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Clinical Prosthetics & Orthotics

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President's Message



Kurt Marschall, CP

Dear Practitioner:

Serious, meaningful, mind-expanding writing, be it prose, poetry, or of a scientific-technical nature, deserves to be preserved for posterity, for reading enjoyment, or for a quick reference at a later date. This end result of the productivity of the human mind and spirit should be assembled and bound in a suitable manner so that it can grace our bookshelves in our homes, schools, universities, public libraries, and knowledge retrieval centers.

The Academy's own publication, *Clinical Prosthetics and Orthotics—C.P.O.*, deserves similar treatment. For many years dedicated Academicians, physicians and other members of the health care professions have contributed articles, lead papers, and editorials of significant value to *C.P.O.*, serving the field of prosthetics and orthotics. The *C.P.O.* format, essentially of a newsletter type, never quite seemed to do justice to such excellence. Your Academy Board of Directors was fully aware of this fact and authorized, as soon as it was financially feasible, to update the format of *C.P.O.*

It is therefore with great pleasure and pride that the Academy presents to you, the practitioner, your own publication—*Clinical Prosthetics and Orthotics*—in a new format which we hope you will like and value. Most importantly of all, it should now be possible to collect and preserve issue after issue of *C.P.O.* for further reference.

I would like to give credit to the *C.P.O.* Editorial Board, Hans Richard Lehneis, Ph.D., CPO, chairman; Charles H. Pritham, CPO, editor; Editorial Board members Charles H. Epps, M.D., Tamara Sowell, RPT, Dennis Clark, CPO, Joanne Shamp, CPO; Chris Colligan, publications director at the National Headquarters, and his assistant, Sharada Gilkey, who have worked so diligently to make this publication representative of a maturing Academy.

We shall continue to issue *C.P.O.* on a quarterly basis. As President of the Academy, I urge you to be aware of our need for articles in future issues. Here is your opportunity to express your views, findings, and expertise. Please give freely of all of the above. Your peers, the community-at-large, and above all, disabled individuals—not only here in the United States but all over the globe—will be grateful to you for your input and contributions.

I sincerely hope that *C.P.O.* in its new format meets your wholehearted approval and acceptance, and increases your pride in belonging to the Academy. May *C.P.O.* always serve as a stepping-stone to better understanding through meaningful communication.

Best wishes,
Kurt Marschall, CP
President of the American Academy
of Orthotists and Prosthetists

A New Perspective



H. R. Lehneis, Ph.D., CPO

It is a great pleasure for me to introduce this issue of *C.P.O.*

As you can see, *C.P.O.* has shed its former appearance for a newer look. More than just a new cover, the new look represents a change in style and content within the pages of *C.P.O.* With these changes we hope that *C.P.O.* will better reflect the latest advancements in the Academy and the orthotic-prosthetic profession.

From an historical perspective, *C.P.O.* evolved from the *Newsletter*, originally published by the Committee of Prosthetics and Orthotics Education (CPOE) of the National Academy of Science (NAS)-National Research Council (NRC). When CPOE became defunct in 1976, Joseph Cestaro, CPO, then-Academy President, fortunately saw the great need to preserve the *Newsletter* not only as an organ of interdisciplinary communication but also as a means for the Academy to have its own publication.

After many months of hard work and negotiations with NAS-NRC, Joe was successful in achieving his objectives. These objectives are still maintained today in the interdisciplinary composition of the Editorial Board, and *C.P.O.* continues to be *the* Academy publication.

We are most grateful to Joe Cestaro, for without his efforts *C.P.O.* would not exist; to Ben Wilson, who was editor until then-Academy President Michael Quigley, CPO, appointed me to chair the Editorial Board in 1978; to Charlie Pritham, CPO, the present Editor of *C.P.O.*, who is doing an outstanding job; and to the entire Editorial Board and staff for their cooperation. Without all of the above, *C.P.O.* would not have matured to the point it is today.

Finally, I sincerely hope that the new look will attract more contributors to future issues of *C.P.O.*

H.R. Lehneis, Ph.D., CPO
Chairman, Editorial Board

Sockets, Linings, and Interfaces

by Eugene F. Murphy, Ph.D.*

A prosthesis, whose Greek source means "put to," must of necessity have contact with the residual limb or stump. The functions of this contact region or socket (perhaps supplemented with lining, sock, and further attachments or harness), are to allow the transmission of forces, bending moments, and torques between the amputee and the prosthesis to be as comfortable as feasible in order to sustain body weight and permit locomotion for lower-limb amputees, and to allow purposeful activities by upper-limb cases. Prolonged and vigorous use of a prosthesis should not cause pain, pressure sores, blisters or corns from friction, nor edema from restricted return circulation. Proper ventilation should also prevent such accumulation of moisture as to cause skin maceration.

Challenging as these major tasks are, they should not lead to neglect of some of the less obvious functions of a prosthesis. The changing pattern of pressure distribution on the body from the prosthesis should provide important sensory feedback on external forces, on positions of remote portions of the prosthesis, and on events such as knee extension. Professor Ernst Marquardt,¹ realizing the value of the limited sensory information transmitted to the residual limb of an upper-limb amputee by the older soft leather socket, was reluctant to change to rigid plastic laminates despite their other advantages. It should also be possible to control remote joints and locks or external sources of power by small reflex or voluntary motions of remaining muscles in the residual limb and through sensing of mechanical motion or myoelectric activity.

Historical Notes

Naturally there is a long history of attempts to meet these challenges, that is scattered in patents, papers, catalogs, and atlases.² There are records of wooden prostheses and peg legs since antiquity, which presumably were padded with fabric or leather. Medieval prostheses, made by armorers, probably had leather or other materials for liners. In the past century,

molded leather shells or lacers supported by metal side bars and cuffs, adapted from orthopedic appliances, were used extensively. These allowed slow adaptation to radial displacement and deliberate readjustment of circumference, and provided some tapered flexibility of radial stiffness above and below the proximal and distal reinforcing cuffs. The typical American artificial limb carved out of wood was completely rigid, though it could be carved deliberately to produce enlargements as desired and could be lined, completely or in selected portions of the circumference, with leather.

