence the Jaipur foot, in the making of which SACH foot served an important purpose as it was modified in

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1968. According to Kabra and Narayanan[3], Jaipur foot provides movement in all three planes. In sagittal plane, it is capable of 22 degrees to 37 degrees dorsal deflection (dorsiflexion plus toe extension) from horizontal. The heel of Jaipur foot is compressible by 1 to 3 cm at a peak load of 70kg. The compressibility is uniform and load dependent. When heel is compressed, simultaneous plantar flexion of the forefoot occurs. The Jaipur foot is capable of 26 to 29 degrees of pronation and 17 to 22 degrees of supination at a peak load of 40kg. Internal rotation of 10 to 12 degrees and external rotation of 4 to 8 degrees was obtained at peak load of 40 kg in this study[3].

Polyurethane prosthetic foot was developed in 1987 as a modification of the Jaipur foot at the application development section, chemical engineering complex, Vikram Sarabhai Space Centre, Tiruvananthpuram and also in Calicut. Trials and field testing on PU foot were time consuming and slow. Feedback information did not come at regular from amputees in view of their social and economic conditions. A fatigue testing machine was designed and fabricated at VSSC, capable of loading up to 95 kg and operating with flex cycles at 40 cycles/ minute and adjustable stroke lengths to simulate walking conditions and loads. It is able to simulate the dorsiflexion, plantar flexion and heel compression[4].

To the best of our knowledge, there are no published data comparing Jaipur foot with PU foot. This study was done to access the clinical use and durability of PU foot and Jaipur foot using parameters of mobility and patient's satisfaction, and draw a comparison between both on standard scales.

Materials and Methods:

Study design: Cross sectional, observational study.

Setting: Out patient door of Department of Physical medicine and rehabilitation, Sawai Mansingh Medical College and Hospital, Jaipur, from 1st October 2009 to 1st October 2010.

Evaluation of study subjects: All the amputees, old and new users were subjected to detailed general physical examination and questions regarding the demographic profile. Specific questions were asked regarding average walking distance in a day, working hours in a day while wearing shoe, total duration of use, ability for cross legged sitting and squatting. Each amputee was subjected to timed up and go test (TUG) and timed walk test (TWT).

Outcome measures: TUG test measures the mobility by assessing many of the basic components of mobility. It was originally developed for use with geriatric population. It is quick, reliable (inter and intra rater) and valid with a variety of conditions. The subject is observed rising from an armchair, walking 3 m, and returning to the chair on a standard carpet. The test is reported in seconds, and the time to carry out the test is 1 to 2 minutes[5].

Timed walk tests (TWTs) measure function in terms of mobility and have been used with a variety of clinical conditions[5], including lower limb amputees.[6] Timing of walking can be carried out in several different ways, either testing speed over a short distance (e.g. 10 meters[7] that can include an 180° turn[8]) or cardiovascular fitness/endurance in which the subject is asked to walk as far as he/she can in a given time (i.e. 2,[8] 6,[9] or 10 minutes[5]).

Locomotor capability index (LCI) is amputee specific and measures lower limb amputee locomotor capability during and after rehabilitation[10]. LCI consists of 14 items divided in 2 sub scales, basic and advanced. Higher scores on LCI, greater the capability of the amputee. It is a self - report tool, takes five minutes to complete and scores are simple to calculate. It is widely used[10]. It had good validity and reliability[10,11].

Houghton score measures function of lower limb amputee fitted with prosthesis in terms of wear and use of prosthesis[12]. It is appropriately responsive to change in prosthetic use in individuals with lower limb amputation after rehabilitation. It consists of four items, length of time wearing the prosthesis, manner in which it is used, whether an assistive device is used outdoors, and the individuals' perception of stability while walking over rough terrain. The responses are summed easily to give a score from 1 to 12[13]. It has content and face validity, poor to good construct validity dependent on the comparison measure, some responsiveness to change (item 4 not on its own), some floor and ceiling effects, good test-retest reliability, and adequate internal consistency. It is recommended for routine clinical use[13].

