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Suspension of the Below-Knee Prosthesis: An Overview

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The student of contemporary prosthetics cannot help but be struck by the plethora of techniques available for the suspension of the below-knee prosthesis. Since the introduction of the patellar-tendon bearing below-knee prosthesis in 1959 the field has been besieged by a variety of methods, all to accomplish a common purpose. The question that inevitably arises is "why?" Is it that the basic methods are so unsuccessful or that the possibilities for innovation so great?

As an abundance of statistics will show, the predominant cause of amputation in western society is peripheral vascular disease, and increasingly the preferred site of amputation is below the knee. The below-knee prosthesis can, therefore, be characterized as the "bread and butter prosthesis," the one upon which the prosthetist counts to pay salaries and overhead. The tendency is to use the method which the prosthetist finds best enables him to satisfy the many needs of the patient most expeditiously and economically. The concern, of course, extends beyond the point of delivery and the prosthetist desires to find a technique that will be both durable and readily adjustable so as to facilitate repairs. There are, of course, other motives than base economics at work.

Given this preponderance of experience with one basic prosthesis the practitioner in time develops the confidence for innovation. (The converse, of course, is true; one is more inclined to eschew experimentation when confronted with an unfamiliar situation.) Secure in the knowledge that he can always fall back on basic techniques the prosthetist is more likely to try out the newer methods he has learned of as well as his own ideas. This tendency is an outgrowth of not only a desire for innovation, but also in reply to perceived inadequacies of the older techniques that come with clinical experience. The majority of below-knee amputees seen not only provides motivation for new developments, but also scope. It is difficult to experiment with non existent patients as well as to gain the experience to either criticize established methods or to perceive the solutions.

The answer to the question then would seem to be multifaceted. If financial forces were the only ones at work the ready and economical solution to obtaining proper suspension for a PTB with cuff suspension strap would simply be to add a waist belt, and we would not have witnessed the development of newer and more sophisticated methods. We may safely asume that prosthetists have been

motivated by such factors as a desire for personal satisfaction, to advance the profession, and a genuine wish to improve the lot of individual patients.

In the following discussion two works in particular are regarded as benchworks: *Orthopaedic Appliances Atlas Vol. 2* (1), and *Human Limbs and their Substitutes* (2). Published in 1960 and 1956 respectively (after many years in preparation) they seem to mark the transition from a period of fertile investigation to a later period of intensive clinical application. Encapsulating the experiences of the first period on the one hand and presaging the events of the second on the other, the work of Dr. Eugene Murphy in both references must be cited as being of particular relevance to the question at hand.

Thigh Corset and Knee Joints

The Verduin Leg (1969) (Fig. 1) shown in Vol. 2 of the *Orth. Ap. Atlas* (3) quite clearly shows the use of a thigh corset and below-knee joints, and since then their use (until the introduction of the PTB) has become synonymous with the "conventional" below-knee prosthesis (Fig. 2). If properly contoured proximal to the adductor tubercle of the knee the thigh corset can provide suspension as well as weight bearing and stabilization against anterior-posterior and medial-lateral forces. The thigh corset is not primarily prescribed for its suspension component, of course, and today thigh corsets and joints are added to the basic PTB in an attempt to bolster a stump that for one

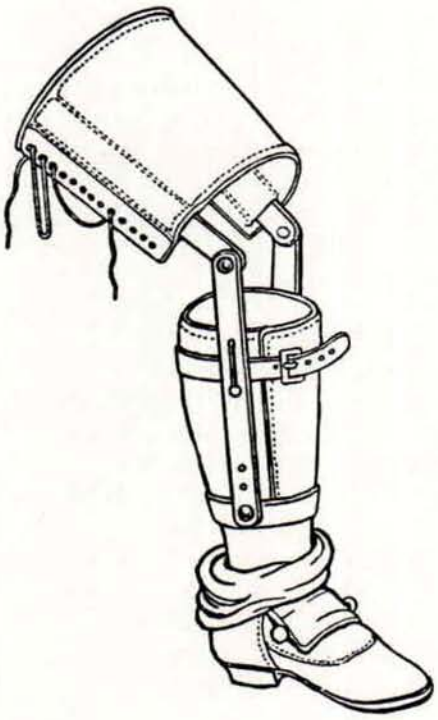


Fig. 1. The Verduin Leg [From (3)]

Fig. 2. The "conventional" below-knee prosthesis

reason or another is unable to cope with the external forces applied to it. None the less, in the spirit of extracting maximum performance from each component it would seem logical to properly contour a thigh corset when used to achieve suspension without a waist belt. The matter does not rest here, however.

In *Newsletter . . . Amputee Clinics* Vol. VII, No. 3 June 1975 (4) the question of using a thigh corset with a PTB was raised with specific reference to whether or not the two were incompatible due to no allowance being made for relative motion between the prosthesis and patient's limb. In response to the question Hugh Panton described methods of dealing with the problem, including loosening the fit of the socket.

In a subsequent issue of the newsletter (5) respondents to the questions, while not addressing themselves directly to the matter, tended to support Mr. Panton's rationale for modifying the socket. If this is the case then a thigh corset that fits intimately enough about the knee to provide adequate suspension can only exacerbate the problem. It may very well be then that a thigh corset incorporating suspension should not be fitted without a slip socket. There can be no ready solution to this conjecture and inevitably the decision must be made on an individual basis.

