Thermography as an Alternative Tool to Determine Pressure Distribution on the Stump of Transfemoral Amputees

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SUMMARY

Lower limb amputation is a highly disabling condition affecting among others, mobility, activities of the daily and overall quality of life of the amputee. Prosthesis are custom made medical device intended to mimic the lost limb function, composed of several components, including a custom made socket, worn directly over the stump, usually made individually by hand to fit each individual stump. The socket is a crucial component, responsible for the load transfer between the prosthesis and the stump, control and stability of the prosthesis. The quality of the socket fit is crucial for the comfort, function, and energy consumption when walking with prosthesis. Despite this fact, the process of designing, producing and adapting a socket is usually a manual process, highly dependent on the experience of the prosthetist and on the individual and subjective perception of load reported by the amputee, dependent on a trial/error process to achieve a better fit, resulting in a costly process due to the number of visits to the workshop, as well as the number of prosthetics sockets that may have to be produced. The assessment of the stump/socket interface and pressure distribution is of paramount importance and the possibility of assessing the variables on a clinical setting on normal walking conditions, represents an important step forward on prosthetic production and rehabilitation. In this study the possibility of using thermography as a pressure distribution indicator is analyzed. The authors concluded that thermography may be a good indicator of force patterns within the socket walls and stump, allowing the possibility to determine among others the type of prosthetic socket, and therefore could be used as a tool on prosthetic production/rehabilitation. Further investigation is in course regarding the study of the stump/socket interface on lower limb amputees.

1. INTRODUCTION

1.1 Lower Limb Amputation

Lower Limb Amputation (LLA) is a highly disabling condition affecting the ability to stand up, walk, run and perform daily life activities involving ambulation. The leading cause for lower limb amputation on developed countries is dysvascular disease, commonly associated with diabetes; however traumatic injuries, cancer and congenital deficiencies are also commonly reported.

Besides affecting walking performance, the increased load on the non-amputated side, is thought to cause additional blood flow deficits in persons with vascular disease (4), back and leg pain (5) and premature wear and tear and arthritis on a long term basis because of the increased ground reaction forces. The effect of lower limb amputation on vascular disease is exacerbated by the common comorbidities that are associated and the impact of overloading the remaining limb. These combined factors result on diminished quality of life and activity levels. The altered weight bearing patterns can be also related to comfort and pressure distribution on the stump, when wearing prosthesis. Most frequently reported problems that had led to reduction in quality of life were heat/sweating in the prosthetic socket (72%), sores/skin irritation from the socket (62%), inability to walk in woods and fields (61%) and inability to walk quickly (59%). Close to half were troubled by stump pain (51%), phantom limb pain (48%), back pain (47%) and pain in the other leg (46%) (5).

It is estimated that on USA, in the year 2005, 1.6 million persons were living with the loss of a limb.

Of these subjects, 38% had an amputation secondary to dysvascular disease with a comorbid diagnosis of diabetes mellitus. It is projected that the number of people living with the loss of a limb will be more than double by the year 2050, in a figure of 3.6 million (1). The leading cause for amputation is also reported frequently. Severe peripheral arterial disease indicating critical ischemia has been found in 1.2% of a general population aged 60 years and in almost 5% of primary care patients aged 65 years (2).
In 2009 the data reported by ACSS - Administração Central do Sistema de Saúde, regarding amputation in Portugal is summarized on the table 1.

Table 1 - Amputations in Portugal 2009 (ICD-9M)

Total (GDH 113,114,213,285)	
Men **(mean age** 70 years old)	**1963 (66%)**
Women (**mean age** 78 years old)	**991 (34%)**

Source: ACSS *Administração Central do Sistema de Saúde database* (http://www.acss.min-saude.pt)

