TRANSFERRING LOAD TO FLESH

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ABSTRACT

Prosthetics soft tissue trauma is attacked with a combination of theoretical and experimental tools. A novel socket design results, accentuating flesh stress relief at the socket brim. Currently, the novel socket has been fitted to two subjects with long histories of stump trauma; field test results are not yet available.

THE PROBLEM

My problem is the prevention of soft tissue trauma resultant from prosthetic devices. Specifically, how is a prosthesis to be joined to the body so as to prevent lesions, cysts, plugs, abrasions, etc. We cannot examine all these problems in one session, so let us consider one problem only in some detail.

Consider the cyst problem. The curious thing about cysts is that they usually form outside the socket, where one would think the mechanical loading would be low (Fig. 1). To quote the dermatologists Allende et al. (1), “Cysts do not occur where the rim of the socket touches the skin . . . instead, the cysts are often found 1 to 2½ cm. above the rim.” To quote James Foort (2), “Often when the stump is refitted and the cysts contained within the socket, they will clear up.” It would appear that some stress is greater outside the socket than inside. But what stress is involved, and what can we do about it?
To explore the problem, we need a description of stresses that result when something soft—flesh—is pressed by something hard—the socket. In particular, we are interested in what happens to the flesh just beyond the socket. Our theory was taken whole from the Russian mathematicians Vlasov and Leontev (3). The problem becomes one of applying the theory, of developing equations describing our special cases. The development is a tedious business and will not be given here. In summary, we are combining the classic theory of elasticity with newer variational approaches, plus a realistic model of flesh as a material. The entire derivation has been given in various issues of BPR going back to 1971, for those interested in the details (4,5).
RESULTS AND DISCUSSION

Some of the results are given in Figure 2, which shows the distribution of compressive stress in flesh produced by pressing a dull-pointed object, say a pencil, into the flesh surface. Obviously, the stress under the pencil will be large. Note, however, that as we move away in a lateral sense from the pencil, the stress falls quickly. What this implies is that no matter how great a compressive stress is applied to the brim area, the transfer of stress to remote areas outside the brim is unlikely to produce large values. Even more discouraging are the results of Figure 3, in which a rigid block representing the socket is pressed into 1 in. thickness of flesh supported by bone. Note that the compressive stress falls off immediately outside the loading block and dissipates within less than 1 in.

We are looking for some form of stress that is greater outside the loading block than within the confines of the block. The results of Figures 2 and 3 suggest that compressive stress is unlikely to be the culprit.

There are but two forms of stress—normal and shear. Normal (compression and tension) does not fit the facts; therefore, let us look at shear. The same analytical procedures applied to shear stress produce the following result: shear stress is roughly equal to the rate of change of compressive stress with distance. In other words, where the compressive stress is relatively "flat" (see Fig. 3), there is no shear stress. On the other hand, where the compressive stress changes rapidly, as it does beyond the edge of the loading members in Figure 3—the shear stress is a maximum. Or, in the case of a socket, the shear stress will peak outside the brim.

Consider shear stress as the culprit. It peaks outside the socket, fitting the observation of Allende et al. Shear stress disappears inside the socket, fitting the Foort observation that cysts frequently clear up if the...
affected area is moved within the socket. While no causal relationship between cysts and shear stress has been developed, the association between the two seems interesting enough to pursue.

The next step is to design a socket with the least possible shear stress. A number of false starts were made here. Figure 4 shows the shear stress associated with a diaphragm-like member similar to a garter. Note the severe shear stress developed at the ends; the concept is poor. A better design is shown in Figure 5. Unfortunately, it would appear difficult to fabricate. Still, it demonstrates what is desired—a gradual transition from full socket thickness to a thin brim. The long transition—and the longer the better—insures low shear stresses. At this point, we felt that theory had been pushed as far as profitable, and we switched to experimental work, looking primarily for confirmation of the analytical work.