Felt, wax-impregnated materials slowly displaced under pressure at body temperature, and resilient or slowly compacted foam plastics or rubbers have been used by various developers. Diagonally woven straps or cords (sometimes called Chinese Magic Finger Grip in the U.S., or Nuremberg Witch's Finger in Germany) have been suggested repeatedly as resilient sockets and perhaps as suspension. Parallel vertical cords between upper and lower rigid frames have also been used for both flexibility and ventilation.

End-Weight-Bearing

Some early sockets attempted to provide direct end-weight-bearing on the unrestrained end of the amputated residual limb. Typically, the amputated end of the bone without deliberate plugging developed only a thin and flexible closure to resist transmission of end load to the medullary canal, causing discomfort or pain. In addition, the ring of bony cortex tended to produce painful direct loading on the skin at the distal end of the residual limb. Early attempts to leave flaps or pads of muscles or other tissues across the distal end merely led to atrophy.

*Retired, Veteran's Administration—Director, Office of Technology Transfer and Director, Research Center for Prosthetics.

Grey, a former apprentice of James Potts who developed the coordinated-motion above-knee prosthesis later called the Anglesea Leg, was very critical of such misguided efforts to develop end-weight-bearing.³ Except for the Syme,⁴ the knee disarticulation, the Gritti-Stokes amputation levels, and some attempts to deliberately plug the end of a long bone⁵—all relatively rare—there were few attempts to attain any end contact, let alone end-weight-bearing.

For generations most prostheses, especially the typical above-knee, caused considerable constriction in the proximal third of the socket, required trial-and-error fitting, and left relatively unsupported the distal end of the residual limb. Because the residual limb was considered "a bowl of jelly," it was constricted proximally but extruded distally in an attempt to secure a firm grip to assist both axial support and control of bending moments. Fortunately, the common firmly-knitted woolen stump sock between the limb and the prosthetic socket—folded over the socket brim and closed at the distal end—supported the skin, fascia, and internal tissues in resisting this distal extrusion and lengthening.

Stump Socks

One or more stump socks were typically worn between a hard socket wall and the residual limb. Stump socks were worn for reasonable as well as fallacious purposes.⁶ Knitted fleece socks provided a slight degree of resiliency and thus redistribution of local radial pressure, especially when freshly laundered. Inevitably, there were mismatches between the residual limb and socket wall caused by slow changes in the limb with edema, atrophy, obesity, or sometimes growth or muscle development. Axial displacement, inaccuracies in the trial-and-error carving of a wooden socket, or even of modification of a plaster model of the residual limb before preparing a plastic socket also led to mismatches. Sock resiliency can overcome minor discrepancies and improve comfort and addition of a sock can help compensate for shrinkage of the residual limb.

A major function of the sock is to cling to the residual limb but slide with respect to the socket wall if there are relative motions between stance and swing phases of walking or caused by discrepancy between the natural proximal joint and

an external mechanical joint. (This important function is impeded if the socket wall is rough or if a perspiration-soaked sock can stick to the wall but chafe the skin.) The sock should also absorb perspiration, provide wick-like action, and allow for ventilation. The closed end or "toe" should provide some support of the distal tissue.

Other than a circular cross-section, addition of one or more socks inevitably distorts the fit. In the triangular below-knee case, although the soft tissues in the posterior portion can change, the bony portions do not, so a spot liner is more appropriate than additional socks.

Sometimes the stump sock was misused by patients to compensate for gross changes which required major refitting, or because of misunderstandings or lack of training. About 1947 Dr. John Young of Mellon Institute and this author met a below-knee amputee who wore five firmly packed socks. Though he did not believe in a "green sock," we finally persuaded him to purchase new socks in order to accompany a newly refitted prosthesis adapted to only one or two socks and to wash the socks daily. Such distortions, however, should not distract from the legitimate uses of stump socks.

Suction Socket

The suction socket above-knee prosthesis was and is routinely fitted with direct contact against the skin of the residual limb. The original suction socket of the Parmelee patent of 1863⁷ may have been intended as total contact, though the evidence is not clear.

A version of the suction socket which came from Germany in 1946–47, was routinely fitted with a "suction chamber" extending below the end of the residual limb. During donning, the tissues were pulled down through a snugly fitted proximal third by a tube of stockinet which was withdrawn through the valve hole in a side wall, thereby creating a significant distortion and elongation of the residual limb. In some cases, the distal end developed chronic edema or discoloration from disturbed return circulation or small hemorrhages.

These problems, as well as basic principles, contact dermatitis, blisters and corns from friction, and cysts just proximal to the brim, were among the major difficulties discussed by Barnes⁸ and Levy⁹ in their classic treatment of

dermatological problems of the amputee. They emphasized the importance of avoiding stasis in the distal residual limb in encouraging total contact and reducing proximal constriction.

THOUGHTS AND THEORIES

After the issue of *Artificial Limbs* by Barnes and Levy was published in 1956, this author was appointed Fulbright Lecturer, based at the Orthopedic Hospital in Copenhagen. In an informal memorandum¹⁰ based on years of observations and discussions concerning fitting of both dental and limb prostheses, three major themes were developed:

- I. Minimize the stiffness gradient between the rigid socket wall and the flexible skin; i.e., taper flexibility of the socket brim.
- II. Approximately match wall stiffness to that of the tissue supported.
- III. Provide a porous wall capable of "breathing" slowly.

We may consider each theme in turn. Both theory and practice can be useful. Practice can develop to a considerable extent without theory; we walked before we learned about the biomechanics of locomotion, and Watt built steam engines before Carnot developed the basic cycle for all heat engines or Rankine the cycle for steam engines. Yet theory can guide our efforts toward improvements, show the areas where greatest progress can occur, and point out the ultimate limits so we do not waste our efforts.

