A comparison between the dimensions of positive transtibial residual limb molds prepared by air pressure casting and weight-bearing casting methods

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Abstract
　Background: Creating a socket with proper fit is an important factor to ensure the comfort and control of prosthetic devices. Several techniques are commonly used to cast transtibial stumps but their effect on stump shape deformation is not well understood. This study compares the dimensions, circumferences and volumes of the positive casts and also the socket comfort between two casting methods. Our hypothesis was that the casts prepared by air pressure method have less volume and are more comfortable than those prepared by weight bearing method.
　Methods: Fifteen transtibial unilateral amputees participated in the study. Two weight bearing and air pressure casting methods were utilized for their residual limbs. The diameters and circumferences of various areas of the residual limbs and positive casts were compared. The volumes of two types of casts were measured by a volumeter and compared. Visual Analogue Scale (VAS) was used to measure the sockets fit comfort.
　Results: Circumferences at 10 and 15 cm below the patella on the casts were significantly smaller in air pressure casting method compared to the weight bearing method (p=0.00 and 0.01 respectively). The volume of the cast in air pressure method was lower than that of the weight bearing method (p=0.006). The amputees found the fit of the sockets prepared by air pressure method more comfortable than the weight bearing sockets (p=0.015).
　Conclusion: The air pressure casting reduced the circumferences of the distal portion of residual limbs which has more soft tissue and because of its snug fit it provided more comfort for amputees, according to the VAS measurements.

Keywords: Transtibial prosthesis, Weight bearing, Cast, Air pressure.

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Introduction

　Prostheses or artificial limbs are used to replace a total or partial missing limb and its function during dynamic and static activities (1,2). The socket is considered one of the most important components of the prosthesis that the residual limb is in direct contact with (3).

　Socket transfers the forces to the lower limb during the stance phase of gait, and also suspends the prosthesis on the residual limb in swing phase (1). If any of these roles failed, an amputee would face an increased risk of experiencing problems such as pain, skin lesions, and injuries in the residual limb (4,5). Manufacturing a precise

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and appropriate socket for the patient requires correct and detailed casting (6,7). A transtibial residual limb is not able to tolerate weight from upper areas and also through whole stump (2,7).

Therefore, in this level of amputation, accurate socket fit is of great importance (8). If this accurate fit pattern that is influenced by casting is not implemented correctly, the patient will be at risk of various problems and complications, as previously stated. Some people may abandon their prosthesis or try several prostheses to achieve their preferred results. This in turn may cause a range of psychological and social problems (minimal participation in social activities, depression…) and inflict economic losses to the patient, as well as to the health systems (9).

To minimize the skill and time required by a prosthetist to manufacture high-quality prostheses, the concept of air pressure casting was first presented by Kristinsson (10) through introducing silicon liner Icelandic Roll On Silicone Socket (ICEROSS) and airbag casting system. More recently, Goh et al. (11) described the use of air pressure casting as a method which produces a socket with uniform pressure distribution on the residual limb through parameters such as the residual limb anatomy and amputee's weight. In this method, the uniform pressure elongates the soft tissue around the residual limb and creates a bigger space in the sensitive limb distal end and also makes the limb harder. Another important feature of this method relates to the socket which is manufactured with minimal modifications in the positive cast. This method mostly utilizes silicon liner, which is difficult to use in many tropical countries owing to high air temperature.

A weight-bearing casting method of transtibial residual limb was first introduced by Ottobock (12). The main aim of this type of casting method was to provide appropriate changes in stump shape and volume during standing and stance phase of gait.

However, no peer-reviewed published literature supports these claims. There appears to be a lack of sufficient evidence for choosing the most effective transtibial casting method for an amputee, and it is important to compare different casting methods to provide information for clinicians and other health care professionals involved in amputee's clinical rehabilitation.

This study compares the dimensions, circumferences and volumes of the positive casts and also the socket comfort between two casting methods. Our hypothesis was that the casts prepared by air pressure method have less volume and are more comfortable than those prepared by weight bearing method.

Methods

By using a non-randomize sampling method 15 male transtibial amputees was chosen and took part in this quasi-experimental study, who had received their first prostheses at least one year ago. Two weight bearing and air pressure methods were utilized for casting their residual limbs. All participants attended the school of rehabilitation sciences (Iran University of Medical Sciences) and ethical approval was granted from Iran University of Medical Sciences. Informed consents obtained from all participants before taking part in the study.

