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Socket design for the above-knee amputee*

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Introduction

Three areas of socket design will be discussed (A) socket function, (B) prefabrication of sockets and (C) automation of procedures for socket design and fabrication.

Developments for me started when I became involved in a study of geriatric amputees at the Biomechanics Laboratory of the University of California. Dr. Johnson and I looked at what was being done to fit such amputees and examined over a hundred who were not getting prosthetic care to see if there were any who should be provided with prostheses. At that time, plaster sockets attached to crutch sticks were being put on by interns and others as means of obtaining "inexpensive" temporary prostheses. Based on the work that had been done and was going on in quadrilateral socket design at Berkeley two options seemed suggested for improving the delivery of sockets to this group of amputees besides the standard one of carving them wooden sockets. We could design a jig which would form the plaster to a better shape, or we could fit a more functional type of socket fabricated by less exacting methods than wood carving. At the same time, work was going on to solve the problem of how to make a good plastic total contact socket for AK amputees. Up till then, what we had done was to make the end impression of plaster, cut the socket, make a plastic end-cap and install this in the cut socket at the end. Alternatively we would take a total impression out of such a socket and make a plastic total contact socket. Considerable work was done to hand-cast AK stumps for production of plastic sockets, but the prosthetists were not so keen on the plaster method because wood was easy to work, quick, and clean compared to plaster. You can see that a variety of experiences were at work which led us eventually to the adjustable brim fitting equipment and procedures and later to prefabricated AK sockets for temporary use.

Thin plastic laminate jigs made to form plaster to shape were tried and soon we put the jigs directly against the stump and merely wrapped the plaster around the distal portions of the stump to obtain the required shape. The shapes were used to make models for the fabrication of total contact plastic sockets. The first six persons fitted reported such good results that we embarked on a programme to develop what are now commonly called the Berkeley Brims. Subsequently, they were used as the basis of shapes from which prefabricated sockets were designed for direct use in the early prosthetic management of AK amputees.

When you start thinking of prefabrication of sockets other considerations arise. The ultimate condition could be that *all* sockets would be prefabricated. Then it would inevitably happen that people would fall outside the range of such socket series and suffer neglect. The ultimate conditions would be realized if *all* sockets could be fabricated from objective data relating directly to the individual involved. That is if we had a system by which a *customized* socket would be available as quickly as a prefabricated one could be drawn from the storeroom. Such a prospect has encouraged me and others to enter into a programme of study to *automate* the design and production of those elements of prostheses which are shape determined. At the present time, we have gone as far as to replicate a socket which an amputee was wearing, produce a cosmetic cover from data taken from the normal leg, all by machine methods. That is a start.

Ultimately the method will lead us back

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toward *prefabrication* of sockets for those who can use them and leave us the option of *customizing* for those who cannot. The basis for such an evolution will be the capacity to *modify* shape on a mathematical basis and we have taken the first halting steps in that direction.

A. Socket function

The obvious functions performed by the socket of the AK prosthesis are;

(a) it links the amputee to the prosthesis for transmission of support and control forces,
(b) it contains the stump tissues so that internal and external forces across the interface will allow optimum biological functions to continue,
(c) it provides sensory information to use in controlling the prosthesis,
(d) it protects the stump from the environment.

I would like to discuss socket function in terms of the *Adjustable Brim-fitting Technique*.

The system is based on the *quadrilateral* socket shape. It developed out of the quest for a "standard" socket system and for a method of dealing with the geriatric amputee which would take into account the biomechanical requirements for an adequate socket. As soon as a committment was made for the development of the "jig" system, a search was made for measurements and contours on which to base design. We had measured a variety of sockets and stumps, and had begun to learn quite a bit about basic shape related to AK socket design. Also, Bill Hoskinson and I had considered prefabrication of sockets as a worthwhile prospect. Estimates were based on three stump lengths and three types which indicated that a good system of prefabricated sockets might lead to the establishment of a bank of primary sockets in the order of 1,200. Such an array of standard sockets, even assuming them to be valid, would pose a difficult problem of storage and selection. The quantity was gradually scaled down to 10 left and 10 right by introducing the limits and adjustable features now present in the adjustable brims. During the process, one change in view that has always seemed important to me was that not *circumferences* but *diameters* were fundamental as a basis for socket design.