1.2 Prosthesis and Rehabilitation Outcome

Transfemoral prosthesis – Fig. 1 are custom made medical devices, intended to substitute the limb by replacing the limb part and mimicking the function of the knee and foot. The device is connected to the reminiscent limb by a socket, custom made to fit each individual stump; this interface has to be designed properly to achieve efficient load transmission, stability and provide sufficient control for the mobility expected when walking.
Supporting body weight in static and dynamic conditions is one of the main functions of the lower limb. Symmetrical weight shifting over the limbs during stance and gait is a relevant clinical problem for lower limb amputees. Due to amputation of one limb the center of gravity is shifted laterally to the side of the no amputated limb, a shift that is not fully compensated by the mass of the prosthesis. However, the commonly reported increase in vertical loading on the non-amputated side is not only related to the difference between the weight of the prosthesis and the weight of the anatomical segment. Other factors, such as pain and/or postural instability are probably responsible for the asymmetrical weight bearing during stance and gait (4).
The prosthetic socket – Fig. 2 is the component where all the forces acting on the body and from the ground interact. The socket should be adapted to fit the stump shape and must be properly contoured and relieved for functioning muscles.
A good prosthetic socket should therefore the following criteria:
a) Stabilizing pressure should be applied on the skeletal structures as much as possible and areas avoided where functioning muscles exist;
b) Functioning muscles, where possible, should be stretched to slightly greater than rest length for maximum power;
c) Force is best tolerated if it is distributed over the largest available area, reducing therefore problems derived from high localized pressure;
d) Properly applied pressure is well tolerated by neurovascular structures;

Regardless of the fitting method employed, the socket for any amputee must provide the same overall functional characteristics, including comfortable weight bearing, stability in the stance phase of gait, a narrow-based gait, and a swing phase as normal as possible consistent with the residual function available to the amputee. These characteristics will provide the format for a description of transfemoral sockets (7).
The socket fit is a key factor and determines the comfort of the amputee when standing, walking or performing everyday activities, as well as the ability to control the device. In the absence of a snug comfortable fit, the amputee may experience discomfort, pain and resulting in friction wounds and walking is then a process less effective in terms of energy consumption (2) The aim of the prosthetic rehabilitation is to provide for the amputees an early return to independent daily activities and mobility with lower limb prosthesis in their own environment. The comfort and satisfactory pressure distribution over the stump plays an important role on the prosthetic rehabilitation process, quality of life and performance the activities of the daily living. Despite the importance of this part of the process, it is usually achieved by a trial/error process, and the socket fitting process includes questioning the patient to assess the perceived pressure and comfort/discomfort zones, listening to unsolicited verbal reports of discomfort from the patient, making visual observations of tissue colors and contact pressures through the clear walls of a check socket, and using the finger or an object as a probe to estimate pressure magnitudes.
An understanding of the load bearing on the socket is of particular relevance to most transfemo-ral amputees because the main pain and discomfort they experience are related to the interaction between the socket and the residual limb. The function of the prosthesis may influence the effects of the applied forces on the residual limb and affect

the amputee's perception of comfort and the degree of control of movement of prosthesis is also dependent on the ability of the amputee to transmit the appropriate forces through the socket.
For a sound understanding of these forces and moments applied on the residual limb, it is essential that the loads measured in experimental conditions reflect those produced during the daily life of trans-femoral amputees. The objective of the present study is to describe a possible way of assessing pressure distribution on the socket of transfemoral amputee during everyday situations and on clinical conditions.

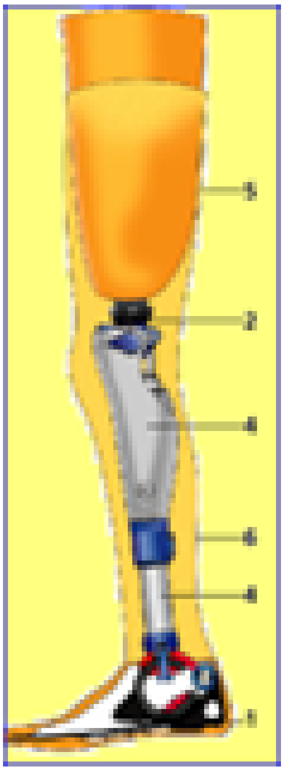

Fig. 1 - Transfemoral prosthesis - constituted by a socket, adaptors and tube prosthetic knee and prosthetic feet (8).

Fig. 2 - Examples of prosthetic sockets (coronal view) - CAT/CAM type and a Quadrilateral type.