Statistical Analysis:

A total of 136 amputees were employed in our study at the start of the study, but we were able to follow 88 individuals up to 6 months. Simple mathematical tools were used along with students' T test for final results.

Results:

Demographics: A total of 68 below knee lower limb amputees, in each category were examined out of which 47 using Jaipur foot and 41 using PU foot could be followed up to 6 months. Most (90%) were male users, with nearly 113 (83%) being in the age group of 18-60 years, 13 (10%) above 60 years and rest 7% below 18 years. Nearly 50% individuals were manual labourers and the rest 50% constituted of private jobs, students and those doing no work at all. Nearly 74 (55%) individuals had an amputation because of vehicular accidents and rest due to other causes including diabetic foot, gangrene, malignancy and congenital anomalies.

Satisfaction levels: This is shown in Table 1. Nearly 70% users of Jaipur foot were satisfied as against only 51% of PU foot users.

Duration of use related to breakage site: It is shown in Table 2 that 41 (87.23%) patients using Jaipur foot had no breakage at the end of 6 months as against 22 (53.65%) in PU foot category. None of the Jaipur foot broke in the first two months as against majority of the PU foot breaking in first 6 months of use.

Comparison of Jaipur foot and PU foot in terms of cross legged sitting and squatting: There was no much difference in terms of squatting and cross legged sitting in both the feet. It is depicted in Table 3.

Comparison on LCI: There was insignificant difference in basic and advanced activity of both the feet (p-value 0.866). It is shown in Tables 4 and 5.

Comparison on Houghton scale: It is shown in Table 6. There was no significant difference in functions of

Table 1: *Satisfaction with Jaipur Foot and Polyurethane Foot*

Sl No	Levels of satisfaction	Cause of dissatisfaction	No of patients using Jaipur foot (%)	No of patients using PU foot (%)
1.	Dissatisfied	Appearance	-	2 (4.87)
		Weight	-	-
		Gait	-	-
		Loose fitting	11 (23.40)	-
		Breakage	3 (6.38)	18 (43.90)
2.	Satisfied		33 (70.21)	21 (51.21)
	Total		47 (100)	41 (100)

Table 2: *Total Duration of Use and Breakage Site of Jaipur foot vs PU Foot*

Sl No	Duration (Months)	Breakage site										No of patients (%)	
		Sole		Ankle		Toe		Combination		No breakage			
		JF	PU	JF	PU	JF	PU	JF	PU	JF	PU	JF	PU
1.	0-1	-	3	-	3	-	-	-	-	-	-	-	6 (14.63)
2.	1-2	-	5	-	3	-	-	-	-	-	-	-	8 (19.51)
3.	2-3	-	3	-	-	-	-	-	-	-	-	-	3 (7.31)
4.	3-4	1	2	-	-	1	-	1	-	-	-	3 (6.38)	2 (4.87)
5.	4-5	-	-	1	-	1	-	-	-	-	-	2 (4.25)	-
6.	5-6	-	-	1	-	-	-	-	-	41	22	42 (89.36)	22 (53.65)
	Total											47 (100)	41 (100)

below knee amputees fitted with prosthesis (p-value-0.785) as measured on Houghton scale.

TUG and TWT: Nearly 42(89.36%) users of Jaipur foot were able to complete TUG test in 6-10 seconds as against 30 (73.17%) of PU foot users. There was no significant difference in mobility of both feet (p-value=0.175) in TUG test and TWT (p-value=0.499).

Table 3: *Jaipur Foot versus PU Foot in Terms of Cross Legged Sitting and Squatting*

Sl No	Squatting/cross legged sitting	No of patients using Jaipur foot (%)	No of patients using PU foot (%)
1.	Squatting absent/cross legged sitting absent	15 (31.91)	15 ()36.58
2.	Squatting present/cross legged sitting absent	20 (42.55)	21 (51.21)
3.	Squatting present/cross legged sitting present	7 (14.89)	2 (4.87)
4.	Squatting absent/cross legged sitting present	5 (10.63)	3 (7.31)
	Total	47 (100)	41 (100)

Table 4: *Locomotor Capability Index of Jaipur Foot versus PU Foot in Basic Activity*