Tapered Flexibility

The first theme was eventually published as the introduction to an extensive series of theoretical and experimental papers by Bennett.^{11, 12} The series ended with limited clinical trials of sockets with flexible brims made of plastic laminates. These sockets appeared to be helpful for patients previously troubled by chronic or recurrent cysts, but the mechanical durability of the laminate was so poor that the sockets often lasted only six months.

After the National Institute of Handicapped Research (NIHR) project at Moss Rehabilitation Hospital began working with polyethylene and polypropylene thermoplastics,¹³ Bennett collaborated with that group on some attempts to

develop more durable flexible-brim sockets using thermoplastics. These appeared to be promising, but the major focus of the project was on light-weight prostheses.

There have been numerous recent efforts to produce a thermoplastic flexible (and often transparent) inner socket or liner supported by an outer shell or other structure. The Scandinavian Flexible Socket or the similar Icelandic-Swedish-New York (ISNY) Socket, and two recent designs from the New York University Institute of Rehabilitation Medicine¹⁴ are examples. If, as in Figure 5 of "Flexible Prosthetic Socket Techniques" by Lehneis et al., the flexible inner liner projects proximally above the more rigid outer laminate shell, it helps to provide the tapered flexibility and transition from rigid socket to flexible skin which was suggested in theme I,¹⁰ and which seemed desirable from Bennett's work.

Matching Wall Stiffness to Tissues Supported

First, consider the principles. The bony prominences near the surface are very stiff against radial indentation under load, but they do not bulge during walking or change appreciably in size or shape over extremely long periods. In contrast, soft tissues may change much more rapidly by brief displacement of body fluids or in moderate time periods (e.g., weeks) by growth or atrophy. Soft tissues are also much less stiff under loads from internal muscular or hydraulic forces, or from external pressure, provided they can be displaced.

Conversely, if fluid-filled soft tissues are sufficiently trapped to avoid displacement, they will behave like an enclosed fluid under hydrostatic pressure. Within the limits allowed by connective tissue, unsupported soft tissue can be displaced a considerable amount, at the expense of distorting blood vessels from their usual circular cross-sections to oval shapes with the same perimeter but a smaller area. Such displacement can also stimulate nerve endings. These displacements may give the illusion of tissue "compressibility."

Soft tissue can also accumulate excessive fluid, creating flushing and edema, if free to expand radially from the center of the body mass. External support will assist the "milking" effect from the pulsating action of muscles

contracting within fascial compartments in pushing fluid into the veins and lymphatics, while on the contrary either external suction or restriction of the return ducts proximal to the tissue considered will favor edema. Similarly, a localized area, with little or no muscular activity that is free from support within a larger region otherwise firmly supported, will cause "window edema" with bulging of skin and tissue through the opening, as in a small opening in a large plaster cast.

Many clinical observations and some systematic tests with sockets, plaster casts, and different designs of prostheses and orthoses relate to this problem of matching socket to residual limb, even though they have been viewed as specific rather than general. The direct comparison of two theories or designs is difficult because methods for preparing the socket and aligning it to the remainder of the prosthesis usually differ. It would seem useful to compare sockets with varying degrees and locations of softness or of flexibility, but similar as to cast, model, and alignment. If different methods or alignments really are needed to optimize results, the reasons should be studied.

The original Navy "soft" socket for below-knee amputees of the late 1940's, provided a limited but equal degree of softness in all regions of the circumference. The cast was prepared with the residual limb dipped in relatively dense dental stone while it hardened. Weight was shifted to the cast after the impression was firm but not quite completely set. The socket was formed over a plaster model without modification or contact with the sock-covered distal end of the residual limb. The distal wall was intended to be tangent to the tapering residual limb. The later Navy "closed-end" socket also provided some additional thickness of cellular rubber in contact with the entire distal end of the residual limb, tapering toward the side walls, with the entire socket lined with vinyl. The Schindler soft socket was formed with gores of foam rubber tailored to fit the warped surface of the plaster model, more precisely than was possible with the single sheet wrapped around the model in the simpler Navy technique.

The Blevens below-knee socket provided an oval pad of sponge rubber, with tapered edges, trapped between layers of stump sock over the calf region of the residual limb. After this pad was compressed and forced through a snugly

fitted proximal portion, it could expand into an enlargement in the rigid socket wall below the popliteal region. It permitted both activity of the remaining remnants of calf musculature, which tended to atrophy in conventional hard sockets, and provided or assisted in support of the prosthesis in swing phase. Its possibilities for control signals remain unexplored.

Fabrication Methods

Carved sockets obviously required skill of the prosthetist and tolerance of the user, who was initially asked to try to fit the residual limb into an unduly tight space which was gradually enlarged until a tolerable fit was achieved. Did the residual limb become engorged or injured in the process? Did the amputee eventually tolerate a certain amount of discomfort as he "broke in" the hard limb—or perhaps broke down the soft tissues to conform more closely to the not-quite-perfect fit? Or did he become sensitized to discomfort, aware of its location and cause, and even more demanding?

Sockets made over plaster models prepared from plaster casts seem more likely than those carved purely from measurements for an immediate accurate fit, or a fit with minimal trials and adjustments. Even so, the prosthetist usually considers that the manual distortion of the wet plaster during the process of taking the cast and "rectification" of the positive plaster model is necessary to avoid an unduly loose fit, often regardless of the resiliency of stump sock or foam lining. Could this view be the result of past experience in preparing casts from residual limbs which have become enlarged from being unsupported while below the body during the preparation period? Would little or no rectification be needed if the amputee were supine with the residual limb elevated for an "appropriate" period immediately before casting? Have a few anecdotal accounts of such attempts leading to excessively tight sockets reflected unduly long elevation times? Did the Navy dip impression allow the denser dental stone, while still fluid, to squeeze fluids from the tissues by an approximately correct amount before solidifying?

Because the socket must transmit the necessary axial forces, bending moments, and torques described by Radcliffe^{15, 16, 17, 18} for all major levels of the lower limb, and Taylor^{19, 20} for the upper, the socket wall must be reason-

ably firm in at least some areas and the interior bone(s) must transfer forces through the skin to the wall in both proximal and distal regions.