Residual Limb Measurements

Before casting, stump length was measured from under the inferior edge of patella to distal end of the stump soft tissue by a measuring tape. Circumferences were measured in 5-centimeter intervals from inferior edge of patella to the end of the residual limbs (Fig. 1) using a measuring tape. Important diameters (anterior-posterior and medial-lateral diameters at below the patella level and anterior-posterior diameter at distal of the stump and casts) were also measured with a caliper. All measurements were done in the standing position. Measurement error in pilot study showed to be 1%.

Negative and Positive Casts Preparation

In the next step, the participants were chosen randomly for providing cast with two different methods with 30-minute interval between each casting process. Weight-bearing method was conducted by applying especial casting device (Ottobock Company) in a double limb stance position. The participant was asked to distribute his weight evenly on both lower limbs. For the first step, 4 layers of stockinet were put on the residual limb and an oversize shell was made with plaster. Then, the residual limbs were wrapped with plaster bandage once again after pads were inserted and a layer of sock was applied to the stump. The participant was then asked to bear 50% of his weight on the cast through casting device and the first stage plaster shell in stance position. The equal distribution of weight on two sides was being controlled by putting a scale under the healthy leg. The main cast was formed under weight-bearing conditions. The casting procedure was conducted through the standard method of Ottobock Company.

The other casting procedure was conducted through the air pressure device of Össur Company in a seated position. In this position and with no weight on the residual limb, a plaster bandage was wrapped around the residual limb and then an air bladder was placed on the residual limb and the plaster bandage. Air was pumped inside the air bladder and the plaster cast hardened under the air pressure. Negative casts were filled with plaster liquid and turned into positive casts without making any changes.

Positive Casts Measurements

The same main measurements (diameters, circumferences and length measurements), as which has done on the stump of participants, were repeated for both positive casts, similarly. The volume of the two positive casts from under the patella to the end of residual limb was also measured using a foot voltmeter set. The volumeter considered to objectively measure volume of the stump or positive cast by using the fluid displace-
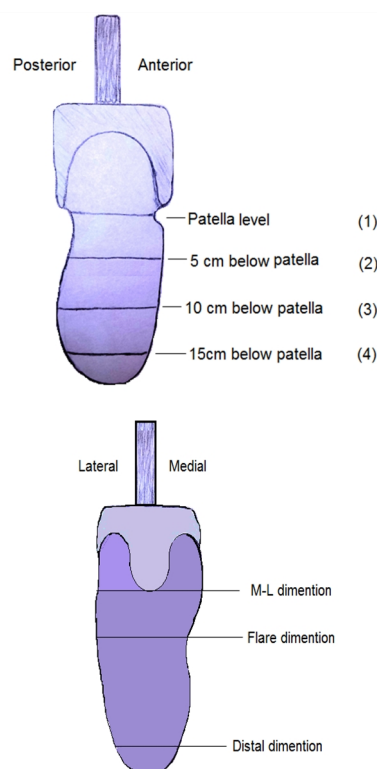

Fig. 1. Schematic figure of a stump which indicates the measured dimensions from patella to distal in 5 centimeter intervals
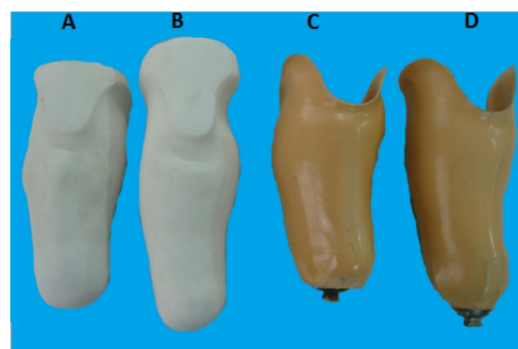

Fig. 2. The weight bearing positive cast and socket (A, C) and air pressure positive cast and socket (B, D)

ment method. The stump and positive casts placed in a water-filled tank. The resultant overflow was collected and measured.