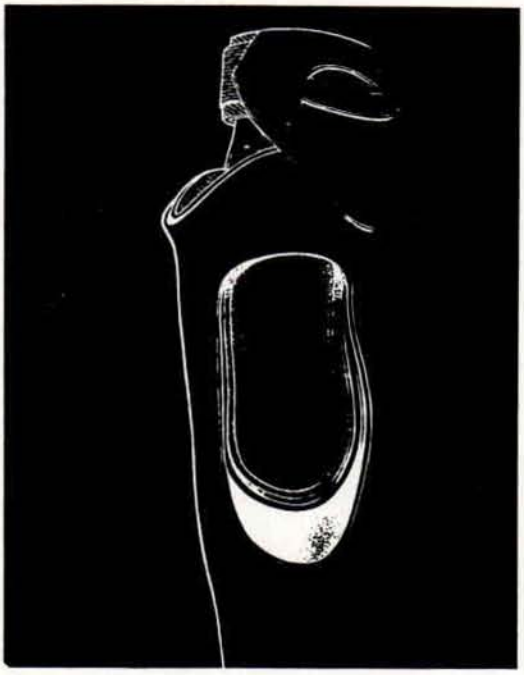


Fig. 3. The cuff suspension strap of the original PTB prosthesis

Cuff Suspension Strap

The cuff suspension strap (Fig. 3) is, of course, an integral part of the PTB prosthesis as described by Radcliffe and Foort (6) and as such has come to figure prominently in the present day practice of prosthetics. Prior to the introduction of the PTB Dr. Eugene Murphy has described the use of a soft suspension strap in conjunction with the "Muley" prosthesis (Fig. 4) (1, 2). As described by Dr. Murphy this precursor of the PTB had apparently been fitted for many years

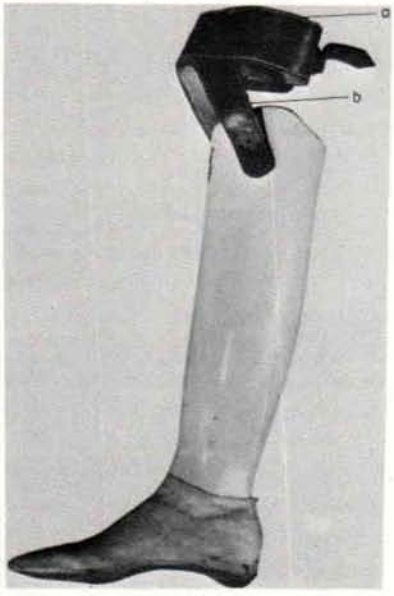


Fig. 4. The Muley Prosthesis [From (2)]

with mixed results with some patients resorting to the use of a thigh corset after only two or three years, while others continued to wear a Muley successfully for considerably longer periods. The disparate results were contributed by Dr. Murphy, not only to more accurate initial fitting, but also to more vigilant and frequent followup. (These same factors, of course, apply today and perhaps the true significance of the PTB is that they have become the norm rather than the exception.) In any event, the straps in the illustrations of Muley prostheses shown by Dr. Murphy are attached rather well forward of the position in vogue today.

In their manual on the PTB, Radcliffe and Foort (6) give explicit directions for locating the attachment points as well as criteria for the proper function of the strap. These exacting conditions are somewhat difficult to fulfill and not all patients lend themselves to them; nor do all prosthetists rigorously make the attempt. The authors of the PTB manual implicitly recognized these facts when they gave equal space to fabrication of a waist belt as to a cuff suspension strap. It is interesting to speculate what percentage of PTBs fitted include a waist belt as well as a cuff suspension strap. Almost all temporary BK prostheses include a waist belt. It is the author's impression that even with definitive prostheses waist belts are used more often than circumstances dictate. That cuff suspension straps are soft and flexible items, and thus readily subject to stretching and wear, can only compound the problem. Recognition of these facts has given cause over the years to much innovation.

The basic strap has been modified by the addition of elastic elements and replaced entirely by Velcro straps and single piece figure-of-eight straps. In their report on prosthetic devices suitable for India, Girling and Commings (7) describe such a strap that consists of a 25 mm. wide cotton tape that wraps around the patient's knee, passes through two slots in the side of the prosthesis, passes posteriorly and is tied together anteriorly. A device is available commercially to facilitate location of the proper attachment points, and not least, such radically different means of suspension as the PTS socket have been advanced.

Waist Belt

A waist belt is most frequently added to the basic below-knee prosthesis in order to supplement the inadequate efforts of another suspensory component. As such it is most broadly referred to as a secondary or auxiliary means of suspension. This designation is questionable since it is possible to gain sufficient suspension with a waist belt without recourse to other means in just about every case, while a waist belt is added to a prosthesis after another form of suspension has proven its inadequacy. It would seem then that a case could be made for designating the waist belt a primary suspensor that relegates other suspensory components to a secondary role when used. Waist belts are objected to by prosthetists as unaesthetic and by patients as uncomfortable, difficult to keep clean, and frequently in need of repair. Perhaps then they should be reserved for last resort when other more appealing means have failed. All of this having been said, it must be acknowledged that there exists a place for the waist belt in the everyday practice of prosthetics.

The first would, of course, be with a thigh corset and joints. In this instance the waist belt is most frequently attached to the prosthesis by means of a fork strap that divides proximal to the patella and courses down from there on either side of the patella to attach to the anterior portion of the prosthetic shin.