Sl No	Age (years)	Basic activity						No of patients (%)	
		0		<21		21			
		JF	PU	JF	PU	JF	PU	JF	PU
1.	0-20	-	-	-	-	4	1	4 (5.81)	1 (2.43)
2.	21-40	-	-	-	-	21	24	21 (44.68)	24 (58.53)
3.	41-60	-	-	1	-	19	12	20 (42.55)	12 (29.26)
4.	61-80	-	-	-	-	2	4	2 (4.25)	4 (9.75)
	Total							47 (100)	41 (100)

Table 5: *Locomotor Capability Index of Jaipur Foot versus PU Foot in Advanced Activity*

Sl No	Age (years)	Basic activity						No of patients (%)	
		0		<21		21			
		JF	PU	JF	PU	JF	PU	JF	PU
1.	0-20	-	-	-	-	4	1	4 (8.81)	1 (2.43)
2.	21-40	-	-	1	2	19	22	20 (44.68)	24 (58.53)
3.	41-60	2	1	4	5	15	6	21 (41.55)	12 (29.26)
4.	61-80	-	-	2	2	-	2	2 (4.25)	4 (9.75)
	Total							47 (100)	41 (100)

Table 6: *Houghton Score for Jaipur Foot versus PU Foot*

Sl No	Age (years)	Houghton score						No of patients (%)	
		7-9		9-10		11-12			
		JF	PU	JF	PU	JF	PU	JF	PU
1.	0-20	-	-	1	-	3	1	4 (8.51)	1 (2.43)
2.	21-40	-	-	3	4	18	19	21 (44.68)	23 (56.09)
3.	41-60	6	2	6	5	8	6	20 (42.55)	13 (31.70)
4.	61-80	1	1	1	2	-	1	2 (4.25)	4 (9.25)
	Total							47 (100)	41 (100)

Discussion:

Jaipur foot has been used for amputees as artificial prosthesis since early 1960. Late professor Emeritus, Dr PK Sethi gave the basic design. The design was not patented as his vision was that technology should be spread at all levels while using local technology to suit local needs. The biggest advantage has been its wide spread use but a great disadvantage was that, many factories and person cropped up for manufacturing due to which the quality was compromised and large number of patients were coming with frequent failure of prosthetic feet.

Though the shock absorption capacity of SACH foot was found to be better, the Jaipur foot allowed a more natural gait and was closer in performance to the normal foot[14].

As observed in our study, the most common cause of lower limb amputation is road traffic accidents followed by vascular diseases, which is in contradiction to the studies done in western countries where the vascular pathologies were reported to be the most common cause of amputation. Majority of amputees in our study were working reflecting the motivation and acceptance of prosthesis.

The average walking distance, floor activity and working hours were comparable in both the groups. On comparison of satisfaction regarding the use of prosthesis, 20 (48.7%) individuals were dissatisfied with PU foot as against 3 (6.38%) by Jaipur foot. The chief reason as per our observation was an early breakage of prosthetic foot, most commonly in the first three months of fitting. There were 2 patients, who were not satisfied with the appearance of PU foot that seemed to be lighter in colour as compared to Indian skin tone.

When we compared the Jaipur foot and PU foot on TUG test and TWT, the difference between the two was not significant there by suggesting that mobility is comparable in both the groups. On comparison of Jaipur foot and PU foot on LCI, there was an insignificant difference in basic and advanced activity of both types of prosthetic foot. Comparison on Houghton scale revealed no significant difference between both.

Amongst the users of Jaipur foot, breakage at the end of 6 months was minimal. Three (6.38%) had breakage at the ankle and 3 (6.38%) had it from sole and toe, forty one (87.25%) had no breakage and were still using prosthesis at the end of 6 months. Breakage at ankle was frequent in Jaipur foot because it allows movement at this joint in all planes. This is in agreement with the findings of Narayanan SG who revealed that that the prosthesis enjoys considerable mobility in three planes, confirming its known versatility, the prosthesis is robust; and, the testing machines deliver reproducible results and are suitable for in-house testing of ankle-foot prostheses[15].