Socket Fit Comfort

To measure the socket fit comfort level of the participants with both casting methods, sockets were fabricated from plasters. Each socket was placed on a similar pylon and similar foot ankle system (Fig. 2). The amputees were asked to walk with each prosthesis for 15 minute. A rest period of 30

minutes was considered before walking trial with other prosthesis (13). To prevent any bias in the results, amputees and researcher were not aware of socket types while wearing.

After walking with both socket types, socket fit comfort of both sockets was measured using a visual analogue scale (VAS on a 0-10 scale, where `0` equals the most uncomfortable socket fit the amputee can imagine, and `10` equals the most comfortable socket fit).

Statistical Analysis

The normality of variables' distribution was tested by Kolmogorov-Smirnov test. This was followed by a repeated-measure analysis of variance test to compare differences between the dimensions of residual limbs and positive casts. A Bonferroni test was also used to compare the difference between all possible pairs of means. Finally, a paired t test was used to compare the volumes of the two casts, number of stockinets and the socket fit comfort. Data analysis was done using the SPSS 17 and level of significance was considered 0.05.

Results

The fifteen transtibial amputees had a mean±SD age of 36±9.7 (year), mean±SD of body mass index 24± 3.5 (kg/m^2) and a mean±SD of residual limb length 15±3.1 (cm). The mean±SD time of wearing their prostheses was 12±2 years.

Based on the length and dimension measurements of the residual limb and positive casts, the Kolmogorov-Smirnov test showed that the data was normally distributed (p>0.05). Repeated measure analysis of variance showed no significant difference in the circumferences of the two types of positive casts made through weight-bearing and air pressure casting methods in patellar tendon area and 5 centimeters below. Yet, both circumferences were about 1 cm greater than that of the residual limb (p<0.001). Tables 1 and 2 show other measured parameters.

The mean circumferences of weight-

Table 1. Comparison of measured parameters (Results of the Bonferroni test) in stump, weight bearing and pressure casts (Mean ± SD)

Dimension	Mean ±SD	p
Cir 1	PC=33.6±1.3 ST=32.8±1.3	<0.001*
	WC=33.8±1.4 ST=32.8±1.3	<0.001*
	PC=33.6±1.3 WC=33.7±1.3	0.41
Cir 2	PC=30.2±1.4 ST=29.6±1.2	0.03*
	WC=30.6±1.5 ST=29.6±1.2	<0.001*
	PC=30.2±1.4 WC=30.6±1.5	0.16
Cir 3	PC=25.2±2.1 ST=26.2±1.9	0.68
	WC=27.4±2 ST=26.2±1.9	<0.001*
	PC=25.2±2.1 WC=27.4±2	<0.001*
Cir 4	PC=24±1.0 ST=25.1 ± 1.8	<0.001*
	WC=26±2.1 ST=25.1 ± 1.8	0.20
	PC=24±1.0 WC=26±2.1	0.01*
A-P diameter below the patella	PC=9.6±0.9 ST=10.2 ± 0.4	0.01*
	WC=9.9±0.7 ST=10.2 ± 0.4	0.07
	PC=9.6±0.9 WC=9.9±0.7	0.01*
M-L diameter below the patella	PC=11±0.4 ST=10.6 ± 0.4	<0.001*
	WC=10.8±0.3 ST=10.6 ± 0.4	0.04*
	PC=11±0.4 WC=10.8±0.3	0.02*
A-P diameter Distal of the stump	PC=8±0.5 ST=8.2 ± 0.3	0.18
	WC=9±0.5 ST=8.2 ± 0.3	0.03*
	PC=8±0.5 WC=9 ±0.5	0.01*
Length	PC=16.4±3.6 ST=15.2 ± 3.1	<0.001*
	WC=14.4±3.5 ST=15.2 ± 3.1	0.91
	PC=16.4±3.6 WC=14.4±3.5	<0.001*

A-P: Anterior – Posterior, M-L: Medial – Lateral, Cir 1: circumference below the patella, Cir 2: circumference 5cm below the patella, Cir 3: circumference 10cm below the patella, PC: Pressure cast, WC: Weight-bearing cast, ST: Stump
* Significant at 0.05 level

bearing positive cast in 10, and 15 cm below the patella were greater than air pressure cast and stump (p<0.05) (Fig. 3). Average PC positives lengths were longer than WC positives and stumps (p<0.001), (Fig. 4).

