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The ICEROSS concept: a discussion of a philosophy

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Abstract

Prefabricated ICEROSS (Icelandic Roll On Silicone Socket) sockets have been in use in Iceland since early 1986. Use of custom-made silicone sockets began several years earlier, and a paper devoted to the subject was presented at the 1984 AOPA Assembly by the author of this article.

The ICEROSS system is primarily used for suspension. At the same time the author believes it considerably improves the weight-bearing capability of the prosthesis and the interface between prosthesis and user. After being turned inside out and rolled over the stump, the silicone sleeve forces skin in a distal direction, stabilising soft tissue and minimising pistoning. Both prosthetist and user may experience some problems initially, although most can be overcome by careful socket design and skin care.

Introduction

There are two conceptually different aspects to the quality of prosthetic fittings. Firstly, there is the quality of available components and materials, i.e. tools, database and the craftsmanship necessary to put them together as a functional unit. Secondly, there are the latest methods of fitting a socket and the involved prosthetist's skill.

Apart from the limitations inherent in artificial joints, the single most crucial part of the prosthesis is the socket, which often establishes the threshold of the user's performance.

Fitting trans-tibial amputees is not often regarded as a major problem. In comparison to fitting trans-femoral amputees, it may not be. Nevertheless, because we have very few parameters to judge by, other than previous, empirically-gained knowledge and subjective feedback by our patients, we may often be misled into thinking we are doing a much better job than is the case. That is, we tend to accept our results as the best obtainable. Problems which appear later may be attributed to uncontrollable factors such as oedema, atrophy, redistribution of soft tissue, change in body weight, etc.

Of course, this is in no way unethical or unnatural. No one can be blamed for fittings, whether good or bad, that do not meet standards he is unaware of or are as yet undeveloped. Just as carriage makers had no idea of pneumatic tyres when constructing primitive wooden wheels covered with wrought iron, modern prosthetists have to rely on the state of the art of the present. This is not to say we are in the same predicament as were the carriage makers, we certainly are not. For a start we have an abundance of new materials; we have a multidisciplinary database to tap from, and hopefully, our intentions are undisputed. Most likely, what we lack are the tools that fit every prosthetist's hands and mind and yield comparable results, regardless of location and the artisan. CAD CAM may be the answer, but more research should be directed towards understanding the complex interaction between socket and limb or more properly socket and skeleton.

In any case the author cannot accept any current state CAD as a toolbox, simply because his view is that all systems seem to have inherited the PTB concept, or rely on the information obtained on the topography of a cast or a "hanging limb". It is not considered that CAD has anything to offer yet besides documentation and ease of fabrication. This will hopefully change in the near future as the systems evolve.

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Suspension

For a long time, suspension has been recognised as an important factor determining the general effectiveness and comfort of the trans-tibial prosthesis. Unfortunately research and development aimed at solving the problems of suspension has not been very successful. In addition to the thigh corset, the PTB strap and similar strapping systems, there are several variations of supracondylar pads and neoprene sleeves, rubber sleeves etc. All these different systems prevent the prosthesis from falling off the limb, and to some degree limit pistoning. This is especially true of the sleeves. None of them, however, can be considered to be very effective.

The trans-tibial suction socket provides a different approach to suspension from the above mentioned systems. Several attempts have been made to solve the problems connected to such devices, with the most promising involving flexible or semisoft sockets. The use of such sockets has not been widespread, perhaps because (with the exception of very voluminous limbs), if the air seal is not to be lost, the sockets have to be made very tight and tend to strangle the limb. Also, they are difficult to fit, and are sensitive to rhythmic or permanent changes of the limb. Such sockets tend to create more problems than they solve.

Generally said, suspension has been so poor that users of trans-tibial prostheses have seen their performance suffer as a result. All the pistoning, due to the prosthesis and limb accelerating relative to one another at every step, and the impact initiating the weight-bearing phase, exerts great stress on the skin, joints and skeleton. To cushion impact, trans-tibial sockets are lined with some kind of soft material to ease shock. This is helpful, of course, but if the fit is not optimal, and only limited areas of the limb are subjected to load, the socket will be uncomfortable, regardless of the quality of the cushioning.