Retention of Fit

A precisely made hard socket fit with direct contact (as in the suction socket) or with a single thin stump sock might be effective for a time, but it might encounter difficulties even with muscular activities or large motion of the proximal joint as in sitting and bending. More important discrepancies would occur over longer periods from edema, growth, or atrophy.

Completely uniform softness might also be questioned because it does not match just those relatively limited areas which alter cyclically with muscular activity or over some time span. Perhaps more critically, uniform softness allows areas of high pressure, intended to match individual tolerance to high pressure, to sink into the soft material and thus to shift some load to areas where the designer desired lower pressure. Beginning in the prosthetics schools in 1957-58, emphasis upon socket planning based on anatomical and physiological considerations and upon avoidance of erratic constriction and looseness was a healthy development.

Some Suggestions

The local radial stiffness of the socket wall might be approximately comparable to the stiffness and physiological motion of the tissue which it touches, though changes should occur gradually from place to place to avoid high local shear stresses in tissue. Thus, the wall near bony prominences might be quite firm if precisely fitted to a nonedematous limb.

Obviously this notion seems the opposite of the usual concept of cushioning the bony prominences. Much of the traditional objection to a hard socket wall in contact with a bony prominence may be due to two difficulties: (1) unduly concentrated pressure because of poor fitting or displacement from the correct position, or (2) slippage and friction from inadequate suspension or joint location, leading to formation of blisters and bursae.

Relatively soft walls opposite soft tissue might allow muscle bulging or tendon tightening at every motion of the limb yet rebound to prevent window edema when relaxed. The stiffness might be chosen to allow deliberate

gripping of the wall for control and suspension, somewhat comparable to the German "Haftprothese"²¹ with muscular bulging to grip a rigid wall to supplement an above-knee suction socket as well as to help support the Blevens below-knee prosthesis. Some softness opposite tissues which tend to change rapidly might also compensate for slight changes such as growth.

Adequate, relatively firm areas must be found for biomechanically necessary forces, including those generating bending moments and torques. In the below-knee case, for example, counterpressure from the posterior wall is needed to hold the condyles anteriorly on their sloping supports. In the above-knee case, the distal lateral and the proximal medial aspects of the femur must generate, yet tolerate, substantial forces to oppose the moment created by body weight acting upon it through the center of gravity appreciably medial to the center of support of the prosthesis during stance phase.

The soft tissues, usually present at the distal end, should be encased thoroughly to prevent displacement, extrusion, and edema, yet held precisely in a wall and floor soft enough to prevent localized painful loading. Page,²² an engineer interested in dental prostheses, discussed with this author in 1946 the concept of "muco-static" fitting with tissues trapped so that, much like fluids, they behave almost hydrostatically. The tissues should not be distorted from resting position when the cast is taken, nor should they be displaced towards hollows left by grinding away apparent ridges actually needed to fit into folds in the tissue. Past failures to create end-weight-bearing simply by taking an impression under load or placing a pad of foam rubber on a flat socket floor need not eliminate the possibility of total contact or end-weight-bearing by more sophisticated methods.

A socket of the style described might have variable but tapered thickness of resilient material, such as closed-cell foam rubber or plastic. Muscular bulging into such material might be developed as a control signal. Alternatively, but perhaps less precisely, a thin resilient liner might be supported by an outer shell providing firm support where needed but having rounded and outwardly flared windows where expansion should be possible. The thin resilient liner opposite the windows could improve heat transfer, awareness of adjacent surfaces, and comfort when seated. The sockets illustrated by Leh-

neis, et al.¹⁴ seem reasonable steps, though one wonders whether "selected fenestration over pressure sensitive areas" would be as logical as carefully molded and slightly relieved or padded areas. Certainly the transparent socket materials are advantageous for checking fit, supplementing their value in the flared flexible brim.

Porous Materials

The skin, as Barnes⁸ pointed out, normally excretes water, gases and various compounds. An impermeable wall pressed tightly against the skin for many hours at a time can lead to dermatological difficulties.

Leather allows some absorption and passage of these excretions, but deteriorates from their presence. Organic materials trapped in the fine pores of leather tend to decompose. The Army Prosthetics Research Laboratory (APRL) developed a protective slightly permeable coating for leather consisting of a particular grade of nylon dissolved in isopropyl alcohol. It is not still commercially available, as it was not very widely used. Care had to be taken to avoid traces of oil on the leather in order to be coated.

APRL also developed a "starved resin" process, producing a somewhat porous thermosetting plastic laminate. Unfortunately, the irregular holes tended to become plugged with debris from the stump sock, dead skin cells, etc., and no adequate cleansing method was found.

Late in World War II, Quamco was developed for raincoats and aviation clothing to resist penetration by rain or sea water yet allow slow transfusion of perspiration. It received brief attention in the early suction socket program. In recent years, Gore-tex has become increasingly popular for sportswear. Though it is difficult to tailor Gore-tex to complex shapes, the recent availability of a molded sports hat may indicate the possibility of considering an individually shaped socket or at least gently warped segments to mount in a fenestrated socket.

Simple mechanical perforations of the socket wall were used, for example, with aluminum sockets, particularly in England. The holes had to be small enough so that the tissue, presumably supported by a stump sock, did not bulge through them. At the other extreme, the

mechanically or electrically perforated plastics, studied around 1949 by the Mellon Institute, sometimes had such tiny holes that organic materials became clogged in them as in leather.

One could imagine a wick-like, minutely perforated liner—and perhaps wall—permitting rapid and effective cleaning and drying. Air flow must permit ventilation yet allow adequate suction suspension, perhaps assisted by muscular gripping as in the Haftprothese, or by a very flexible inner liner collapsing against and adhering to the residual limb, as in a Northwestern University design²³ tested upon both upper- and lower-limb amputees. Care must be taken to provide a suitable balance of wicking capillary pressure in excess of negative air pressure so that moisture is not drawn back into the socket during swing phase. Conceivably, a porous supporting liner within an outer supporting structure might provide total contact and biomechanical reactions for the residual limb, but for a small and slowly ventilated chamber between the two, perhaps serving as a suction chamber during swing phase.