The quantity I eventually settled on for dimensioning the brims was the *mediolateral diameter*. But most fundamental to the design of the proximal socket shape was the triangle defined by the *ischial tuberosity*, the *tendon of adductor longus* and the *greater trochanter*. Finally, I found that it was sufficient to determine the distances between the ischial tuberosity and tendon of adductor longus and between the tendon of adductor longus and the greater trochanter. The third side of the triangle was so closely related to the tendon-trochanter distance that the additional measurement was of no value. Further, I found that if the person being measured was seated, the distance *up* from the chair-surface to the tendon of adductor longus was not significantly different from such measurement as would be obtained by having the patient stand so that the distance could be measured between the tendon and tuberosity.

Because there were few systematic measurements available the system was developed from a size central to the whole system and the increased and decreased sizes followed. The middle size, that size which is most commonly used, has a mediolateral width (equivalent to the tendon-trochanter distance) of approximately 16cm. For this size, the tuberosity-tendon distance is commonly about 8.75 cm, and socket dimension is comparable. Laterally, the width of the socket brim from front to back where it is largest is approximately 11cm.

A reasonable assumption made was that if the radii of curvature around corners and over edges were made gradual enough, the brims would be adequately shaped for *all* stump types. These were based on typical socket shapes seen in the clinical study programme, which related significantly not only to the stump requirements, but also to the sort of tools used to shape the sockets.

In summary, the brims are sized on the basis of mediolateral stump widths or diameters; are adjustable on the medial and lateral sides to allow accommodation of different stump types within them; have radii of curvature common at corners and edges; and are based on the quadrilateral socket shape.

Brim selection

Selection can be based on the mediolateral width or diameter of the stump being fitted. Another method of selection is to try the brim in the middle of the set and then if it is too large move to the middle of the range of sizes between the smallest and that one just tried. Other alternatives are obvious.

Immediately you may legitimately ask "*But what if the basic shape is inadequate?*"

Go back to the idea of the *triangle* bound by the ischial tuberosity, the tendon of adductor longus and the greater trochanter.

You will diverge from the basic quadrilateral shape on the basis of how the residual limb deviates toward the lateral side from the quadrilateral shape due to sparsity of musculature posteriorly and anteriorly where the brim diverges to its widest dimension.

The aim is to securely "lock" the proximal end of the stump into the socket in a way that optimizes the main functions of linking the prosthesis to the body for support and control, containing the tissues for optimum biological function, obtaining sensory information and protecting the stump.

You must be cautioned that to use the brims without regard for the variations required by the nature of the particular residual limb being fitted is to miss the point of the basic triangle around which the proximal socket fits and how the basic quadrilateral shape may be varied due to the volume of musculature toward the lateral aspects of the residual limb.

Positioning

We are led to believe that *ischial weight bearing* is the prime source of support during loading of the artificial limb in stance phase. If you note what actually happens however, you will be aware that the location of the ischial tuberosity is much more dependent on the *type* of stump (based on the volume of stump tissues) and that such rules as "one inch in from the corner" do not really hold up. I pay attention to getting the tendon of adductor longus in the right place. I only expect that the ischial tuberosity will be at the correct *level*, that is flush with the posterior brim. I have seen instances when the amputee experienced best comfort when the ischial tuberosity hung over the medial brim, or over the posterior brim! Such things occur when the prosthetist organizes the pattern of weight bearing or force transmission within the socket to provide function in a certain way or to avoid force applications on certain regions of the residual limb. That is good.