PU foot had significant number of breakages occurring within the first three months, 17 (41.46%) and more than half of the individuals (53.6%) reported foot breakage by the end of 6 months. On statistical comparison, durability of Jaipur foot was found to be significant (p-value=<0.05). Heim[16] commented that durability needs of the foot should be at least 3 years. It appeared that 3 years is the minimal life-expectancy target for prosthetic feet in low-income countries. Thus, Jaipur foot seems to match breakage criteria as against PU foot. Jensen *et al*[17] state that the results with the conventional SACH foot constructions with polyurethane as filling and covering materials were so poor after 18 months that their use cannot be recommended in tropical areas of the developing world.

BMVSS started a project on PU foot with support from ISRO and various rubber industries, the PU foot could be manufactured on large scale while keeping a strict industrial quality control as against Jaipur foot which is hand crafted. The PU foot for this study was procured from BMVSS.

The Jaipur foot is made from natural rubber compound and wooden blocks. The main function of proximal wooden block/ankle block is to provide anchorage for the carriage bolt and this bolt moves with wooden blocks in various movements. The sponge rubber universal joint is the most important design feature of Jaipur foot. Several layers of rubber are glued together to form a large block. The entire block is then enclosed in closed shell of a hard rubber. As the sponge rubber block is made of separate layer, it causes dissipation of stress along the line of cleavage, thereby protecting the sponge rubber block from breaking up, and lastly the two mm thick hard rubber encloses the structural component of foot pieces. The exterior is covered with rubber cushion compound and sole is made of rubber tread compound. The cosmetic features are very satisfactory and acceptable to these patients and during bare foot walking it gives a realistic appearance[18]. As against this, Jensen and Raab[19] report the failures of Jaipur foot were due to skin fracture and gliding between sponge rubber layers of the heel block.

The polyurethane foot on the other side is made of microcellular polyurethane foam, which is widely used as shoe soling, structural foam, car bumper and other exterior parts of vehicle. Polyurethane used for soling material is tough, flexible, hard wearing, durable elastomeric material over the wide density material. With polyurethane, it is possible to produce single density out soles in any range of thickness and shape over the density, range predominantly between 350 and 650kg/m^3[3,20].

The current polyurethane design has small hard plastic ankle block which extends a little up to mid foot section to provide keel effect and rest of the foot is made of injected and molded polyurethane foot. The possible mechanism, where the movements take place will be gliding of polyurethane shell over the hard plastic rubber, due to continuous shear of two different materials, polyurethane microcellular foam and hard plastic, result in early breakage and invariably in all cases of breakage, foot is broken at or near the tip of hard plastic block.

Perry[21] mentions three main functions of the physiologic foot as shock absorption, weight bearing stability, and progression. Valmassy[22] further described five functions of the foot as load bearing, leverage, shock absorption, balance, and protection.

The polyurethane foot has good heel cushion allowing well the initial first rocker but after the loading response there is no forefoot keel which would help roll over from second to third rocker and also the fall of tibia from mid stance to pre swing result in large shear force acting between the hard plastic block and polyurethane cover causing breakage from inside to outside. So in spite of good shock absorption and weight bearing surface the lack of proper keel might be responsible for early breakage that has been observed[23].

The strength of our study was that to our knowledge it is the only comparative study between the Jaipur foot and PU foot. We included function as the end point of our study, it was not physician assessed and it was wholly subjective both in terms of acceptance and function. There was a large follow-up which is rare in Indian scenario. Limitation of our study was small sample size and no objective evaluation of prosthetic feet was done.

Conclusions:

Jaipur foot is more acceptable as far as movement, function and cosmesis is concerned. Most of researchers have labelled it as a handicraft item but being made individually, by hands, which is a strong positive factor for Jaipur foot. PU foot has its advantage that it can be made in large numbers and with consistent quality, but it still has basic design flaws and is not very well cosmetically accepted.

PU foot holds promise as a future prosthetic foot in developing nations but further research and design up gradation is needed. Taking the plus poits of Jaipur foot PU foot can be modified for the benefit of the amputtee.

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