Socket shape and volume

This author's firm belief is that a trans-tibial socket, designed to transfer loads primarily to limited areas of the limb such as the patellar tendon and the medial flare and condyles of the tibia, for instance, is in most cases both ineffective and uncomfortable. The most effective socket, in the author's view, is one that relies on the hydrostatic principle for load transfer. This principle is at work in the majority of "best" trans-femoral fittings. To obtain such a fit, one must realise that the goal of a hydrostatic fit can only be realised to a certain degree. The stump is of a complex mechanical nature, but for means of simplification will be referred to as an elastic solid with low stiffness surrounding a piston, the tibia with its condyles. If this mass can be fitted into a containing vessel corresponding exactly to its volume, the fitting can be expected to behave like a hydrostatic system when loaded. Then, in the absence of motion, there is no shear stress; the internal state of pressure at any point is determined by applied pressure alone. Hence, the pressure at a point is the same in all directions and the pressure required to support the weight would be determined by the cross-section of the socket opening. A hydrostatic system is stable only as long as it is tight. As soon as it begins to leak, it begins to lose its mechanical stiffness. Even if it cannot be referred to as an effectively closed hydrostatic system, the limb-socket interface (interaction) may probably pass as being an elastic coupling with hydrostatic characteristics during weight-bearing. Given that the posterior wall is high enough and that the consistency of the soft tissue prevents it from leaking out of the vessel and past the condyles, this system should be able to transfer the forces generated during weight bearing without any need for limited area loading or even conformity to the underlying skeleton. There are questions about mechanical stability and the internal dynamics of the limb, enclosed and acting in such an environment, that have to be answered. Research in this field is much needed.

Of course, the force transference between socket and limb must be a compromise between limited area loading and hydrostatic loading. Furthermore, the stump of an active amputee most likely is not of the same volume towards evening as it is in the morning, or in June and December of the same year. Hence, the socket fits differently at different times, and hydrostatic stability may be lost at regular intervals, even with a reasonably well fitting socket. What needs to be done, for a good initial fit, is to ensure that the soft tissue present at fitting, is stabilised at ideal volume by an ideally matching container during loading; and, while being suspended, the prosthesis is securely anchored to the limb with minimal longitudinal displacement. No method that solves both these problems was known when development of the ICEROSS was begun.

ICEROSS

The ICEROSS (Icelandic Roll On Silicone Socket) consists of a cylinder closed at one end, with an attachment coupling for distal fastening integrated into the closed end (Fig. 1). ICEROSS is made of a very soft, stretchable silicone material, with extraordinary elongation and tear resistance capability. Being a silicone, however, the material has certain limitations. Careless handling can result in tearing of the wall and destruction of the socket. Consequently, prosthetists must be aware of this and instruct the user in proper care and handling.

From the closed distal end, where wall thickness averages 4-5mm, the socket wall thin out to 2mm at roughly 100mm above the bottom. When the socket is turned inside out, the inner wall (now facing out) of the relatively thick distal portion stretches, and the outer wall similarly compresses. When donning, the user presses the exposed bottom of the ICEROSS against the end of the stump and then rolls the socket all the way over the knee (Fig. 2).

Tension previously created in the stretched inner wall during the inside-out procedure is then released; the surface contracts, displacing the skin downwards. The phenomenon can be observed by the user, who can both feel and see the skin being displaced down into the socket during the rolling-on process. When the ICEROSS has been rolled properly over the stump, the soft tissue is stabilised. The combination of radial pressure and

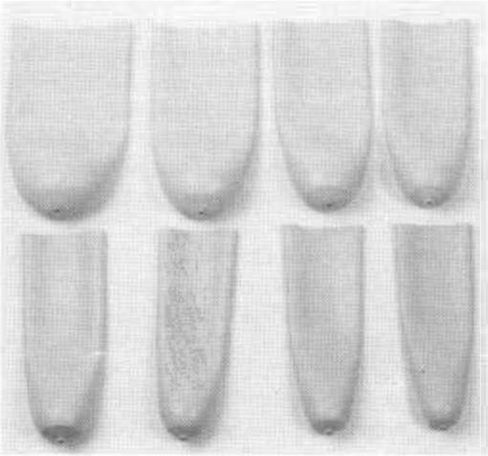

Fig. 1. The ICEROSS socket.