Weight bearing

Consider the situation in which a man stands down firmly on his prosthetic socket. Let us identify every possible portion of the residual limb which can contribute to weight support;

(a) the ischial tuberosity,
(b) the tendinous structures emanating from the ischial tuberosity,
(c) the gluteus maximus,
(d) the posterior aspect of the proximal femur,
(e) the posterior aspect of the more distal parts of the residual limb,
(f) the lateral aspect of the femur, hip joint adducted,
(g) the inguinal crease area,
(h) the tendons from the ischiopubic rami (including the tendon of adductor longus),
(i) the pubic symphysis,
(j) the total stump musculature, especially when tensed,
(k) the tissues as a fluid mass, (Redhead 1973),
(l) the other areas of the pelvis including the ischiopubic rami, coccyx, iliac crest,
(m) the end of the stump-bone, tissue, muscle.

As you can appreciate, if you do your fittings with all of these regions being considered, your approach to fitting and the results you will get will be much different than if you rely on the quadrilateral shape of the brims. Nor is it enough to consider these potential weight supporting regions in isolation from *movements* which are possible between the socket and the residual limb. These movements are dependent on the *period* of the weight bearing cycle you are considering.

As examples of the influence of the significance of the *period* of the walking cycle on socket shape you need only consider the shape of the anterior brim of the typical AK socket. The flare is very generous here in line with the somewhat soft and dispersed nature of the weight bearing surface in the inguinal crease region.

This inguinal crease area of the stump is loaded especially at and just following heel strike.

Posteriorly, against the gluteal fold region, the flare is also pronounced, but less so than at the inguinal crease because of the more definite support possible and the assistance to support provided by the ischial tuberosity and the hamstring tendons.

This posterior area which includes the ischial-gluteal regions is loaded especially toward the middle of the stance phase and onward until toe-off.

I discuss these factors mainly to give you a feeling for the way in which I consider socket loading in relation to shaping of the socket through cast modifications or whatever method I use as an alternative to brim-fitting.

And when you consider the forces and movements in relation to socket shape, do so in a way that areas of the stump are visualized, and in a way that forces are changing as the movements proceed. Do not think in terms of the static situation as you fit, and stop thinking in terms of lines of force directed at points. Start thinking in terms of areas available for support and in terms of how these are likely to interact with the socket as the body moves over the prosthesis in its various phases of action.

I have laid a great deal of stress on the proximal socket regions. Typically they carry most of the load. But if too much reliance is placed on the proximal end of the socket for weight bearing and control, the circulation of body fluids may be disrupted.

Aim to distribute the forces as evenly as possible along the entire length of the residual limb supporting the distal tissues as evenly and as firmly as the amputee's condition allows.

How easily you realize your aims in fitting a socket with the brim-fitting technique depends on how you use the equipment for making the impression and what you do to adjust the model.

The impression

It is tempting to stand the amputee with his residual limb held in the brim as it is supported on the stand provided. My own preference is to have the amputee lie down with his amputated side up and his residual limb somewhat abducted to improve access to it. I then select the brim by trial and error. The brim selected is put on the residual limb and adjusted as it is held in place by straps or by a second person, even the amputee can assist.

This method is comfortable for the amputee and places him in a very accessible position for the person making the impression of the parts extending beyond the brim. The muscles are relaxed, the tendency for oedema formation otherwise experienced is prevented and the bony lateral structures are made prominent as the tissues sag away toward the medial side.

This method of positioning the amputee is as useful for hand-casting methods as for use with the brim-fitting technique. The brims are, after all, not much more than measuring calipers which give volumetric as well as linear information about the residual limb.

As the plaster impression is made, you will be thinking of the control and weight bearing requirements of the socket and will be anticipating the modifications you will make to the model for more accurate realization of these aims.

As an example of the process of continuous planning as you proceed through the various steps, you may well insert wads of plaster bandage *between* the brim and the residual limb to improve your results, even going *above* the brim to form an impression of pelvic areas which might help you produce a better result.