One hopes that a simple, inexpensive, individually moldable material with appropriate range of perforations will become available. Ideally it would be available in various thicknesses, stiffnesses, resiliencies, and strengths and in a choice of transparency or appropriate skin colors. Of course it must also be nontoxic, noncarcinogenic, and odorless.

Until then, however, we must make do with the increasing array of compromise materials and our growing but imperfect understanding of principles of sockets, linings, and interfaces. Bit by bit, we can improve service to the severely disabled patients whom we serve.

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Evolution of the AK Socket

by H. R. Lehneis, Ph.D., CPO

The lead article for this issue of *C.P.O.*, "Sockets, Linings, and Interfaces," by Dr. Eugene Murphy represents the culmination of many years of research, writing, and studying the principles of socket design and interfaces.

Admittedly, very little advance has been made in AK socket design since the development of the total contact socket. Today, the principles espoused by Dr. Murphy of selective flexibility/rigidity of socket interfaces can be realized in clinical practice.

There is a pressing need to re-evaluate the traditional quadrilateral AK socket design in light of the drastic changes over the years in the amputee patient population. Today, the vast majority of AK amputees are geriatrics—a complete reversal from the time of development of the quadrilaterally-shaped socket. Most practitioners would agree that the most prevalent complaint of geriatric amputees is discomfort. This is not surprising, considering that most geriatric amputees suffer from reduced muscle tone, sensation, and vascularity.

Thus, it has been proposed by this author to re-examine the cross-sectional configuration of AK sockets to specifically address the physiological alterations in stump shape and consistency of geriatric amputees, to evolve a socket design specific for this patient population. Such

new configuration, combined with contemporary interface materials, e.g., silicone, copolymer inserts, and selective flexibility/rigidity, should lead to much improved physiological and biomechanical function and comfort (see Winter issue *C.P.O.*—Vol. 8, No. 1).

Other attempts to improve comfort are seen in Scandinavian socket designs in which the entire socket is semi-flexible except for the medial wall and a portion of the proximal brim area. In the Ockenfels design, the socket contains selective fenestrations and an inner elastic cloth liner or sock to prevent window edema. The so-called Contoured Adducted Trochanteric Controlled Alignment Method (CAT-CAM), developed by Sabolich, is to not only improve comfort but supposedly the patient's gait pattern.

Now that these new developments are emerging, it seems rather puzzling, in retrospect, that there was such a long hiatus in the application of soft or flexible interface materials in AK sockets. And so it appears that we are on the verge of a major breakthrough, particularly in AK socket design and interface materials. Though not universally practiced, these noteworthy developments will change the practice of prosthetics in dramatic ways to improve comfort and function our patients so much deserve.

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Questionnaire: Sockets and Interfaces

As alluded to by Dr. Lehneis in his editorial, there is considerable ferment in the area of socket design today. Dr. Murphy's article is therefore particularly timely. Theoretical substantiation can be found in his work for some of the concepts currently being explored, and surely consideration of his musings should lead to new efforts in the area of socket design.

In light of these facts, the results of a survey among members of the Academy engaged in clinical practice should be most interesting. The participation of all readers is invited.

Charles H. Pritham, CPO
Editor

1. Do you believe further work needs to be done in the area of socket design?

Yes ____ No ____

2. Which general group do you believe is in greatest need of new designs? **Check one only in each column.**

<input type="checkbox"/> Geriatrics (light duty users)	<input type="checkbox"/> Above knee amputees
<input type="checkbox"/> Extra-ambulatory users	<input type="checkbox"/> Below knee amputees
<input type="checkbox"/> Congenital amputees	<input type="checkbox"/> Partial foot amputees
<input type="checkbox"/> Females	<input type="checkbox"/> Upper extremity amputees
<input type="checkbox"/> Other (specify)	<input type="checkbox"/> Other (specify)

3. Which of the developments mentioned by Dr. Lehneis would you like to know more about? **Indicate order of priority from 1-maximum to 6-minimum.**

Scandinavian Flexible Socket (SFS),
a.k.a. ISNY
 CAT-CAM
 Ockenfels's work
 Reconfigured quadrilateral socket
 New interface materials
 Other (specify)

Send all questionnaires to Charles Pritham, CPO, Durr-Fillauer Medical, Inc., Orthopedic Division, 2710 Amnicola Highway, Chattanooga, Tennessee 37406.

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FOLD UNDER AND TAPE CLOSED

Analysis of Questionnaire on Research and Development

There were seven respondents to the questionnaire on research and development published in *C.P.O.*, Volume 8, Number 1. Not too surprisingly, they were unanimous in their opinion that not enough money was being spent on R&D and that inappropriate R&D was being done. No clear measure of agreement could be discerned in regard to question three, to which the respondents were asked to list in order of priority which areas of R&D within the general areas of prosthetics and orthotics should be funded. Not all respondents replied to all segments of the question and three checked off topics without indicating order of priority. An attempt has been made to analyze the results, and the following priorities for R&D have been assigned:

Prosthetics

1. Improved extra-ambulatory prostheses
2. Improved body-powered upper extremity prostheses
3. Cosmesis
4. Alignment and gait analysis
5. Sensory feedback for upper extremity prostheses
6. Geriatric (lightweight) lower extremity prostheses
7. External powered upper extremity prostheses

Other:

- a. Amputee training programs
- b. Improved harnessing
- c. Improved suspension for prostheses

Orthotics

1. Seating
2. Spinal orthotics
3. Lower extremity orthotics
4. Gait analysis
5. Upper extremity orthotics

Other:

Quality checkout

General

1. Material
2. Fabrication techniques
3. Basic science

Additional Comments

1. I think we need feedback from the amputee to see what is most important to him.
2. Quality assurance in orthopedic appliances.
3. A little physics would not hurt.

