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Below-Knee Prosthesis with Total Flexible Socket (T.F.S.): A Preliminary Report

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Recent efforts in Oklahoma City, and San Diego have borne fruit to a promising new way to fit below-knee amputees. The basic design consists of a thin walled thermo-plastic socket secured in a frame by nylon strapping tape so that most of the socket is left exposed and unsupported (Figure 1). This design, named the Total Flexible Socket (T.F.S.), was conceived out of necessity with a few patients that were so difficult to fit that even aggressive techniques such as multiple transparent diagnostic sockets, alginate injections, total surface bearing modifications, and silicone gel inserts failed to provide a measure of comfort acceptable to them. It was felt that a more unconventional method would have to be implemented. Currently, this

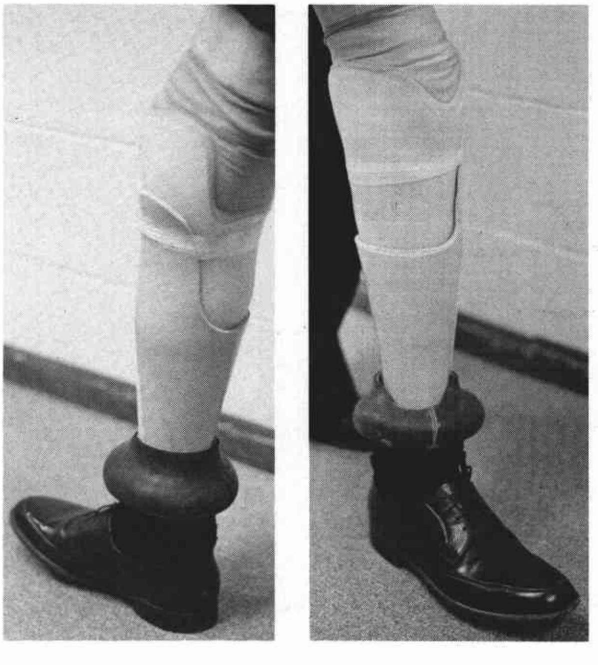


Figure 1. Medial and lateral views of T.F.S. in an exoskeletal version. Suspension sleeve and cosmetic hose rolled down for clear view of socket secured in place with band of fiberglass tape.

technique is being used with most of the geriatric population seen, and with time and experience it is being applied to an ever increasing proportion of the total below-knee amputee population served. Forty or more of these sockets have been fitted over the past five months to patients ranging in age from ten to 89 years with results that were beyond initial expectations. Patient reaction has been extremely positive. Plans are to submit an up-dated article when over 100 documented fittings with the described technique have been accomplished.

The idea for the T.F.S. design was prompted during the course of fitting a patient with a flexible diagnostic test socket. The patient was comfortable in this socket even when bearing his full weight on a padded fitting stool. Subsequently, when a full socket receptacle for the test socket was laminated and it was rigidly contained, this comfort was lost. The patient still complained of pressure even when holes were cut out over bony prominences.

Finally, when the maximum amount of material was cut away and the former socket receptacle was reduced simply to a means of attaching the socket to the rest of the prosthesis, thus allowing the socket to return to its former measure of flexibility, comfort was regained.

Several interesting phenomenons were noted:

1. Since the T.F.S. design is totally flexible, allowing ML as well as AP expansion and retraction, the socket finds and seeks its own level of pressure distribution. If the AP is too tight, it automatically expands, causing the ML to tighten up, wrapping around the tibial flare and the fibula. This, of course, is not true when a receptacle is only opened up over bony areas allowing no reciprocal ML-AP displacement and minimal flexibility, even over bony areas. With the T.F.S., if the ML is too tight, then the AP automatically tightens as the ML loosens, and vice-versa if the AP is too tight (Figure 2).
2. The AP-ML "Milking" action seems to have a positive effect on circulation since the residual limb seems palpably warmer when a T.F.S. is removed, as compared to when a rigid socket is used. In the case of flexible sockets thinner than 3/32 inches thick, the entire socket moves with the residual limb, seeming to expand and contract due to the open nature of the frame. This phenomenon can be felt better than seen by holding the socket as the patient alternately places weight on the prosthesis and removes it, especially after the socket warms up to body temperature.