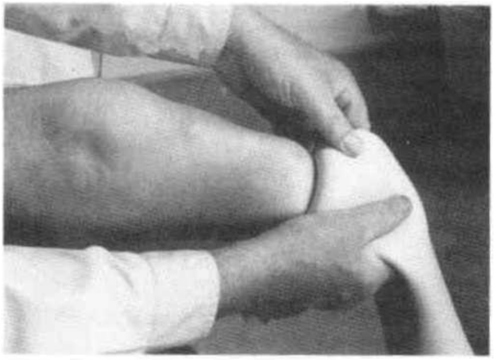

Fig. 2. Donning the ICEROSS socket.

the displacing of the skin in the distal direction presents the prosthetist with an entity quite different than the freely hanging limb. The possibility of longitudinal displacement of the skin envelope has been greatly reduced. Gripping the silicone covered limb with one's hands and attempting to move the soft tissue in distal and proximal direction, in order to imitate pistoning, makes clear the tremendous improvement in body/prosthesis interface this simple device represents.

The silicone is covered with a thin nylon sheet, and then goes into a rigid, laminated or thermoplastic socket. If the limb becomes smaller in volume, a thicker sock can be pulled over. Should it become larger, a new socket is usually required.

Being so thin and easily stretched, the ICEROSS can follow movements of the skin over the knee, and even collapse into concavities without sacrificing its ability to adhere to the skin. The silicone could almost be referred to as a second skin. The interface between skin and socket is free of friction, which has been transferred to the interface between the ICEROSS and the socket. As a result, considerably less strain is exerted on the skin.

An important feature of the ICEROSS is a reinforcement, which is integrated into the thicker distal portion. This part of the socket will stretch radially, but only slightly axially (longitudinally). Restricting axial stretching distally to the knee contributes greatly to the effective suspension. The arrangement makes it possible to counteract the shear forces during suspension. This is possible at least as far up from the bottom as the reinforcement extends, as the skin is locked against a relatively unstretchable

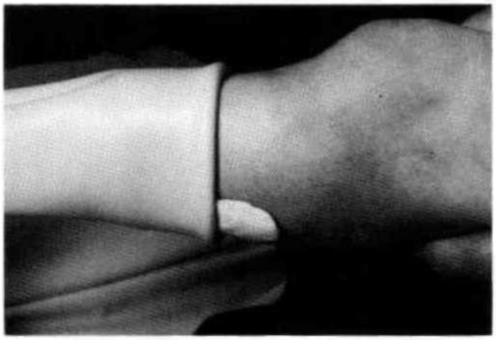

Fig. 3. Positioning of the fibular pad.

Fig. 5. Applying plaster of Paris bandages.

wall with the stump under radial compression. Furthermore, it prevents the socket from stretching away from the end of the stump, which creates problems associated with negative pressure.

The cushioning characteristics of silicones are quite different from those of foams, which are porous or cellular. Cells can be open or closed, and are filled with gas. In the case of open cells, the gas escapes when the material is compressed, collapsing the pores and decreasing the volume. If cells are closed, the encapsulated gas compresses. During this process, the compressing force works against a component of elasticity — the spring component. Depending on the size of the spring component these materials rebound more or less on impact, with more or less "kickback", more for the rubbery foams, less for polyethylene foam for example. Silicone, on the other hand, is solid, and accepts very little, if any, compression. Instead, it redistributes, flowing from high to lower pressure areas. The silicone used is somewhat energy absorbing. Almost no spring component is present, making it an excellent shock absorber.

During initial theorising about hydrostatic fitting or total surface bearing for trans-tibial amputees, we realised that an ideal fit should eliminate the need for cushioning. We were also, however, aware of the fact that even if an ideal matching were achieved between limb and body during fitting, the situation would probably be short-lived. The mature stump is conical. Small fluctuations in its volume result in a mismatch as the limb enters the socket at various depths, and the angle of attack for the sloping surface changes. Hence, if the limb does not sit exactly in the receptable as intended, trouble is bound to occur over bony prominences. To rectify the situation, we build up reliefs for the fibular head and tibia. The only cushioning used is the silicone wall (2mm thick proximally). A 3mm Pelite liner was used initially, but soon abandoned in light of its high friction and because we realised it was unnecessary.