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Mandatory Continuing Education— Update

by David C. Schultz, CPO



Academy President Kurt Marschall, CP in his remarks upon assuming office, stressed that one of the focal points of his administration would be mandatory continuing education. In his remarks, President Marschall voiced the opinion that the only way for a profession to achieve excellence was through a mandatory continuing education program. He further stated his intention to establish such a program during his term in office.

Accordingly, a Continuing Education Committee composed of four members was appointed. They are: Joan Weintrob, CPO; Robert E. Teufel, CPO; John W. Michael, CP, vice chairman; and David C. Schultz, CPO, chairman. In addressing our committee, President Marschall outlined its purpose for the year ahead. The duties assigned were singular in nature: to write a mandatory continuing education program which would be equitable to the members yet which would contain enough prestige to make it acceptable to allied health fields and consumers as well.

On April 26, 1984 the Continuing Education Committee presented their first draft to the members of the Academy's Executive Committee who made a thorough review of the draft. Armed with suggested word changes, revisions, and other suggestions as recommended by the Executive Committee, the Continuing Education Committee began to write the second draft of the program.

At this time, as the committee continues to rewrite its proposal, I can say that the program, as prepared, will be a fair and equitable one. It will allow for membership entry over a fairly long period of time. It does not require large numbers of continuing education units (CEU's) from each member. Instead, it requires CEU's that are easily within reach of every member. In addition, the proposed program provides the means by which members will have access to programs in order to obtain the CEU's.

The basic formula for awarding CEU's is being prepared by the Continuing Education Committee of the American Board for Certification in Orthotics and Prosthetics (ABC). This committee is presently at work on this difficult problem which is a major part of any mandatory continuing education program. Implementation of the mandatory continuing education program is dependent upon a program being in place that will award accreditation equitably.

At the Academy Board of Directors meeting to be held in mid-August, the Academy's Continuing Education Committee will present its final draft of the mandatory continuing education program. Pending acceptance by the Board, the program will be presented to the

membership at its annual meeting in San Francisco in 1985.

The subject of mandatory continuing education has been one of controversy within the Academy for a number of years. The pros and cons of mandatory continuing education have been debated over and over. No solution was ever forthcoming. Now, however, it appears as though we have a solution that is equitable and fair to the members, but is still within the bounds of providing good quality continuing education.

In the interim, while the program is still in its preparation stages, the Continuing Education Committee encourages all members to come forth with their comments on mandatory continuing education or on the program that is presently being written. Comments may be addressed to any member of the committee.

David C. Schultz, CPO
Academy Secretary/Treasurer
Chairman—Continuing Education
Committee

Calendar

1984

September 12–14, Fourth Annual *Advanced Course in Lower Extremity Amputation and Prosthetics*, Nassau County Medical Center, East Meadow, New York. Contact: Lawrence W. Friedmann, M.D., Chairman, Dept. of Physical Medicine and Rehabilitation, Nassau County Medical Center, 2201 Hempstead Turnpike, East Meadow, New York 11554; tel. (516) 542-0123.

September 14–15, Ohio Chapter of the Academy Meeting, in conjunction with the Ohio Orthotics and Prosthetics Association, Columbus, Ohio.

September 20–22, Academy seminar, "Current Clinical Concepts of Electrically Powered Upper Limb Prostheses," Alumni Hall, Northwestern University Medical School, Chicago, Illinois.

September 22, Combined Meeting of the Southern and Northern California Chapters of the Academy, Miramar Hotel, Santa Barbara, California.

September 29, New York State Chapter of the Academy Seminar, Columbia Presbyterian Medical Center, New York, New York. Contact: Glenn F. Hutnick, CP, 212-781-6900.

September 30–October 5, 16th Congress of the International Society for Orthopaedic Surgery and Traumatology (SICOT), London, En-

gland. Contact: Conference Services, Ltd., 3 Bute Street, London, SW7 3EY, United Kingdom.

October 1–3, Discovery '84: Technology for Disabled Persons, McCormick Inn, Chicago, Illinois. Sponsored by University of Wisconsin-Stout. Contact: Office of Continuing Education, University of Wisconsin-Stout, Menomonie, Wisconsin 54751.

October 15–21, AOPA General Assembly and International Congress, Fontainebleau Hotel, Miami Beach, Florida. Contact: AOPA National Headquarters, 703-836-7116.

October 23–27, IFAS '84, the 18th International Trade Fair for Hospital and Medical Supplies, Zurich, Switzerland. Contact: Joachim Schafer, Executive Director, TEAM, P.O. Box 3092, 265 Varsity Avenue, Princeton, New Jersey 08540; tel. 609-452-2895.

1985

January 24–29, American Academy of Orthopedic Surgeons Annual Meeting, Las Vegas, Nevada.

January 30–February 3, Academy Annual Meeting and Scientific Seminar, Cathedral Hill Hotel, San Francisco, California. Contact: Academy National Headquarters, 703-836-7118.

The Application of Ionomer Resins in Definitive Below Knee Prostheses: A Limited Study

by Bruce P. McClellan, CPO*
Susan Kapp, CP**
Melvin Stills, CO†

INTRODUCTION

For the past 30 years, polyester resins have been the material of choice for socket fabrication and exoskeletal lamination for all types of prostheses.¹ Without question, these thermosetting plastics have proven to be strong, durable, and effective for such application, and, at the time of their introduction, thermosetting plastics provided a quantum leap forward from the age of wood. The advent of plastics allowed for a more hygienic and less bulky prosthesis. More importantly, lamination provided a medium for duplicating a modified replica of the patient's residual limb. Thus, a more intimate fitting socket with greater weight-bearing characteristics was possible. In fact, the use of thermosetting resins continues today as the accepted state-of-the-art.

As with any material, the polyester resins have certain characteristics which are not ideally suited for all situations. With this as a basis, the University of Texas Health Science Center at Dallas, in conjunction with the Dallas Rehabilitation Institute, began investigating the use of alternative materials for definitive prosthetic design. One of the most attractive substitutes appeared to be thermoplastics. A clinical study was undertaken to evaluate the group of thermoplastics known as ionomer resins and their role in definitive prosthetic application, as opposed to the polyester resins in use today.