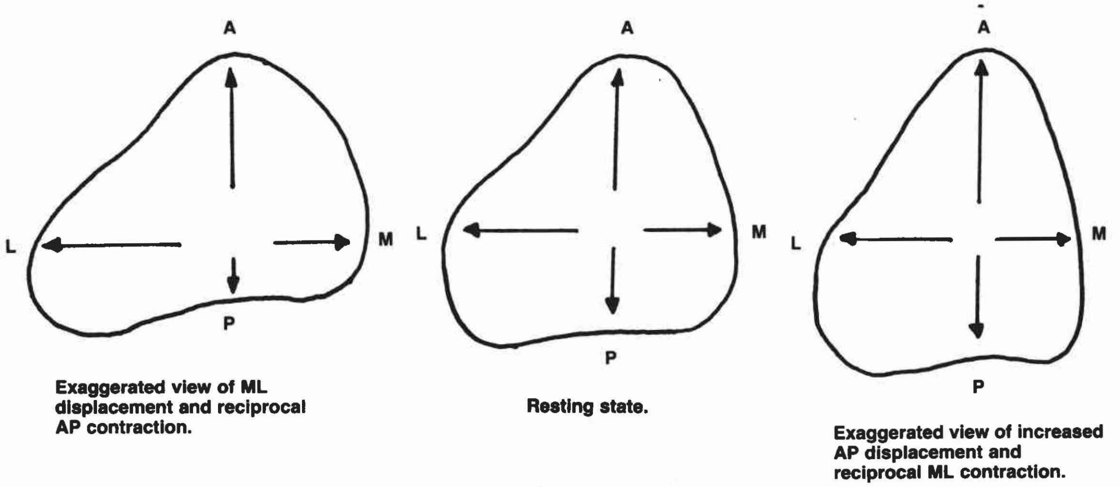
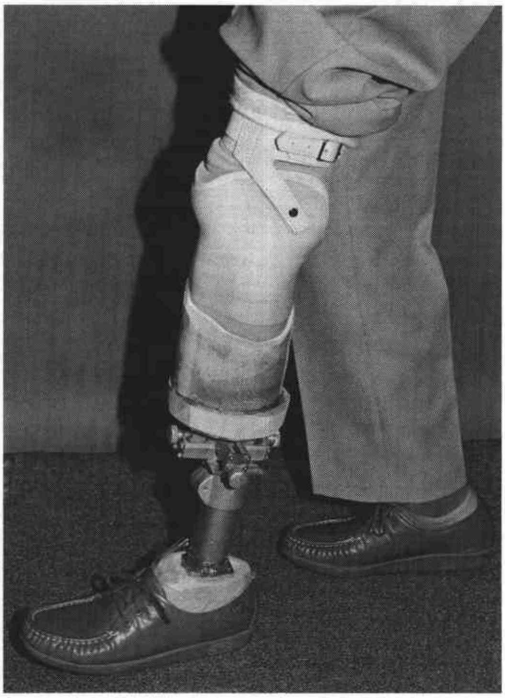


Figure 2. Transverse view of a socket cross section showing, in an exaggerated fashion, the reciprocal AP-ML displacement.

This dynamic socket movement and improved circulation could be very significant for the geriatric P.V.D. patient. This action also seems to enhance atmospheric suspension: when the patient removes weight, the socket collapses and grips the residual limb like the familiar childhood toy, a Chinese fingertrap.