Touching on the matter of the art of being a prosthetist, some general observations can be made which might be of use to you:

(a) For short residual limbs, fit high, going beyond the brim to enclose a considerable part of the pelvis, especially laterally, anterolaterally and posterolaterally.
(b) For long residual limbs, fit looser proximally than you would for shorter ones.
(c) If weight bearing characteristics of the residual limb make it necessary to fit tighter mediolaterally, compensate by fitting looser anteroposteriorly.
(d) Bony residual limbs tend toward a triangular shape proximally while the more heavily tissued ones tend more toward the quadrilateral shape.
(e) An especially lightly tissued residual limb should be fitted by hand-casting methods rather than by the brim-fitting technique.

Model modification

When the model is poured, you have an *approximate* shape. What to do with this model cannot be outlined in foolproof manner just as it cannot for any method of casting. You *must* consider the shape in terms of the forces and motions you have to deal with in the final socket. The sooner the model is modified after the impression is made the better it will be. But I can make some observations again:

(a) For the short residual limb, the model must be modified to give a bottle-like effect in the final socket. Thus, the plaster is carved inward to form a gentle sealing ring to ensure retention of the limb by suction, the preferred method of suspension for short residual limbs. Forcing mediodistal tissues upward also assists in filling up the spaces just below the sealing ring to increase its effectiveness. The medial and posterior flares should be extended outward to allow ample material for trimming later, posterolaterally the gluteal shelf should curve upward to close in the space behind the trochanter. Increasing the outward-projection of the anterior flare and curving it upward to meet a greatly extended lateral wall can also be helpful, especially when the person is heavily built and fat. The typical femoral triangle bulge inward is greatly shortened in this process of "undercutting to form the sealing ring".

(b) When the anterior brim is too high, it tends to drive the socket off when the person sits. Commonly, the prosthetist grinds the brim down but fails to flare it again to bring it to the original curvature. This is a mistake that can lead to pimples and abrasions due to increased pressure over the smaller area of skin compressed.

(c) Over-modification of the model is seldom a problem when the impression is made with the amputee standing in the brim. When the impression is made with him lying down on his natural side, then more care is required in modifying the cast. The difference arises because less oedema is present when he lies as compared to when he stands.

(d) Prosthetists who provide generously flared surfaces at the brim of the socket are more likely to succeed as far as comfort is concerned than those who make less rounded curves. It stands to reason that if those with fragile skin and sensitive tissue respond well to the more rounded contours, then those who are more rugged will not object to finding similar features in their own sockets.

The radii of curvature at corners and over top surfaces of the socket can be constant at any given region for all sockets.

It is the distance between the various socket surfaces, which relates to the size and firmness of the particular persons, that vary. Also variable is the angle each surface makes with respect to the other from person to person, including the angle with respect to the axis of the socket as well as the angle one would see between walls in a cross sectional view.

I have treated the walls as though they were flat for purposes of this argument, and that is not a bad way to visualize them for sake of understanding what you are doing, but in the last analysis, each surface must be contoured for optimum comfort which means that the gradation of pressure or force from section to section will be as gradual as possible, consistent with the best force distribution for weight bearing and control, the balance between internal and external forces, the provision of sensory information, and protection.

B. Prefabricated sockets

A prefabricated socket is defined as one which is made in specified sizes on permanent moulds for "off-the-shelf" application. The experience I have had was in the use of sockets I had designed in approximately 1959–60, and which were improved in Winnipeg during the early 1960s. These particular prefabricated sockets were made in four sizes left and four sizes right; they were fitted to any of the recently amputated patients for whom we wished to make a temporary prosthesis. While these sockets were designed for the limited purpose of early initiation of prosthetic management and conditioning, others have been designed which have potential for use in definitive prostheses for some amputees.