Alternative means of attachment do exist although they are infrequently, if

ever, used. Dr. Murphy (2) describes what might be termed an abbreviated fork strap as it attaches on either side to the uprights proximal to the knee joint rather than distal to, as in the former case. He also mentions how rollers may be attached to the uprights and cords passed through them to correct with the waist belt posteriorly as well as anteriorly. This latter case would have the advantage of maintaining equal tension in all positions of hip flexion and of distributing the load more broadly about the belt.

The second common use of a waist belt would be with a temporary PTB prosthesis and cuff suspension strap as mentioned earlier. The desire here, of course, is to provide a readily adjustable means of gaining good suspension during a period of rapid change and thus avoid the possibility of damage to the immature stump.

The third use of a waist belt is with a definitive PTB for one reason or another. While other means of suspension exist, some prosthetists and clinic teams will resort to a waist belt rather than to other methods when the cuff fails as a means of suspension. The most compelling reason for this is mental confusion on the patient's part. Most people are familiar with fastening belts and straps and thus readily adapt to the use of a waist belt when they may have difficulty with other forms of suspension. When a waist belt is worn with a cuff suspension strap (particularly in this last cited case) it is not infrequent to see the cuff worn altogether too loose, either as a result of improper adjustment or of wear and stretching. In this case, then, the waist belt converts the cuff suspension strap to a form of fork strap that happens to be attached posterior to the knee center rather than anterior.

One variant that gives recognition to this fact is that described by Jack Caldwell, C.P., in 1965 (8). The cuff suspension strap (Fig. 5 and 6) is done away with and replaced by two straps and a stainless steel ring as used in upper extremity prosthetic harnesses. As described, each strap is fastened at some point at the anterior portion of the socket, pass proximally up through the ring, and then distally to a point in the popliteal area of the socket. The straps are allowed to pass freely through the ring during flexion and extension and the ring is joined to the elastic thigh strap of the waist belt with a quick disconnect snap fastener. The author further states that hyperextension of the knee can be controlled by varying the location of the anterior attachment points.

Suspenders

Over the shoulder suspenders used with a below-knee prosthesis are so rare as to constitute a genuine curiosity when encountered. Their use can not be dismissed altogether, however. It may very well be that for any number of concomitant reasons a particular patient can use no other means of suspension; and there always exists the true individual who will hear of no other means however powerful the clinic team's arguments against it. The author encountered such a person a number of years ago who suspended his prosthesis (which also included a thigh corset) with an arrangement much the same as a baldric used to suspend a sword from the shoulder. A single broad belt passed proximally from the ASIS on the involved side up over the contralateral shoulder, distally down the back, and around the side to the originating point where the two ends were secured together. From there an elastic strap and "Y" strap were used to secure the baldric to the prosthesis.

It is, of course, possible to devise considerably more complex arrangements using two suspenders, chest belt, waist belt, and either elastic straps anterior-posterior to the prosthesis or rollers and

Fig. 5. Top view of the V-straps with the knee extended

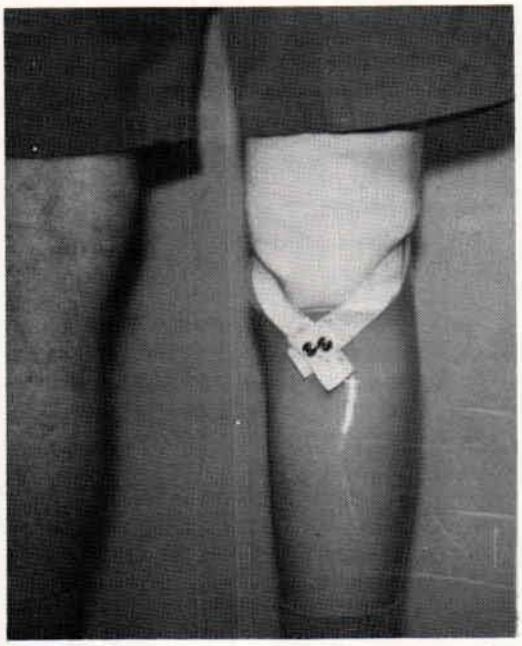


Fig. 6. Posterior view of the V-straps while patient is standing

roller cords. Franz and Aitken refer to such a setup for infants calling it a "toddler harness." The premise is that the chubby child and relatively indistinct skeletal features of the infant necessitate such drastic measures. An additional reason is, of course, the need to make the total prosthetic system "wriggle proof."

Blevens Undercut Calf Socket

The socket (Fig. 7) developed and patented by Emmett Blevens and evaluated by N.Y.U. can be regarded as a precursor of a number of concepts just recently beginning to receive serious attention. As described by Murphy (1) the socket was carved of wood to accommodate a stump encased in two wool stump sockets with a hollow carved in the posterior wall distal to the popliteal. A foam rubber pad was sandwiched between the two sockets so as to fill the hollow once the socket was properly donned. Since the pad was fitted so as to remain compressed, tension was developed between the socket and stump and a suspension effect was obtained. Apparently some amputees, with time and proper effort, were able to redevelop previously atrophied muscles and, thus, eventually discard the rubber pad. In addition, a sunction valve was fitted to some sockets and negative pressure was used to enhance suspension.