Thermosetting Resins

As indicated, thermosetting resins such as 4110 laminac have many positive attributes when used in the prosthetic arena. Some of the

negative characteristics which prompted the investigation into other materials are equally impressive. The toxicity of the fumes given off during the lamination stage is certainly a matter of concern. The ability to modify a socket fabricated from polyester resin to accommodate residual limb change or pressure on bony prominences is essentially limited to grinding away an area for relief, or adding material to reduce socket dimensions. The cured polyester resin also is fairly rigid in nature—a factor which formed the major emphasis for research into the area of alternative materials.

Ionomer Resins

The thermoplastics which were utilized in this particular study of prosthetic application are classified as ionomer resins. The resins are based on copolymers of ethylene and methacrylic acid, which are partially reacted with metallic salts to form ionic crosslinks between acid groups of single chain or between neighboring chains.² The name Surlyn® is the registered trademark of the ionomer resins produced by DuPont and was the material used in the fabrication of the prosthetic sockets. Some of the characteristics which made Surlyn® an attractive option for prosthetic use are as follows:

*Bruce P. McClellan, CPO, Assistant Professor and Director, University of Texas Prosthetics-Orthotics Program, School of Allied Health Sciences, Health Science Center at Dallas, 5323 Harry Hines Blvd., Dallas, Texas 75235.

**Susan Kapp, CP, Prosthetic Instructor, University of Texas Prosthetics-Orthotics Program.

†Melvin Stills, CO, Assistant Director, University of Texas Prosthetics-Orthotics Program.

Clarity

Surlyn® is virtually transparent even in thicknesses up to ¼ inch. This allows the prosthetist to evaluate socket fit visually while the patient is standing with full weight bearing on the residual limb (Figure 1).

Adjustability

The nature of ionomer resins is compatible with heat induced molding which greatly facilitates modifications to the socket. Areas of pressure over bony anatomical structures are simply heated and relieved with no adverse affect on integrity or clarity of material. Surlyn® may also be buffed, sanded, drilled, and riveted in the same manner as the laminates.

Ease of Fabrication

Surlyn® comes in a sheet form and is heated and softened in an oven to allow drape vacuum forming. Unlike other thermoplastics, Surlyn® can be formed directly over a wet cast with no need for a lacquer coating or nylon stocking interface. This differs greatly from polycarbonates which require prefabrication dehydration and a dry cast for good results. Additionally, no post-fabrication curing is required to drive off skin irritating styrene gas, as in the case of polyester resin which has a greater than 25 percent flexible resin content. Additional fabrication time is required, however, in the case of long below knee and Symes level amputations because of the need to weld the posterior seam of the Surlyn® socket.

Flexibility

This factor has proven to be the most significant advantage of ionomer resins from the patient's standpoint. Sockets fabricated from Surlyn® have much greater flexibility than those fabricated from polyester resin. Patients report that the socket feels more like a part of them and is appreciably more comfortable. The exact deformation occurring in the socket during ambulation has not been quantitatively measured at this point, but clinical trials indicate that anatomical weight-bearing surfaces are not adversely affected by the dimensional changes.

Clinical Applications

Initially, the ionomer resin sockets were used only as "test" sockets prior to fabrication of an



Figure 1. Symes amputee with clear Surlyn® prosthesis.

intermediate or definitive prosthesis. Later, use broadened to include intermediate prostheses, and eventually definitive application. The move toward definitive use was prompted by the patients themselves. Those who had been wearing intermediate prostheses made of Surlyn® complained of the rigidity of the laminated socket when their permanent prosthesis was delivered. This provided a significant clue as to the direction which should be taken in regard to providing a more comfortable definitive prosthesis.

FABRICATION PROCEDURE

Though the technique is very similar to standard vacuum forming of orthotic devices, some specific steps are employed when making the definitive prostheses. To prepare the Symes cast for vacuum forming, the Symes foot retainer is attached to the modified positive model with plaster, using the vertical fabrication jig for alignment. A small hole is drilled into the popliteal area and the patellar bar of the cast to assure a good vacuum in these depressions. A piece of cotton stockinette is stapled above the trimline and stretched over the cast mandrel and

the holes in the hand drape pipe. Pressure sensitive tape is used to hold the stockinette in place on the pipe.

The thickness and dimension of the Surlyn® sheet to be used will vary according to type of prosthesis (i.e., Symes or BK) and the size of the patient. Most Symes casts require no more than a 24" × 24" sheet of $\frac{3}{16}$ " Surlyn® (for the lighter or less active patient $\frac{1}{8}$ " Surlyn® may be sufficient). The sheet is heated on a teflon rack for approximately seven minutes in a 350° F oven. The heated sheet is draped over the cast and sealed down the posterior side with the vacuum turned on. Excess plastic is cut away and trimmed almost flush with the socket before it is allowed to completely cool, eliminating the need for excessive grinding. Once cool, the posterior seam is grooved in preparation for welding. Three welds are run over the entire seam. The socket is then removed from the cast and trimmed. The foot is attached and the prosthesis is ready for fitting and delivery.

The below knee prosthesis is fabricated in the same manner one would fabricate a thermo-plastic test socket. It is frame draped with a 12" × 12" sheet of $\frac{1}{2}$ " Surlyn.® Care must be taken to not create webs below the trimline. It is then formed onto the Berkley alignment fixture for dynamic alignment. The socket may be permanently incorporated into an endoskeletal system or be finished in an exoskeletal manner using acrylic resin for the outside lamination. Using acrylic resin will not impair the flexibility of the socket to the extent that polyester resin will.

CLINICAL RESULTS

The fittings of the ionomer resin sockets for definitive use began in April, 1982. Of the ten patients who were definitively fitted with Surlyn,® eight were Symes level amputees. The remaining two patients were below knee amputees (Figure 2).

In the Symes amputee group, five of the eight patients experienced failure of the prosthesis at the ankle/foot juncture (Figure 3). The shortest use time until breakage was 14 days and the longest was five months, with a mean of 11 weeks for the group experiencing breakage. Two of these patients were refitted with a second Surlyn® definitive, one of which failed again after two months, while the other prosthe-



Figure 2. Below knee type prosthesis with ionomer resin socket.