Prefabricated sockets *could* be designed to cover *every* possible use to which an AK socket might be put! However, it is not very likely at this stage that such an ambition could be realized and if it were that it would be the best way to go. Therefore, our ambitions will fall short of the maximum possibility and in designing them *they should be designed according to specified end use on the basis of an established need for which they can be used without threat to the wellbeing of the amputee.*

If we look at the *use* such prefabricated sockets can be put to and think in terms of the least good we can derive from them then I would list the following;

(a) protection of the residual limb,

(b) control of oedema,

(c) conditioning of the amputee to the feel of containment,
(d) preparing the amputee psychologically for prosthetic rehabilitation,
(e) assessing his potential as a prosthesis wearer,
(f) permitting early initiation of rehabilitation when the alternative is to wait,
(g) providing a means of ambulation while the definitive prosthesis is being made,
(h) serving as a tool for the therapist in reconditioning the amputee.

If we wish to go beyond these limited aims so that (a) the amputee can be sent into outpatient activities or (b) can use such a socket as part of a definitive prosthesis then the design must meet increasingly stringent criteria.

Let us assume that the user has the sort of needs that are typical in the early stages of rehabilitation following amputation and ask what factors make for successful results with the designs that are available;

(a) the amputee who can be confidently fitted is at a low level of activity,
(b) he will use the prosthesis under competent supervision,
(c) he will be in a protected environment such as a rehabilitation unit,
(d) the stump is well padded with tissues and oedema,
(e) the prosthetic components and their alignment are appropriate,
(f) the suspension system provides optimum control (shoulder harness is preferred),
(g) the appropriate size and shape of socket is available to the prosthetist,
(h) the skills available to serve the amputee are appropriate.

Factors which can lead to failure are as follows;

(a) improper selection of the person for the system available,
(b) improper design of the sockets,
(c) absence of the required skills to use the system.

The prefabricated socket must be of a size and shape which is compatible with the person who will be fitted with it and appropriate for the level of activity at which the user will function.

I can say with confidence that if you have a group of people to deal with under conditions such as I have specified and you are not starting prosthetic management early, then you *should* try some temporary AK sockets on modular or other components in an attempt to improve the flow of cases through the rehabilitation process. What system should you try? Naturally, the one with the greatest variety of sizes and shapes would be best *provided the criteria for the selection of the appropriate socket are sufficiently well specified to allow selection to be correctly made.* The systems available allow adjustment of girth so that the stump can be accommodated as it changes shape with conditioning up to a point and also, functional improvements in fit can be made by adjusting the size to the most appropriate dimensions for the size of stump being fitted. Some people also make *modifications* by adding liners or grinding material from such prefabricated sockets. Such a practice is to be avoided, it suggests that the amputee is not appropriate for the size or the system available. In that case, a fitted socket should be used. I have added felt liners taped in with medical adhesive tape to improve results, and suspect that others will do the same to maintain function when hard pressed.

If you have no experience and wish to initiate actions which will speed up the process of rehabilitation without putting undue pressure on the prosthetist, the following procedure is suggested:

(a) Stock a few sockets in the sizes from 15 cm to 18cm wide in the mediolateral direction. If the number of sockets within this range of sizes is too great for your resources, stock every other one within that range of sizes. Another option would be to use the simpler Winnipeg system.
(b) Try the most appropriate of these sockets on a few selected amputees who are passing through the rehabilitation phase when to do so would enhance their rehabilitation—i.e., training on a prosthesis will be started sooner.
(c) Restrict use of the prefabricated sockets to inpatient services, at least initially.
(d) Extend use to increasing numbers of patients and for increasing levels of activity when to do so will; (1) improve results for the patient; (2) speed up the rehabilitation process; (3) increase effectiveness of staff.