This, the work of a private individual, failed to find favor with the "prosthetic establishment" and little or nothing has been heard of it since. The reasons for this conservatism are not hard to fathom. The PTB had not yet been properly introduced and once it was, considerable effort was necessary to overcome the obstinacy with which a corsetless BK prosthesis was greeted. In addition the

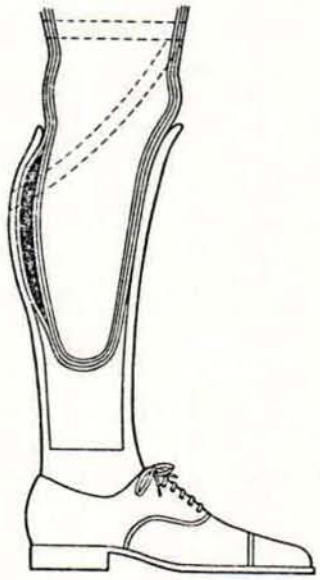


Fig. 7. The socket designed by Blevens

Blevens' socket, being carved of wood, required, as all such sockets, considerable skill and trial and error to fit and as such it was undoubtedly considered unprofitable to formalize the Blevens' method and teach it. While little information about the technique appears to be available and the efficacy of compressing the highly vascular structures of the posterior calf is open to question; the two hurdles mentioned have been conquered and perhaps the time is now ripe for further study of the methods of Blevens. As will be seen in the following discussion such study on the part of some researchers is underway. In a related development Fred Hampton of the University of Miami has in private communication described the use of a similar if not identical suspension technique (by serendipity and as auxiliary suspension only) for edematous and bulbous immature stumps frequently seen when fitting early temporary prostheses. In such instances to avoid damage to the fragile tissues, Mr. Hampton has used a liner building up the posterior and medial areas proximal to the bulbous end of the stump. This liner is removed from the socket and donned separately and the stump and liner are then pushed into the socket. Mr. Hampton reports that considerable suspension can be gained by this expedient.

Muscular Grasp

Relatively little attention has been paid to this concept over the years. Dr. Murphy describes it in conjunction with the Blevens' socket (1) and Grevsten (9) mentions it in his description of the suction socket below-knee prosthesis. There can be little doubt that many amputees use it to supplement or eliminate more conventional means of suspension. More than one patient, when questioned closely, has described being able to walk short distances about the house without fastening the cuff; and this mechanism presumably accounts for the ability to ambulate without ill effects or complaints with an improperly fitting cuff suspension strap. The author encountered some years ago two young amputees (secondary to congenital defects) who had discarded any other forms of suspension. One, a young female in her teens, had literally thrown the medial brim of her supracondylar suspension prosthesis away, and the other, a female in her 30's, was an active skier who evinced a desire for an auxiliary suspension aid only in that activity.

Recently Dr. Ernest Burgess of Seattle, Washington, has described his research in this area (10, 11) referring to it as physiological suspension. This is an outgrowth of his earlier work to create more functional stumps by such methods as myoplasty and myodesis, and has led him to re-evaluate the concepts of Blevens.

Certainly, the idea is philosophically attractive. Not only would it result in a cleaner looking, more cosmetic prosthesis

without a cuff or supracondylar brims to protrude above the knee in sitting, promote greater activity of the remaining musculature with physiological benefits, it would also maximize the patient's potential to minimize his dependence on an external aid with important psychological and philosophical overtones. Certainly, the technique is not applicable to all patients and much work needs to be done to develop logical criteria for the method's application.

Suction Socket

In his discussion of suction socket below-knee prostheses Dr. Murphy (2) states that the U.S. Army's Commission on Amputations and prostheses in its tour of Germany after the war observed a few suction socket BKs and considered them relatively unsuccessful. Dr. Murphy attributed this to the relatively high ratio of bony prominences to soft tissues (as compared to the above-knee stump) and the consequent need to establish an initial accurate fit and subsequently maintain it with great accuracy despite changes in stump volume and contour. The attractions of suction are great and certainly are not to be dismissed lightly. If suspension can be established in the distal portion of the socket the proximal trim lines can be lowered with greater cosmesis and free the patient of constraints about the knee. Further, suction should reduce the possibilities of skin abrasions and increase the patient's awareness of the prosthesis.

While American interest in the suction socket for the below-knee amputee has been dormant, since about 1968 Swedish investigators (9, 12) have been working with the PTB suction prosthesis. Considerable work has been done by them over the years to demonstrate the effects of suction sockets and this work was recently summarized by Grevsten in *Prosthetics and Orthotics International* (9). Similarly Gunnar Holmgren has discussed the matter from the prosthetist's viewpoint (12). Both authors stress the necessity to displace the soft tissues of the stump distally, both for safety in weightbearing and to develop tension between the skin and socket walls for suspension. Indeed Holmgren is quite emphatic about this being a major factor in the proper function of the PTB-suction socket. This use of tension between the socket walls and the skin is very similar if not identical to the principle used in the Blevens socket. However, as the information or technique is scanty it is difficult to fully assess these matters. One distrubing note concerning the Grevsten article (9) suggests itself. In the picture sequence showing the patient donning the prosthesis the use of a rubber suspension rubber suspension sleeve to preserve suction in extreme knee flexion is mentioned. The true advantage of a suction socket would seem to be the elimination of the necessity to encompass the knee for suspension.