1.3 The stump/socket interface and possible pressure measurement process

The basic principles for socket design vary from either distributing most of the load over specific load-bearing areas or more uniformly distributing the load over the entire limb. The skin and the underlying soft tissues of the residual limb are not particularly adapted to the high pressures, shear stress, abrasive relative motions, and the other physical irritations encountered at the prosthetic socket interface. No matter what kind of design, designers are interested in understanding the load-transfer pattern. This knowledge will help designers to evaluate the quality of fitting and to enhance their understanding of the underlying biomechanical rationale. Many studies have been conducted to evaluate and quantify the load distribution on the residuum by either clinical measurements or computational modeling.
In order to design a good socket fit with optimal mechanical load distributions, it is critical to understand how the residual limb tissues respond to the external loads and other physical phenomena at the interface (6). Pressure measurements within prosthetic sockets have been addressed by several authors including the use of transducers, their placement at the prosthetic interface, as well as the associated data acquisition and conditioning approach. An ideal system should be able to continually monitor real interfacial stresses; both pressure and shear, without significant interference to the original interface conditions (6).A variety of transducers have been developed for socket pressure measurements.
However the techniques for placement of transducers at the residual limb or socket interface can be divided into two categories. They are either inserted between the skin and the liner/socket, or positioned within or through the socket and/or the liner. Only thin sensors are suitable for insertion between the skin and socket. In this particular case mounting is relatively easy and it is not necessary to damage the prosthesis. However, for many of these sensors, interference is unavoidable from their protrusions into the socket volume, because of their finite thickness. Positioning the transducers within or through the socket with the sensing surface being flush with the skin would make the thickness of the transducer becomes less critical. For such mounting, holes would need to be made on the experimental sockets to recess the transducers (6). Commercial systems have been designed such as the Rincoe Socket Fitting System, Tekscan F-Socket Pressure Measurement System, and Novel Pliance 16P System. The F-socket (type 9810 or 9811) transducer is a force-sensing system particularly

designed to use with lower limb amputees. This type of technologies are potentially very interesting to use on the prosthetic fitting process, however they still pose some limitations. The main requisite for such an application may be described as follows: non-invasive, non-intrusive, ease to use on clinical/production setting, reliable and allowing for a close normal walking conditions assessment. Thermography is a possible technique as it is noninvasive and nonintrusive technique, relatively easy to use on clinical setting.

2. METHODS

The subject, a 48 years old traumatic transfemoral amputee, walked for 10 minutes in a crosswalk at a comfortable speed (4m/s); during this time we were able to simulate a normal walk of approximately 700m – Figure 6. For the experiments it was used the thermal camera FLIR® A325 with a special resolution of 320x240 pixels and a thermal sensitivity of 68 mK. The images were taken before and after the exercise, both to the subject and to the prosthetic socket.

3. RESULTS AND DISCUSSION

The thermal images of the amputee stump after ten minutes walking revealed extremely low temperatures in the distal end - Figure 3, as well as an uneven heat distribution pattern. This may be explained by the fact that the stump is experiencing circumferential or clamp uneven pressure, on the proximal region, just by being inside the socket, which is an abnormal pattern of pressure to the limb possibly causing disturbance on the blood flow. The low temperature in the distal end of the stump clearly demonstrates that there was no contact or friction with the prosthesis. We can expect that lower limb amputees, due to the biomechanics characteristics of the prosthetic sockets, may experience circumferential or clamp type forces, as well as frictional, rotational and distal bearing forces over the stump, which are very abnormal patterns to the skin and tissues. The end pressure will be the sum of the stabilizing pressure pre imposed on the socket, creating vacuum inside the socket continuously and the pressure imposed by the forces associated with walking, namely on the stance phase. It is also interesting to see that the image of the inner socket walls also show the same temperature distribution, as the correspondent stump - Figure 4. These are coincident with the expected pressure points on the stump/socket interface as the recruited areas for weight bearing on the quadrilateral type socket are all located on proximal region of the stump/socket, namely over the medial, posterior and anterior portions of the stump/socket. According to this, it is also possible to distinguish that the socket that is being used by the amputee is of the Quadrilateral type. Another important finding is the high temperature recorded in the supporting zones - Figures 5; once again this was also observed in the prosthesis and maybe an indicator of areas where the socket walls are tighter and create extra pressure on the stump. Figure 6 shows a picture of the setup, camera and amputee. Also, from the thermal results, one can clear identify the areas of the socket where the contact with the body is more intense, which naturally results in a temperature increase, as it reduces the thermal resistance. Therefore thermography seems to be a very useful tool to help the fine tuning of the socket to the stump, as to give the better comfort to the amputee.