3. Atmospheric Suspension (A.S.) assorted methods of achieving suction suspension for the below-knee amputee have been tried for years, with varying degrees of success. The main reason behind this effort is the desire to solve the number one problem of the below-knee amputee, that of skin shearing and pistoning between the residual limb and socket. Another major problem has been that of the patient wanting a lighter weight, more responsive prosthesis. With the T.F.S.A.S. combination, most patients have been responding favorably with such comments as "It feels like my own leg!" and "It feels like part of me!" With atmospheric suspension, the patient no longer needs to wear a suspension sleeve to maintain full suction. The Total Flexible Socket holds suction better than a rigid socket because the socket can move and conform to the changing contours of the residual limb, through all phases of gait and sitting. A loose elastic knee cage is recommended to enhance proximal brim seal during knee flexion past 90°. For sports prostheses, use of a rubberized sleeve of choice is recommended. Cosmesis is also enhanced since the patient no longer has the extra bulk of socks or inserts increasing calf circumference. It's a little too early to tell, but it is felt that atmospheric suspension may well become the standard below-knee fitting technique for all types of patients.
4. Use of a cuff suspension strap is improved since the cuff and socket brim can contour in about the patella (Figure 3). Use of a suspension sleeve with the T.F.S. is also possible, and if anything, enhances the function of a T.F.S. since the suspension sleeve supports the socket brim and soft tissues, holding the two in close conformity through the full range of knee motion.



5. Flexibility allows greater containment posteriorally in the popliteal region. The posterior wall can be higher since it flexes away during sitting. Little posterior flare is needed. In fact, this area could be rolled in slightly, similar to how the cubital fold is contained in myoelectric below-elbow arms (Figure 4). If the practitioner desires, the socket can be made flexible all the way down to the distal tibia. This is accomplished by building a thick distal end pad (with or without an insert) inside the socket, or an extension on the exterior of the socket which extends the trimline of the frame distally, allowing total flexibility in the distal regions of socket.
6. The ML measurement of the knee becomes wider as the knee flexes. This can be demonstrated by placing an ML gauge on the knee and watching the gauge as one puts the knee through its range of motion. The T.F.S. design allows for this dynamic variance.

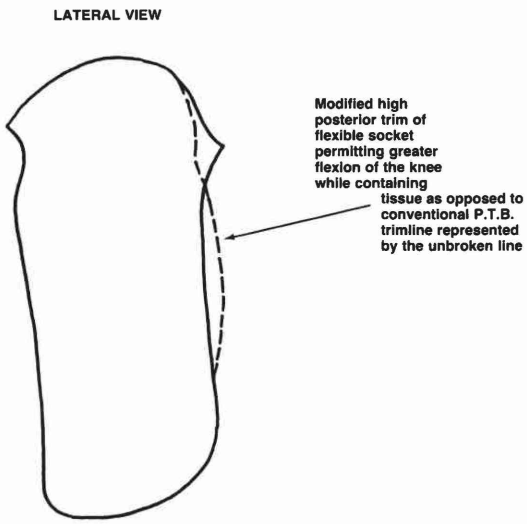


Figure 4. Lateral view of T.F.S. showing suggested modified contour.

Last but not least, overall hygiene and circulation seem to be dramatically improved. Especially impressive is the absence of red marks on the skin following doffing of the T.F.S. There are none of the usual red marks left by conventional sockets. Patients who had to have many reliefs before in their rigid sockets now require none.

Since several prosthetists have been fitting these sockets successfully, using various modification techniques, it has been concluded that it is irrelevant which particular modification technique is used. Results from all modification techniques have been improved utilizing the Total Flexible Socket. The use of negative modifications only is recommended. One simply does not need to add positive build-ups to the model since the reciprocal AP-ML displacement dynamically accommodates the patient's anatomy. The bony areas are accommodated automatically (most of the time) as the patient ambulates. It is, of course, most exact to use multiple transparent diagnostic sockets, alignate, or oil injection procedures (as well as other means) to obtain the best fit possible.

The flexible socket seems to work so well that it is tempting to skip the check socket stage. Do not succumb to this temptation, or you will never know just how comfortable the socket can be once you get the patient fairly