Rubber Sleeve Suspension

Since about 1968 (13,14) the workers at the University of Michigan, Ann Arbor, have accumulated considerable experience with a form of suspension using a rubber sleeve (Fig. 8) in conjunction with and without a gel liner. In an article (13) describing an investigation of the functioning principles three suspensory forces are attributed to the rubber sleeve: negative pressure, friction between the stump and socket, and longitudinal tension in the sleeve. With the use of pressure transducers and by means of selectively introducing leaks in the sleeves of nine subjects the investigators were able to demonstrate to their satisfaction that negative pressure played an important role in the suspension of the protheses. It is interesting to note, as the investigators point out, that one subject with a very full and fleshy stump showed

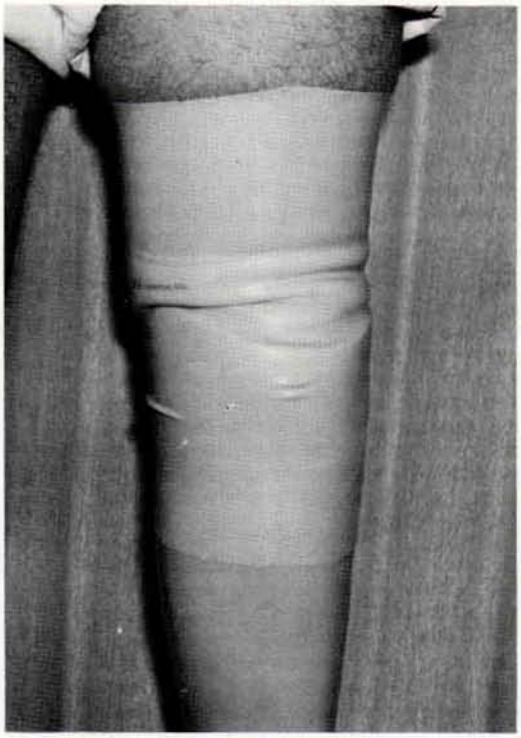


Fig. 8. The rubber sleeve suspension technique

no degradation of suspension affect when the sleeve was punctured.

It is obvious, then, both from a clinical point of view and from laboratory studies that the rubber suspension sleeve is a relatively simple and effective means of suspension. The only question that remains is whether or not the suspension effect is worth more than the side effects. While doubtlessly many patients are more than satisfied using suspension sleeves other patients have been disturbed by the sense of constriction, heat and perspiration build-up under the sleeve, and the relative fragility of the sleeves. The question must, of course, be answered on an individual basis, but it is possible in a broader sense to register an objection on aesthetic or idealistic grounds. It would seem that the true advantage of suction suspension is the freeing of the knee joint from the constrictions necessary for suspension. A rubber suspension sleeve that passes proximal to the knee joint would seem to violate this principle. Whether or not it is possible to maintain suction without a sleeve remains to be established and the simplicity of application of the sleeve is certainly a point in its favor.

Brim Suspension

In contrast to the suspension techniques discussed until now, brim suspension techniques find no mention in the two works of Dr. Murphy cited earlier (1,2). It would seem then that the concept is a new one and a logical outgrowth of experience with the PTB (the author can not assert positively that there is no precursor as the world literature is unavailable and by no means has a search for historical predecessors been made). It is interesting that the extensive armamentarium of brim suspension techniques developed while such earlier forms of self-suspending sockets as suction and muscular grasp were slighted. It is also interesting that the pendulum has begun to swing in the other direction.

In any event the central issue of brim suspension is how to permit passage of the wide femoral condyles through the relatively narrow inlet necessary to secure a proper grip immediately proximal to the adductor tubercle. It is the various solutions to this question that has given rise to the many variations reported on in the literature. In addition to suspension, extending the trimlines proximal affords other benefits as well. An increase in surface area encompassed leads to a decrease in the unit pressure, while the extension of lever arms proximally and intimate grip of the bony structure of the knee increases stabilization against such undesirable motions as lateral shift in the case of supracondylar suspension and

supracondylar-suprapatellar suspension and, in addition, hyperextension in the case of supracondylar-suprapatellar suspension. The net effect then of such a prosthesis when properly fitted is an increase in patient control and comfort with a decrease in pistoning and other undesirable motions. These positive benefits must be balanced by such negative factors as a possible decreased cosmesis, increased weight, greater expense, difficulty in fitting, and difficulty in adjustment to the supracondylar pressure. It must also be remembered that brim suspension techniques have made it possible to fit patients that otherwise would be unamenable to anything but knee joints and a thigh corset (15,16, 17). For the most part, it is now necessary to resort to this latter extreme only in cases where the patient's stump needs positive relief from superimposed weight.

The proliferation of PTB variants led the Veterans Administration to issue a Program Guide in 1970 (18) that organized the variants in a logical fashion, developed a consistent nomenclature, and gave recommendation for their prescription. Since then the nomenclature presented has come to be adopted by most writers in the field. Every attempt is made in the ensuing discussion to adhere to this standard nomenclature in referring to brim configurations. A revised version of the chart to reflect developments made since 1970 is shown in Figure 9. In a similar vein James Breakey (19) set forth the method he used to objectively determine the specific brim configuration (supracondylar vs. Supracondylar-suprapatellar) that best met a particular patient's needs. Despite these efforts, there is no universally agreed upon procedure or set of recommendations for prescribing brim configuration, wedge or suspension type, or socket type (hard vs. soft). Nor is there one manual or standard procedure for casting and fitting the various brim suspension techniques despite their many points of similarity. It may be argued that it is unnecessary to develop such universal procedures but it should be kept in mind that the present system, shrouded as it is in parochialism, denies all patients equal access to all the options and means that a prosthetist attempting an unfamiliar technique for the first time may have nothing in the way of written guidance to go on. This may very well mean needless experimentation, frustration, and eventual abandonment of an otherwise successful variant.