Table 2. Comparison of volume, stockinet layers and socket fit comfort in two methods; Paired t-test results

	Weight bearing cast (Mean±SD)	Pressure cast (Mean±SD)	p
Volume	1004 ±268.6	945.3±243.3	0.006*
Stockinet layers (n)	3.3±.4	2.3±.6	<0.001*
Socket fit comfort (VAS)	7±1	8.1±0.9	0.015*

Discussion

In this study, two sockets with two different casting methods (weight bearing and air pressure methods) were prepared for 15 transtibial amputees (totally 30 sockets). The size of the casts and the sockets fit comfort levels were compared.

The average length of the cast prepared by air pressure method was 1.2 cm longer than stump which can be the result of the pressure applied to soft tissue at distal circumference of the residual limb in this
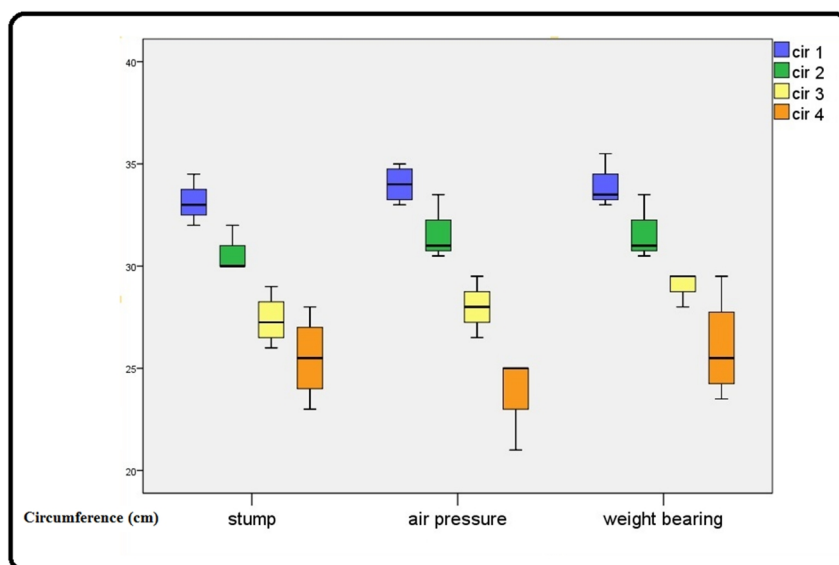

Fig. 3. Comparison of circumferences in four areas of stump and two positive casts.
Cir 1: Circumference below the patella, Cir 2: Circumference at 5 cm below the patella
Cir 3: Circumference at 10 cm below the patella , Cir 4: Circumference at 15 cm below the patella
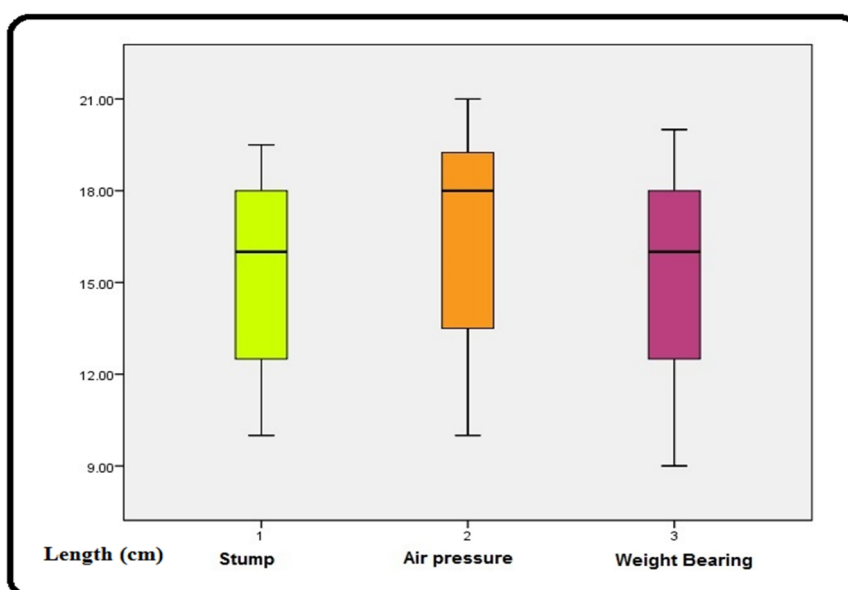

Fig. 4. Comparison of stump length and two types of positive casts

method. The decreased stump length in weight bearing method (not statistically) is the result of direct weight on the residual limb in this method. These results are similar to those reported by Fleurant et al. (7), and Tzeng et al. (14).