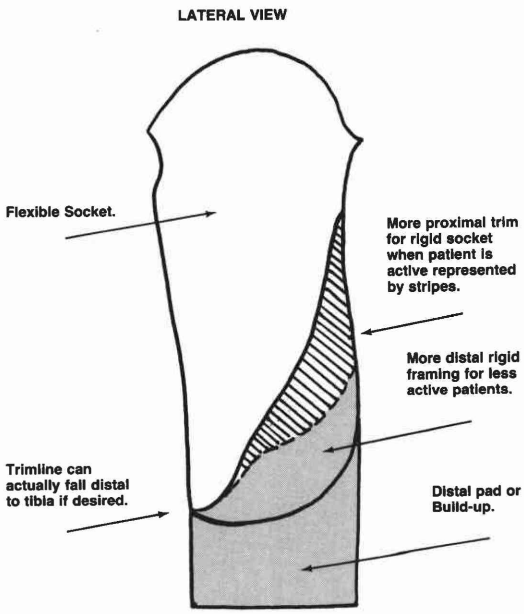
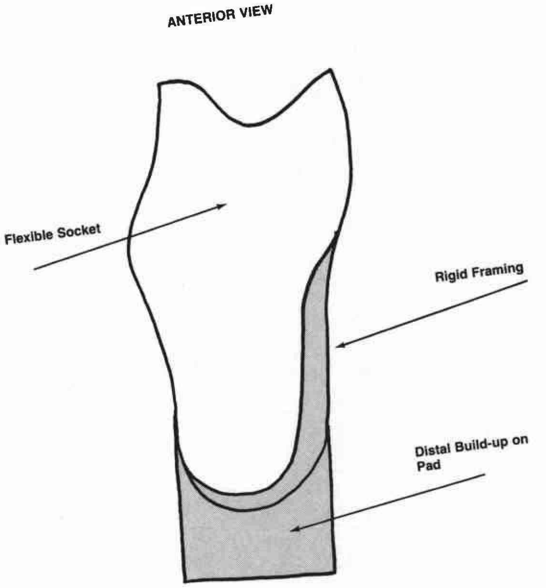
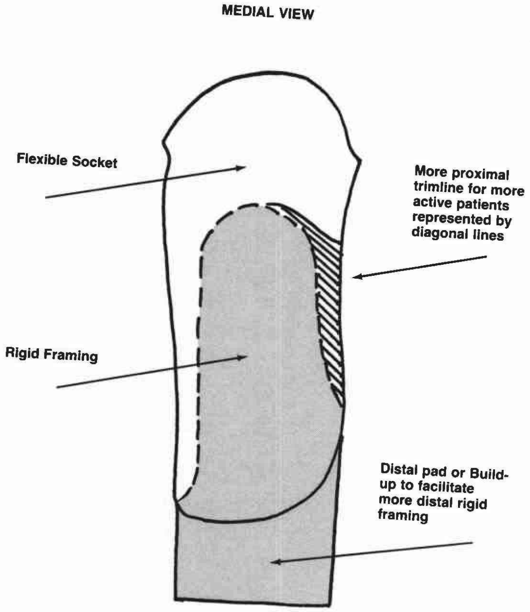
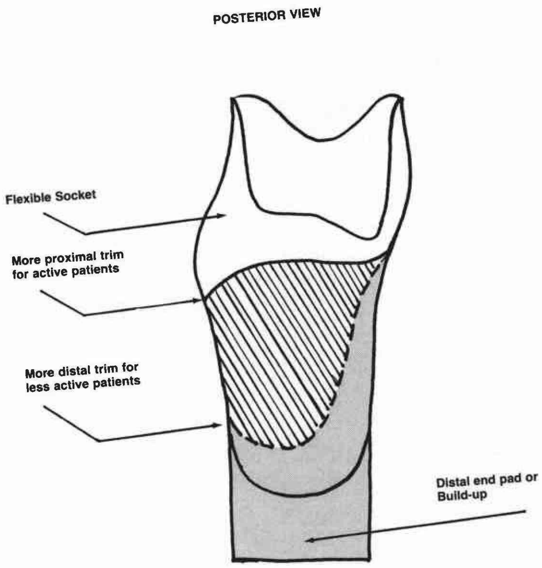


Figure 5. Four views of the T.F.S. showing sports and geriatric trimlines and distal end pad or buildup. Distal buildup is especially useful when it is desired to cut the anterior trimline below the distal tibia.







comfortable in the rigid transparent socket and clone it to the T.F.S.

After the hard socket is fit, it is necessary to remove an additional 1/4″ to 3/8″ of plaster from the positive model around the superior brim, close to the patella, to allow a flexible clamping action about the proximal brim. Use of this extra modification can not be emphasized enough for final comfort and stability. An intimate fit must be maintained around the proximal brim with the T.F.S. design. No other additions or modifications are necessary.