The ideal experimental procedure is one involving direct testing on human subjects. Unfortunately, this would involve instrumentation implants and biopsies. These are not easy to arrange. As a substitute, we have employed a material called Spence-gel in the role of a model flesh (Fig. 6).
The basic idea is to press upon the edge of a slab of Spence-gel trapped between rigid flat plates. One of the plates is a window, through which we can see the deflections of the gel. Before testing, the slab is marked with a coordinate system. Compressive stress is shown by a shortening of any of the rectangles when under load. Shear stress is directly proportional to the departure from a right angle of the gridlines at any intersection of interest.

A typical test is shown in Figure 7. Here a dull chisel is pressed into the simulated flesh under a load of 1.1 lb. The reason for picking this type of loading—the dull chisel—is that the theoretical solution is particularly simple. Therefore, even though the dull chisel load is impractical, it lends itself to a good check of theory versus experiment.

A comparison of the predicted and experimentally determined compressive values for the dull chisel case are given in Figure 8. The curves represent the theoretical prediction of compressive stress along certain contour lines and the points are the experimental results. The quantitative agreement is disappointing; discrepancies as large as a factor of two appear between theory and experiment. It is not clear to me as to where the errors originate—both the theory and the experimental work con-
tain severe oversimplifications. Certain of these assumptions are in
direct conflict. For example, we assume that any vertical gridline re-
mains vertical in our theoretical work, whereas we make no such as-
sumption in our experimental work.

Granted that the lack of quantitative agreement is disappointing, it
should be noted that there is total agreement in a qualitative sense. That
is, every significant trend is supported by both theoretical and experi-
mental results. Remembering that our goal is the reduction of trauma,
our ability to predict and understand stress trends would appear an
adequate tool. Either the analytical or experimental treatment is suffi-
cient for this purpose.

How do we reduce shear stress? The basic idea is to reduce the rate of
change of compressive stress. Consider Figure 9. Here we have the dull
chisel case again, except we have inserted a thin cover plate between the
chisel and the flesh. Comparing Figures 7 and 9, you will note that the
cover plate reduces the magnitude of the shear stress under the chisel to
zero and creates relatively small shear stress values at the outer edges of
the cover plate. In short, it is possible to influence both the magnitude
and location of shear stress by control of the means of load application.
A simulated socket brim sustaining an inertial load owing to stump acceleration is shown in Figure 10. Note that significant shear stress exists only at the brim or outboard of the brim. Once into the socket, shear stress disappears.

What is wanted in a socket brim is something like the cover plate effect of Figure 9, some way of reducing the compressive stress gradient at the brim.

At this point, I worked with a prosthetist to put together a practical design (see Fig. 11). The socket consists of an inner layer compounded of flexible resin and an outer layer compounded of a rigid laminate. The outer layer is removed wherever we desire a low shear stress, i.e., in the vicinity of the brim. In this manner, deflection of the inner layer serves
to reduce the compressive stress gradient at the brim. The approach is analogous to that of the cover plate of Figure 9, and the brim solution of Figure 5, yet avoids the awkwardly thin sections of these approaches. Wherever considerable load must be taken at the brim, as at the ischial seat, the outer layer is simply left intact.
Two subjects have been fitted with such sockets. Both are hard cases with long records of stump trauma in the brim vicinity. Medical inspection is being conducted by Dr. Emilio Ejercito of the Castle Point Veterans Administration Hospital Staff, on a before, during, and after basis with frequent followup examinations. To comment on the results of two fittings is clearly premature; we shall await more fittings and the passage of some time before field test results are announced.

We plan to fit a total of six hard cases within the next year. Hopefully, this should be sufficient to indicate the presence or absence of merit in our approach.

CONCLUSION

We have dealt with brim area trauma in this paper and in the cyst problem in particular. This problem area is a fair example of our task and approach. It would be our hope to extend this type of approach to prosthetic flesh trauma problems in general.
REFERENCES