Figure 3. Stress fracture at ankle/foot juncture of Symes prosthesis.

sis continued to function one year after a modified ankle/foot juncture was devised (Figure 4). The modification made was one of reinforcing the distal end of the socket with glass cloth adhered with acrylic resin.

This same method has since been used on two other prostheses in the Symes group. However, over a period of one year, both of these prostheses failed at a level just proximal to where the glass cloth reinforcement stopped. The re-

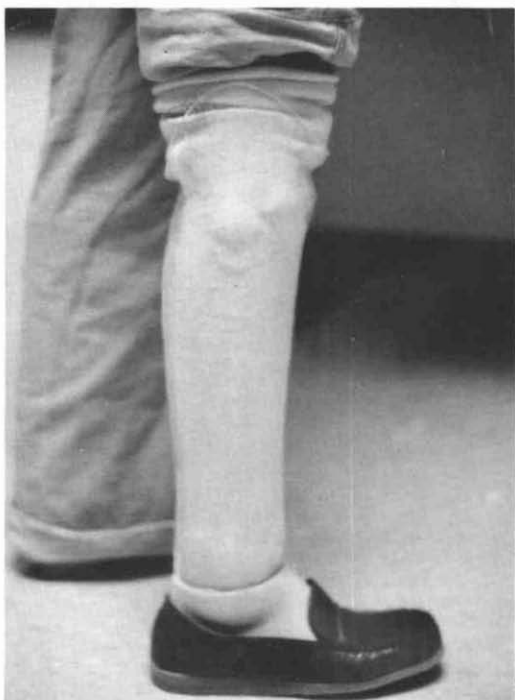


Figure 4. Closed socket design type now being used with reinforced ankle. Suspension is provided by a closed-cell polyethylene shim or pad encompassing the leg proximal of the malleoli and retained in place with a cast sock. Prosthetic socks are worn beneath the shim as usual.

maining patient in this group was an elderly lady who is a limited household ambulator and has experienced no known problems to this date.

One of the two below knee patients wore his Surlyn[®] socket prostheses for 11 months before a crack developed. That patient weighed in excess of 230 pounds and participated in sports on a routine basis. His socket developed a crack in the proximal postero-lateral corner which eventually migrated down the posterior wall. He was subsequently refitted with a polyester laminate socket. The other BK amputee was a 110 pound woman in her twenties who continues to ambulate with her Surlyn[®] socket prosthesis one year and seven months after fitting.

CONCLUSION

As indicated by Stills and Wilson,³ Surlyn[®] may not be ideal for applications where high

unit stresses are anticipated. Although this seems to have been borne out in this initial group of patients, we still believe that ionomer resins might play an important role in definitive prosthetic fittings. This may be accomplished by reinforcement at crucial stress points, a variation in the ionomer resin itself, or by finding a different material that is better suited to long term stresses. The frame type design being used in the above knee Scandinavian socket may also hold significant promise in a below knee configuration.

The potential benefits of ionomer type resins to the amputee population are too great to dismiss without further evaluation and clinical analysis. It is hoped that others in our profession will actively participate in seeking viable materials for definitive socket application.

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Follow-up Experience with an Orthosis Combining the Supracondylar Knee Orthosis and the Spiral Orthosis

by Thomas A. Martin, CPO*

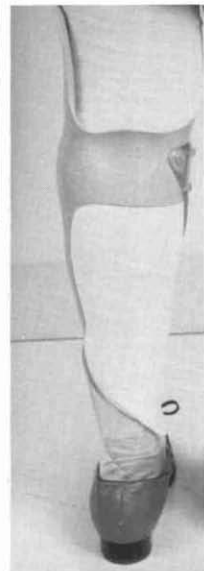
A seventy-one year old woman, post polio of long duration, presented herself to our facility with a Supracondylar Knee Orthosis¹ that had a spiral type AFO² attached to it over ten years ago. She had fractured the AFO component just proximal to the malleolus, about one year ago. Another facility had attempted to replace the Nyloplex[®] spiral AFO with polypropylene material. Her ankle was fixed at 120 degrees plantar flexion. Our investigation indicated that her knee went into genu recurvatum despite the SKO, hence the problem—how to attach the spiral unit to the SKO and duplicate the same alignment that she had been comfortable with after all these years. It is noteworthy that the SKO was held in position by a waist strap.

It was our opinion that the SKO no longer fit due to laxity within the knee cavity itself. She was quite adamant, however, that her brace system had been working well and it was our job to fix it. She declared that the waist belt was no problem and further stated, in no uncertain terms, that she wanted what she had because it had been of good service for over a decade.

Possibly being more persistent than intelligent, we proceeded. We were unsuccessful in our attempts on three separate occasions in reapplying the spiral type AFO. We finally tried #4134-30 percent and #4110-70 percent polyester resin, laminated with four layers of fiberglass and two layers of glass, and used 1/16" polypropylene welding rods that ran the entire length, one inch apart.

Using the old holes of the SKO, we were unsuccessful in obtaining satisfactory alignment when attaching the spiral unit. Therefore we were forced to tape the two units together until we had a compatible arrangement. Once the two components were riveted together, she had some problems in gait, especially between heel strike and foot flat, clearly indicating that the SKO was affecting the knee by not allowing it to go into recurvatum.

In summary, we feel that in using the resin as opposed to the Nyloplex[®] (we used the same plaster mold) we may have compromised some



Side and posterior views of orthoses similar to that described by Mr. Martin in his article. (The photographs supplied by Mr. Martin proved to be unusable.) These are supplied courtesy of H. Richard Lehneis, Ph.D., CPO.

flexibility, but gained, through rigidity, a successful duplication of past gait patterns.

Presently this woman is walking better than formerly and is quite satisfied with our results.

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*President Baja Orthotic and Prosthetic Services, 205 Church Street, Chula Vista, California 92010.

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