If a liner or insert is used, it is fabricated over the positive model with a thick distal end pad to provide extra distance distally. This extra length is necessary if one desires to make the distal tibia area flexible since the frame can be trimmed more distal, even past the end of the distal tibia. Alternately, as mentioned, an extension can be added to the socket following vacuum forming.

One can use any of four materials for the flexible part of the socket: The first is Surlyn,® which is preferred in most cases. This material can be molded fairly thin, and yet it provides excellent structural strength and integrity. Surlyn® stock material of 1/8″–3/16″ thick is used (depending on the degree of flexibility) for vacuum forming. A final thickness of about 1/16″ or less is adequate. It is not necessary for this socket to be extremely flexible, as with a fenestrated socket, since the majority of the socket is open and flexible in all directions with two adjacent sides being able to move relative to the frame.

The second material is polyethylene, which is more flexible and sometimes more desirable for children or geriatrics who are somewhat inactive. The third is Streifylast, which is a material that is being utilized more and more lately since it has a high level of flexibility while maintaining its structural integrity, and is especially resistant to tearing and breakage. A fourth material called Polyethylene Plus® (available through Maramed) seems to be superior even to Streifylast and has an extremely good tear resistance.

Once the socket is vacuum formed, a fiberglass nylon polyester frame is fabricated. Carbon fiber and acrylic resin can be used, if one desires greater strength and less weight, but is not necessary in most cases. The thickness of this frame depends on the activity level of the patient, but usually ranges in thickness from 1⁄16″ to 1⁄8″.

As in Figure 5, there are two basic frame designs: one for geriatrics, and one for active or sports oriented patients. The geriatric type extends proximally to the medial tibial flare and is cut away everywhere else except around the distal end pad (Figure 6). The sports type frame for younger patients comes more proximal posteriorally, lending more strength. It maintains total AP-ML flexibility since it still has only two sides adjacent to each other. As long as one does not place a third wall on the frame, reciprocal AP-ML flexibility is preserved and provides for automatic pressure distribution. It must be emphasized that these are only guidelines and the actual trimlines of the frame are variable and modified as the patient's needs dictate.

The flexible socket can be attached to the rest of the prosthesis by using two or three bands of nylon fiber tape wrapped circumferentially about the frame and socket to provide strength, while not affecting flexibility. If one desires even more strength, pressure sensitive tape can be wrapped over the nylon tape or even over the whole frame and socket. The socket can be riveted or fastened with Chicago screws in addition to the tape, for additional security.

The final finishing of the prosthesis is relatively simple. If an endoskeletal approach is used, the soft foam cover hides the socket frame interface as well as the nylon strapping tape and results in a very cosmetic prosthesis (Figure 7). The T.F.S. prosthesis finishes especially well as an endoskeletal since it feels more life-like all the way up the prosthesis. If one desires an exoskeletal finish, one can easily

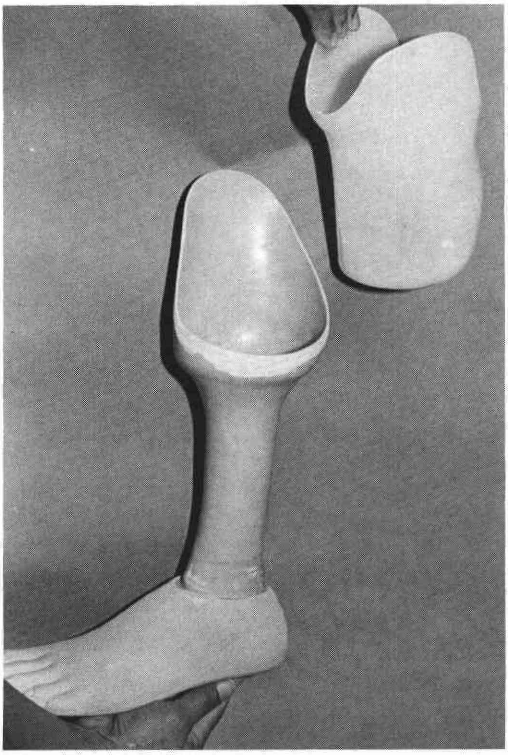


Figure 6. T.F.S. showing geriatric trimline. Ultralite construction.