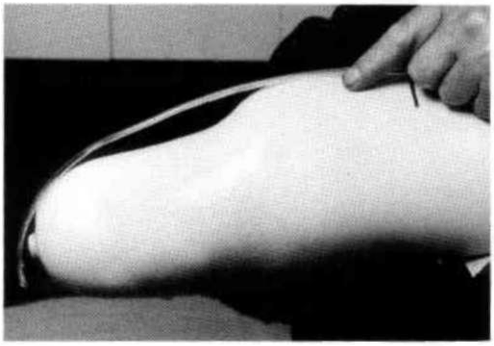

Fig. 4. Position of the stump for casting.

Casting and rectification

When casting for a total surface bearing socket, we recommend the silicone socket be fitted and the cast subsequently taken thereover. Build-up over the tibia and the fibular head can be placed directly on the skin, under the silicone, by using silicone pads of appropriate thickness. In such cases, the fibular pad should not be positioned before the rolled on silicone approaches the relief area (Fig. 3).

Casting is then done with the limb in full extension and relaxed. The silicone is richly lubricated with hand lotion (Fig. 4).

Normal plaster of Paris bandages are used, 15cm wide, and most of the plaster is drained off. No local pressure is applied anywhere, the cast is only smoothed with firm hands and the anterior towards the posterior (Fig. 5). Pressure is not applied under the patella or on the patellar

Fig. 6. Removal of the cast.

tendon. Excessive casting material collects over the posterior aspect.

The mediolateral (ML) dimension is measured with a pair of calipers. The cast is cut over the patella (inclined cut with a scalpel) and pulled off (Fig. 6).

Those afraid of cutting the silicone should place a plastic tube under the cast. Using the measurement taken with the calipers, the ML measurement of the cast is adjusted. Do not cut out the posterior opening, just pour plaster into the unmodified cast. A build-up for the posterior opening is added to the model and the only rectification is for volume (Fig. 7).

Check sockets

A check socket procedure is considered essential. These are made of a transparent thermoplastic, and should be stiff enough to prevent losing their shape during the test procedure. Sockets which are too tight initially, a problem sometimes difficult to spot, are detrimental for our purpose. If anything, we prefer to begin with a socket that is too loose. It is easy to go back to the model, remove material, reheat the socket locally and shrink it with the aid of an elastic bandage.

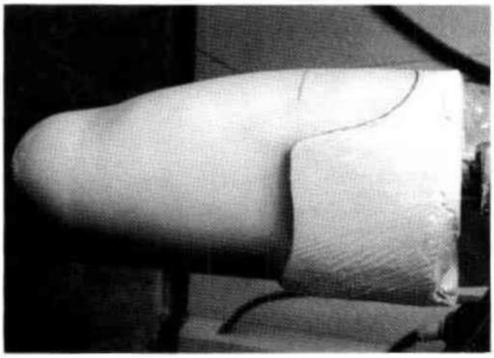

Fig. 7. Build-up for the posterior opening.

A socket made to fit by stepping into, but lacking any allowance for forced elongation, may have to be made too short and too wide. Pistoning can be the result. In many cases it is preferable to use a pulling string system rather than a shuttle lock of some kind. On the other hand, eliminating all relative movement between limb and prosthesis may not be desirable. Even a snug socket, fitted by first displacing the skin into the ICEROSS, and followed by stretching the silicone covered limb distally so that it will bottom in the receptacle, shows some degree of pistoning when intermittently loaded in both directions. When the string has been locked against the check socket and a load applied in the distal direction, a gap can be observed between the socket and the silicone covered limb. Usually, a nylon sheath is pulled over the silicone to reduce friction, because, by allowing for the limited pistoning, less strain is put on the skin at the interface with the silicone. In addition, a more dramatic mismatch becomes obvious when the knee is flexed, and disallowing movement of the limb and socket relative to each other is a sure way to invite trouble.

Trans-femoral prosthesis

The combination of an ICEROSS and a vaguely narrow mediolateral shaped trans-femoral socket is often very successful for elderly patients (Fig. 8).

The socket can be made of thermoplastic with a medial frame, having small proximal extensions, just enough to secure the socket against rotation relative to the frame (Fig. 9).

An even more flexible socket is made of polyurethane elastomer with an integrated frame. Elderly patients are very pleased with the softness of the polyurethane sockets and it is amazing to see how easily they roll on their ICEROSS and step into their prosthesis. It only takes a minute or two.