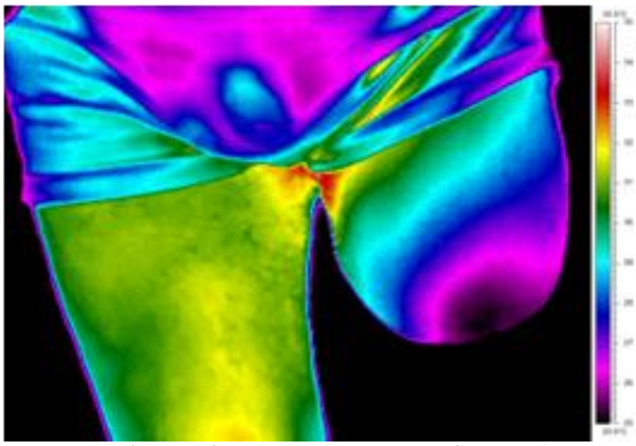

Fig. 3 - Subject, front view 10 min after walking.

The anterior distal end of the stump is indicating temperatures between 20 C° to 25 C°.

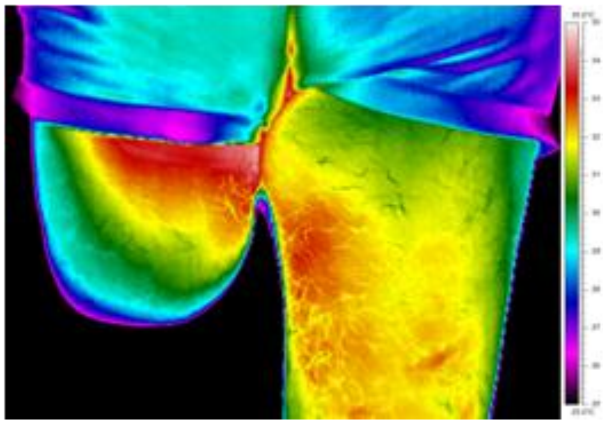

Fig. 4 - Subject, rear view (zone of load support).

Whereas on the distal proximal region the temperature levels raise up to 34 C° - 35 C°.
These differences are a strong indicator of how the overall pressure is being distributed over the stump after a 10 min walk, and may be used to assess the possible best fitting socket and socket type.

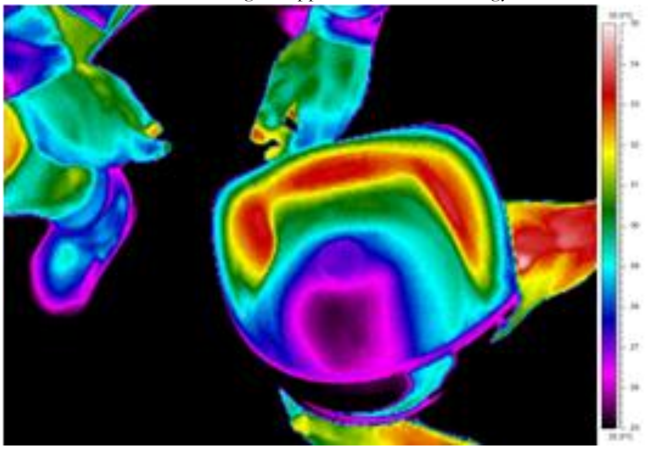

Fig. 5 - The thermal patterns on the prosthesis.

On the socket walls the same heat distribution is observed, indicating that the patterns obtained by thermography are congruent.

Fig. 6 - The walk exercise and the heat recording set-up.

4 CONCLUSIONS

The use of thermography as a possible tool to assess pressure distribution patterns over the amputee stump was analyzed on a single subject, conveniently recruited from the amputee population attending CRPG – *Centro de Reabilitacao Profissional de Gaia*. The subject, a transfemoral traumatic amputee, was a very experienced prosthetic walker and at the time of the study self-reported to be comfortable with the prosthesis. On the day to day the lower limb amputees are expected to compensate the absence of a segment of the lower limb, with a mechanical device (custom made medical device) which is fitted individually to the stump. The forces generated between the stump and the socket are known to be responsible for the lack of comfort, blisters and friction wounds among others, leading to a decrease on mobility function and sometimes prosthetic abandonment. Therefore the design of a mechanically sound interface between the socket and the stump is crucial on prosthetic rehabilitation. The availability of a simple, non-intrusive assessment method, applicable on a rehabilitation setting could help greatly the effort of producing a prosthetic socket, usually a very long and costly process. Thermography may be of help on this process as an indicator and further studies are being developed to evaluate it applicability on a routine clinical practice. However the authors would like to highlight that other variables should also be addressed when analyzing the stump socket interface, such as the effective pressure on the skin and friction, the moisture, muscle activity among others.

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