use polyurethane foam for shape, laminate the outer covering, remove the flexible socket, and grind the foam away from around the frame and cosmetic shell as desired. This leaves a void or hollow of about 1⁄8″ (all that is necessary) between the flexible socket and cosmetic shell. Alternately, the prosthesis can be shaped and finished about the socket in the same fashion as an endoskeletal prosthesis. The proximal external contours can then be established with a soft fairing of PE-LITE™ or Plastazote glued to the flexible socket and frame.

Fabrication of an Atmospheric Suspension Socket is the same as for any T.F.S., except for the placement of either an expulsion valve or a small suction valve on a 45° angle at the distal posterior of the total flexible socket (Figure 8).

Modification on the other hand, is a little different than a non-atmospheric suspension T.F.S. The socket must be a little snugger to accommodate total self-suspension. After achieving the "perfect skin fit" with a clear diagnostic socket and the alginating proce-

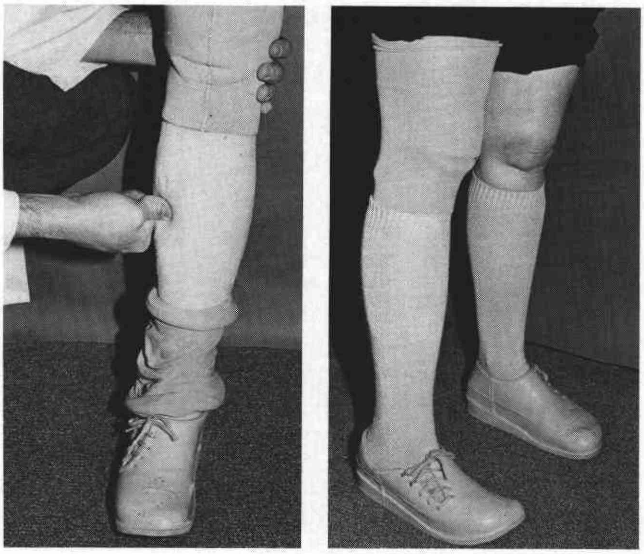


Figure 7. T.F.S. with soft cosmetic covering.

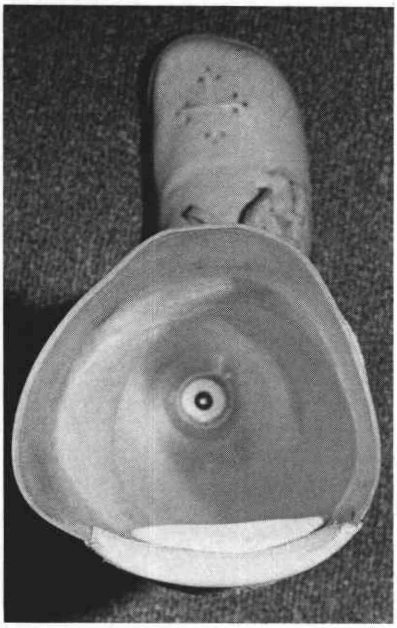


Figure 8. T.F.S.-A.S. showing placement of valve distally.

dures, the model is poured and modified the same as any T.F.S. by slightly tightening it about the patella area. The technician then takes the modified model and laminates a two layer cotton rigid socket over it, which is rolled or slushed twice with promoted liquid polyester resin to tighten all areas of the socket equally. This socket, with reduced internal dimensions, is then poured with plaster of Paris and the T.F.S. socket is subsequently vacuum formed over the resulting positive model. It is felt that this extra tightening is necessary to compensate for the fact that a rigid diagnostic socket cannot be donned as easily as a T.F.S. of equal or greater tightness.

In conclusion, a new concept for the fabrication of a below-knee prosthesis has been described, as well as the preliminary results of fitting some 40 patients for up to five months. It is sincerely hoped that other prosthetists will find it as beneficial to their patients as it has been found to be in both Oklahoma City and San Diego.

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