Contraindications

Use of silicone sockets for the elderly (and the disabled in general) is only recommended when adequate care and handling can be guaranteed. Consequently, sockets should not be prescribed for persons unable to put them on and exercise proper hygiene, unless caretaking personnel or relatives are available for assistance.

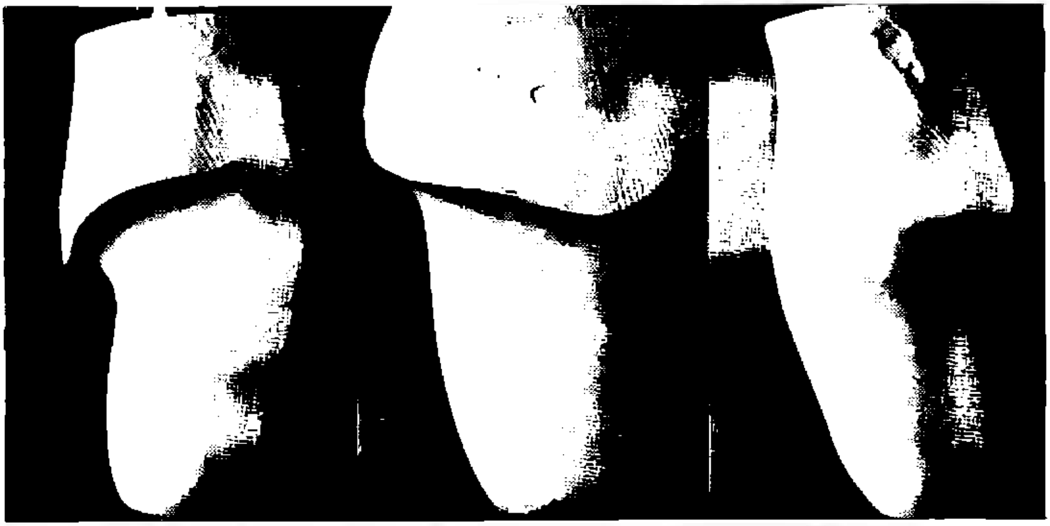

Fig. 8. The cast for the trans-femoral socket.

Open wounds and skin necrosis: Silicone sockets are not employed before the post-operative wound has healed. They should, however, be prescribed as soon as possible as a shrinker, replacing elastic bandaging. A study on post-operative application is underway, but at present no benefits have been verified.

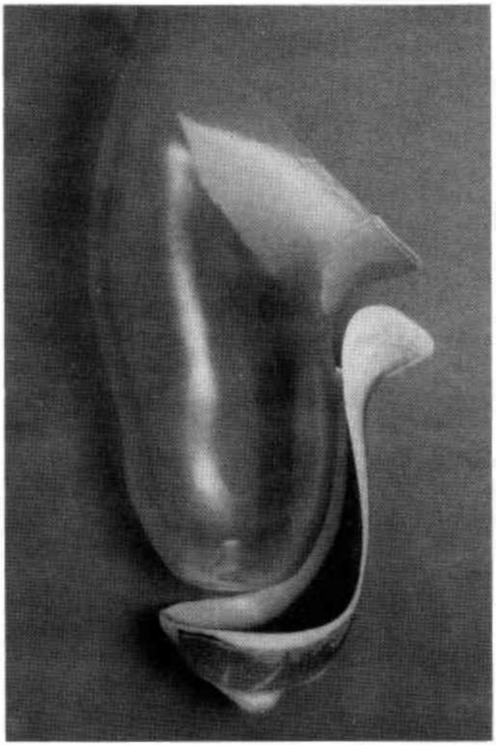

Fig. 9. The trans-femoral socket.

People occasionally come in with damaged skin caused by excessive local pressure. Healing is effected by relieving the area under pressure, and usually does not require rest and airing.

Complications

Elderly patients may develop blisters, especially on the patella, in the early stages of training. Apart from the fragility of the skin, one possible reason may be the selection of a socket size which is too small. This problem can be remedied by cutting out an opening to relieve the patella, and using a soft dressing as protection. After healing, trials show blistering ceases if careful readaptation is exercised, accompanied by regular resting and airing of the limb.

Conclusion

The ICEROSS system is primarily used for suspension. At the same time it apparently considerably improves the weight-bearing capability of the prosthesis and the interface between prosthesis and user.

Total surface bearing or hydrostatic sockets are recommended. Properly fitted such a socket does not require an additional soft liner.

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