Supracondylar-Suprapatellar PTB (PTS)

Apparently the first formal introduction of the supracondylar-suprapatellar technique (Fig. 10) occurred in a 1964 edition of *Atlas d'Appareillage Prosthe'tique et Orthope'dique* (20) by Pierquin, Fajal, and Paquin who referred to it as the PTS (Prosthe'se tibiale Supracondylienne). Points of contrast between the PTS and the PTB were covered in a subsequent issue of Orthotics and Prosthetics in 1965 (21). Kurt Marschall and Robert Nitschke described the PTS in the American literature first in 1966 (22) and again in 1967 (23) and have become in time inextricably linked to the development of it in this country.

As described by these various authorities the supracondylar-suprapatellar (SC-SP) PTB includes a flexible insert and extends proximal to the patella and femoral condyles. Great emphasis is put on the role of the suprapatellar identation for suspension of the prosthesis and for prevention of undesirable hyperextension of the knee by the patient in gait and stance. In contrast to the work of other developers relatively little emphasis is given in these early reports to the suspension possibilities inherent in the supracondylar extensions. More emphasis

Fig. 10. The PTS system

is given to their contribution to stabilization of the prosthesis.

While the names of Nitschke and Marschall have become almost synonymous with the use of a liner, in both articles (22,23) they describe in passing the use of a hard socket and even mention in one (23) the possibility of using compressible medial and lateral wedges in a hard socket, if necessary. Similarly, Breakey and Foort in 1970 (24) described a SC-SP PTB featuring a socket laminated of flexible polyester connected to a pylon by a rigidly laminated socket receptacle that also provided support in the weight-bearing areas. Hard socket PTB's with SC-SP suspension continue in use but their use is very much taken for granted as there is little or nothing published describing the particular features or problems involved in their use. Presumably the lack of a yielding or removable element above the condyles would imply that a hard socket PTB with SC-SP suspension would be used for a patient for whom only a small reduction in supracondylar ML was necessary or who could achieve sufficient suspension elsewhere (suprapatellar, muscular grasp, etc.). Patients who wear such a socket generally don it from the posterior aspect through the suprapopliteal opening with a corkscrewing motion.

Removable Medial Wedge

In 1966 Dr. C.G. Kuhn (25) published details of a prosthesis he named Kondylen Bettung Munster (KBM) and in June 1966 Carlton Fillauer (26) published in *Orthotics and Prosthetics* details of the development and fabrication of a similar design (Fig. 11) based on Dr. Kuhn's work. Mr. Fillauer proposed to call this prosthesis the S.T.P. or Supracondylar Tibia Prosthesis. Neither name ever really caught on and today the design is generally referred to as PTB with removable medial wedge or PTB with Fillauer wedge.

In any event, whatever the name, it describes a hard socket PTB cut low over the patella with supracondylar wings and a removable medial wedge. The wedges are prefabricated of Plastisol, in a range of sizes and thicknesses and available from Fillauer Orthopedic Supply. In use the cast is taken over the wedge which is secured in place proximal to the medial condyle by a strip of tape. Elastic plaster-of-Paris bandage is used and snugly wrapped proximally to reduce the supracondylar ML diameter. Similarly the cast