The mean posterior-anterior diameter at patellar tendon bar level was greater in weight-bearing method, and it can be attributed to weight-bearing on the cast and expansion of this diameter. In air pressure casting method, the soft muscular tissue displacement dispersed the pressure and this led to an increase in mediolateral diameter at patellar tendon bar level.

A comparison of the mean circumferences in the areas below the patella and 5 cm beneath it showed that the two weight-bearing and air pressure casting methods made both sockets larger than the residual limbs. However, in the air pressure casting method, these two circumferences were slightly smaller, yet this difference was not significant in comparison of the two casts. This may be the result of applying pressure on weight bearing areas in the upper parts of the residual limbs in weight-bearing casting and displacement of the soft tissue in air pressure casting.

The circumferences of the residual limbs at 10 and 15 centimeters beneath the patellar tendon were smaller than that of weight-bearing method because of the pressure applied to the soft tissue at the end of the residual limb. The increase of the stump length in air pressure cast may indicate that the soft tissue at the end of the residual limb displaces towards the lower parts. This observation supports the work of Wilkinson (15) who also showed that the lower circumferences were decreased with air pressure casting.

Comparison of diameters in both casting methods indicated that the two casting methods had no significant differences in the upper sizes of two provided positive casts, and their difference is mostly observed in their distal perimeter size.

A comparison of the mean volume in both casting methods showed that the cast volume in weight-bearing method is more than air pressure method. This can be due to restriction in the transformable volume of the end of stump caused by the plaster band wrapped over it. Because of applying weight and extrusion of tibia bone inside the soft tissue, the volume of the cast has been increased. It seems circumferences, diameters and volumes were greater in sockets built through a weight-bearing method than in pressure casting method. In addition, the amputees needed to put on an extra pair of socks to have a better fit while walking with weight-bearing socket. Research undertaken by Wilkinson (15) compared two methods of manual casting and air pressure casting. The casts produced through air pressure were shown to have less volume than those casts produced by manual methods. The highest volume decrease was observed in the lower circumferences of the casts which is consistent with the results of our study.

Comparisons of comfort levels in both sockets showed a significant difference (p<0.05). The results showed that amputees were more satisfied with a tighter socket in the distal area and with more stump length in air pressure socket. These results are consistent with the results of Deutsch's study (16). A probable reason of the amputees' higher satisfaction with air pressure casting can be attributed to uniform distribution of pressure on the residual limb, especially in the circumferential areas and distal end of the residual limb. In a study by Tzeng et al (14), sensors were installed in a socket which was built through fluid pressure casting. It was concluded that pressure distribution in sockets cast through air pressure method is smoother than other casting methods. Other probable reasons that describe why amputees find the sockets prepared by air pressure casting method more comfortable may include factors such as tight fitting of the sockets, no need to stockinet, less rotation movement of stump inside the socket, and no contact between the distal end of tibia and socket's end as the socket cast is longer.

Future researches are recommended to compare air pressure casting method which has triggered greater satisfaction among the amputees in this study with hydrostatic casting methods that water is used as a fluid instead of air.

Conclusion

In this study, dimensions of two positive casts obtained from weight bearing and air pressure casting methods were compared with each other and with those of residual limb. The comparison of results indicated that circumferences at lower half of stump (10 cm below the patella) in the air pressure method were significantly less than those of the weight-bearing cast but the circumferences and diameters at upper half of the stump did not differ significantly.

This study showed that a casting method will transform stump shape especially in massive soft tissue area. The air pressure casting with its pressure provides snug fit in the distal half of socket. This method is suitable for the stumps with heavy subcutaneous tissue. The weight-bearing casting may create a distal loose socket which may be more suitable for thinner stump.

Limitations

It would be better if pressure inside the sockets and load distribution could be measured by pressure sensing instruments like Pliance (Novel, Germany). The authors could not compare the fit comfort of the socket types after a longer period of prosthetic use.

Conflict of interest
None declared.

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