When I look back over the more than 20 years since Bill Hoskinson, then prosthetist on the project at Berkeley and I, acting as research engineer, would discuss the prospects for making prefabricated sockets my surprise is that it has taken so long for good systems to develop. My feeling is that as people commit themselves to use such systems as exist for what they *will* do, then designers will meet whatever demand may develop for extending the limits of usefulness. It will be possible for designers to develop the means by which large numbers of AK amputees can be fitted directly with prefabricated sockets in a prosthetic system which will serve definitively. For now however, the choice is limited. 1. There is the "super universal" system, which consists of air filled bags set into tubular frames. This is a suitable system to use in the very early phases of rehabilitation before the patient has reached a healed state or the functional level at which he should be experiencing use of a prosthetic knee. It is used only during the training period and so does not offer continuous conditioning or protection. It is especially comfortable to use, and may in fact precipitate complaints at later stages when the "cushiony" feeling cannot be matched in the socket designed for more vigorous use. 2. There is the Winnipeg system which consists of four sockets for each side. These are in common use in Canada and perhaps in other regions. It is suitable for use on patients who are being trained as inpatients in a rehabilitation unit. 3. There is the U.S. Manufacturing Company system which has a far better range of sizes than the original Winnipeg system. Its drawback is that it cannot be adjusted distally where most of the stump changes occur. However, I would rate it as the best system so far. 4. There are systems which employ "laced" sockets. The quadrilateral shape is absent. Based on the knowledge that such sockets have been available for many years and have never been widely used, the prospects are that they have less to offer than the other systems. The closer the prefabricated socket resembles the socket which will be fitted finally the better, otherwise the amputee faces a reconditioning step in his rehabilitation.

The question arises as to the place of prefabricated sockets in the scheme of treatment when there also exists the option of using plaster sockets as in the application of immediate post-operative prostheses. The temporary prosthesis which includes a prefabricated socket follows *after* the first plaster socket is removed unless a subsequent plaster socket is required as a means of dealing with wound healing. Or the rigid prefabricated socket follows on the "air splint" type of socket when that option is used in lieu of plaster socket. Or the rigid type of prefabricated socket is applied once healing is complete or near enough so to allow use of a prosthesis under supervised conditions. Of all of the options, plaster, air splint, laced or rigid—the rigid type of prefabricated socket will be used for the longest period of time and hence it should be the aim when time is of the essence to go directly to this rigid prefabricated system for the management of the new amputee. When consideration is being given to using such a prefabricated socket in a definitive prosthesis, the U.S. Manufacturing Company system, or any system comparable is to be preferred.

A word for designers. Now that there is sufficient experience to demonstrate the viability of prefabricated sockets for rehabilitating AK amputees, there may be a case for developing improved versions. Designers who are considering such a project should not do so unless they are able to enlist the aid of a computer system within which they can store basic shapes for the extrapolation and improvement of shapes to be used as moulds for construction of the prefabricated socket series. Such a system of shape storage is being worked on at UBC and holds promise as the ultimate means by which to generate the required series and keep it current.

C. Automation and utilization of shape data

In reporting on the project in which we are involved at the University of British Columbia (Duncan et al, 1973) I cannot give you information you can use, but prepare you for a different future than you might expect for shape data processing.

The first question to answer is whether or not it is feasible to quantify shape for use in prosthetic procedures. The answer is a definite yes. The next question is whether or not it will be economically sound to use in any prosthetic procedures. Again the answer is yes. Another question which you will be wanting answered is what such a method is. Finally you will, given a suitable level of curiosity and imagination, want to know when such methods might enter useful service some possible uses having entered your mind.

It is to the method and the prospects that I now turn.