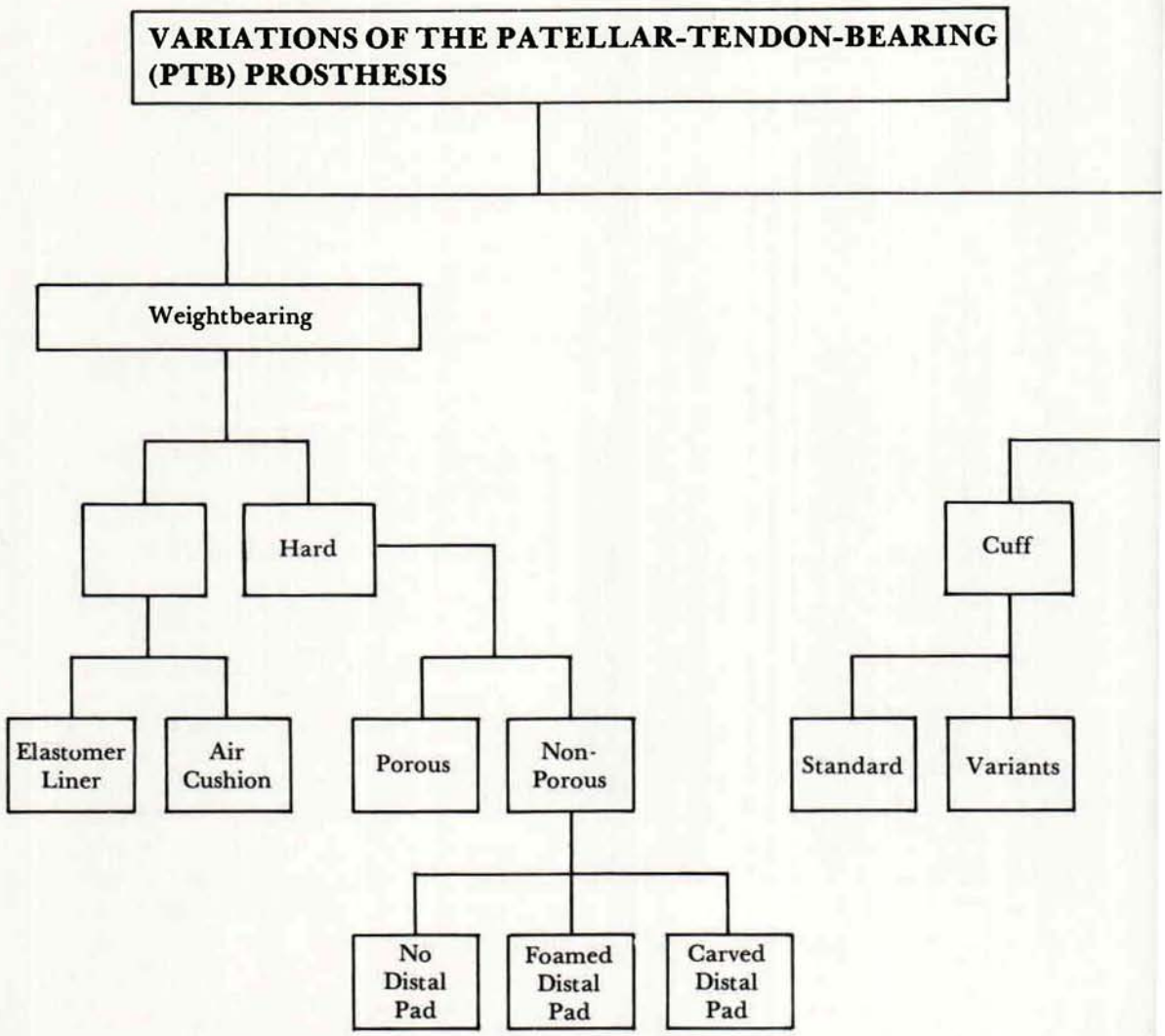
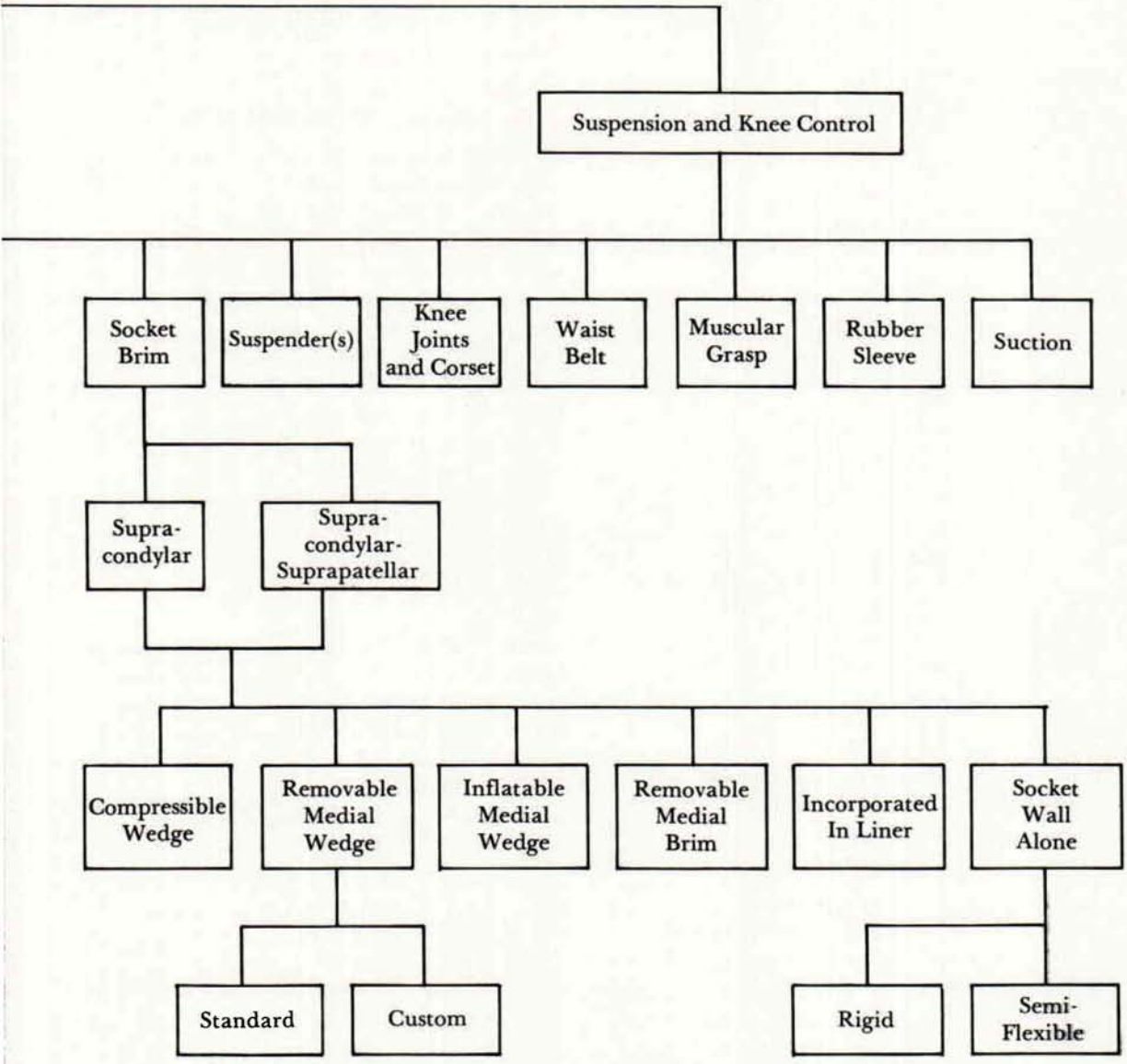


Fig. 9. Variations of the Patellar-Tendon-Bearing (PTB) prosthesis (Revised from (18) to reflect


Suspension and Knee Control
Socket Brim
Suspender(s)
Knee Joints and Corset
Waist Belt
Muscular Grasp
Rubber Sleeve
Suction
Supra-condylar
Supra-condylar-Suprapatellar
Compressible Wedge
Removable Medial Wedge
Inflatable Medial Wedge
Removable Medial Brim
Incorporated In Liner
Socket Wall Alone
Standard
Custom
Rigid
Semi-Flexible

is filled with the wedge in place and the model is modified to provide a narrow lip in the socket proximal to the wedge to hold it in place. The socket is also laminated with the wedge in place.