Take an empty picture frame and lay it on its back. Drive a row of tacks into each of the narrower sides so that the tacks face upward. String fishline onto these tacks so that the space between each thread is approximately equal to twice the diameter of each thread. You will end up with a "harp" with which you can play with light. Place below the harp any suitable object, perhaps a ball. Shine through the harp a point-source light, setting the light at some angle which will produce shadows of the strings on the object underneath. As you look through the harp at the object below, concentrating particularly on the shadows where they clash with the overlying strings of the harp, you will see "interference fringes" when the light is in a good position. These Moire patterns are suitable for use as contour maps (Takasaki, 1973). Take a picture of the shadowed object through the harp with the camera directly overhead; now you have a shape-map or contourgraph of the object under the grid. The relationship between the camera position, light source position, grid and object can be mathematically defined. Steps in the process by which the shapes can be reproduced in concrete form are;

(a) collecting the data photographically using the Moire fringes to get the "shape-map",
(b) tracing the maps off for storage in the computer using the Gradicon electronic tracing table,
(c) correcting the data in the computer using established programmes,
(d) using tape from the computer to programme the milling machine which gives the sculptured shape.

The sculptured shapes are used in the conventional way for the production of prosthetic components which are shape determined.

In one of our experiments we recorded the natural shank to obtain data for the cosmetic restoration, and we took data from the socket being worn so that it could be replicated. The person for whom this was done continues to wear the prosthesis routinely after more than two years.

For such a system to be of use in prosthetics and orthotics it must be possible to *modify* shape. Some modifications are very easy. For instance, in the case of the replicated prosthesis, we could change the left side shape into a right side shape with a negative sign. Other shape changes for which we have programmes include elongation or thickening. It would be as easy to write programmes which would twist, bulge or taper shape. A more complicated programme allows us to elevate or depress various regions we choose. Such operations on a shape are equivalent to carving material from, or adding material to, a plaster model of a stump for example. The operations which must be elegantly mastered to make such automated procedures undisputed heir to our artisan methods are;

(a) an optimum method of sensing shape,
(b) a method by which the shape can be programmed instantly,
(c) means by which the shape can be modified easily,
(d) improved means for carving the shapes,
(e) improved methods for utilizing the carved shapes.

The best results will be achieved when these things are tackled in a spirit of co-operation rather than in a spirit of proprietorship. The current method of mapping has already been improved. We can now make a map as though we had "peeled" the information off the shape like a skin by revolving the shape as we move the film in the camera. At BRADU in London, using one of our contourgraphs, the possibility of digitizing such shape maps in one fiftieth of a second has been demonstrated. (This is to be compared with our minimum of 20 minutes by hand digitizing methods on the tracing table). Much work needs to be done to make shape modification more useful if we are to have a total system. As for improved carving, the machines exist which will expose our shapes in minutes. As for utilization of the sculptured models, such techniques as vacuum forming are made to order. Also, we have made "blow moulded" cosmetic covers experimentally and have postulated a re-usable mould made on the principle of the bean bag which is rigidified by vacuum and which can be used over and over again in the production cycle to produce a female mould into which cosmetic covers can be blown.

But for the immediate needs in prosthetics, there is the prospect of putting existing shapes into the computer as an alternative to storing such shapes, and generating a whole family of shapes from a single one, both for left and right sides. There is the prospect of modifying shape in specified ways, simple ways initially but finally in complicated ways so that we can use the computer as a potter uses his thumb.

I will attempt as my first effort to match a stump with a pre-established shape on a split television screen by changing the dimensions and size of the pre-established shape until the match is close. I will make a socket of this shape, and try it on the amputee. This sort of application can soon be realized for practical purposes and will develop naturally out of the line of enquiry we are now pursuing.

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REFERENCES

Duncan, J. P., Patterson, F. P. and Foort, J. (1973). Three dimensional shape-sensing and reproduction of limbs and limb remnants. Interim report. Department of Mechanical Engineering, University of British Columbia, Vancouver 8.

Redhead, R. (1973). Above-knee amputation stumps and their prosthetic management using total surface bearing self-suspending sockets. Ph.D. Thesis, Department of Mechanical Engineering, University of Surrey.

Takasaki, H. (1973). Moire topography. *App. Optics,* **12:4,** 845–850.