An interesting variation on the basic concept of a removable medial wedge is that developed at the Prosthetic Research Study in Seattle, Washington. Described as early as 1969 (27) this technique was described in greater detail by Joseph Zettl at the "Workshop on Below-Knee

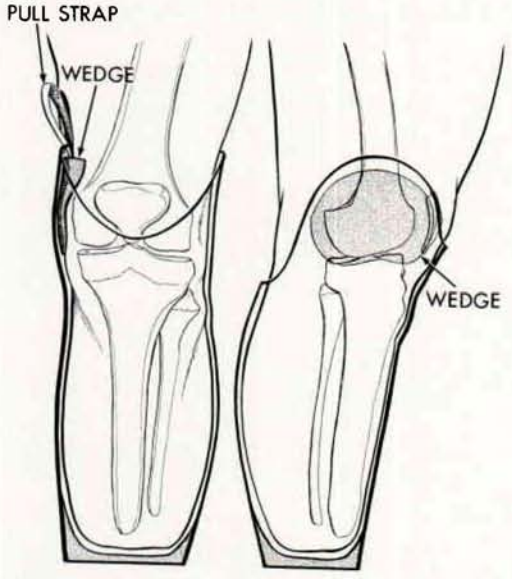


Fig. 11. The Fillauer removable medial wedge system

and Above-Knee Prostheses" held in Seattle, Washington January 1973 (28).

Basically, a custom fitted wedge is fabricated over the modified model of the patient's limb using nylon stockinette, Dacron felt, polyester resin, and Sulkafloc. One or two pins protrude medially from the wedge and lock it into place on the medial wall of the socket. If only one pin is used, the wedge is free to pivot during flexion of the knee, affording greater comfort to the amputee. This latter point is a refinement from the original technique where two pins were routinely used. Mr. Zettl emphasized that the wedge could be used with both supracondylar and supracondylar-suprapatellar sockets, any kind of soft insert, readily modified, and, if necessary, padded.

Compressible Medial Wedge

The Compressible Medial Wedge is a suspension variant peculiar to southern Florida where it has achieved a considerable measure of popularity. Perhaps the earliest mention of it in the literature occurs in the August 1970 issue of *Newsletter . . . Amputee Clinics* (29) in which Dr. Newton C. McCullough III briefly describes it and attributes its development to William Sinclair, then chief research prosthetist at the University of Miami. Similarly Dr. Augusto Sarmiento writing in the Spring 1971 issue of *Bulletin of Prosthetic Research* (30) describes the wedge and states that some 200 patients had been fitted with it by that time.

Essentially the medial and lateral brims of the PTB socket are extended proximally above the level of the adductor tubercle and during the fitting process a soft wedge similar in shape and cross-section to the removable medial wedges sold by Fillauer Orthopedic Supply is located in place above the adductor tubercle so as to achieve proper suspension. When proper shape and location of the wedge is determined it is glued in place and covered with leather. In use then, to don or doff the prosthesis the patient would merely push or pull his limb in or out of the prosthesis and the wedge would compress to allow passage of the femoral condyles. William Sinclair has stated (28) that in most instances a medial wedge alone has proven sufficient, but, if necessary, a lateral wedge

can be used and in cases of supracondylar-suprapatellar suspension the compressible wedge has been extended anteriorly proximal to the patella. These wedges are most often carved of the polyurethane foam used for SACH foot heel cushions using a wire wheel, although Hugh Panton in personal communication has mentioned molding them of the RTV Silicone Elastomer formerly used for below-knee distal end pads.

This then would seem to be a very useful and easily adopted suspension technique, and the reasons why it has not enjoyed wider popularity are somewhat puzzling. There would seem to be nothing radically different to be done in the casting and modification procedures and the carving and fitting of the wedge would seem to offer no particular difficulties. Once glued in place and covered the wedge is an integral part of the prosthesis and can not be removed and lost, which should be a welcome thought to those used to the vagaries of some patients' behavior.

Removable Medial Brim

Apparently the first mention of the removable brim (Fig. 12) technique occurs in June of 1971 in an edition of *Newsletter . . . Amputee Clinics* (31). Carlton Fillauer then gave fuller details of the rationale behind the brim's development and the fabrication technique in December 1971 (32). In this article Mr. Fillauer stated that the development of the removable medial brim resulted not from dissatisfaction with the removable medial wedge, but rather from the need for a technique to accommodate patients in whom the difference between the condylar ML diameter and the supracondylar ML diameter was greater than could be accommodated with the available prefabricated removable medial wedges. The method consists of fabricating a supracondylar PTB hard socket with a curved metal bar and channel positioned medially so that the entire medial wall proximal to the widest point of the femoral condyles could be removed and replaced. No attempt is made to cushion or upholster the medial wedge and Mr. Fillauer stated his belief, in opposition to those who advocated such soft wedges, that hard wedges when properly fitted were well tolerated by patients.

The hardware has changed some since its original introduction but the method remains substantially unchanged. Material can be added or removed from the medial brim as necessary and indeed the fit can be altered if needed by bending the metal bar to bring the wedge in or out

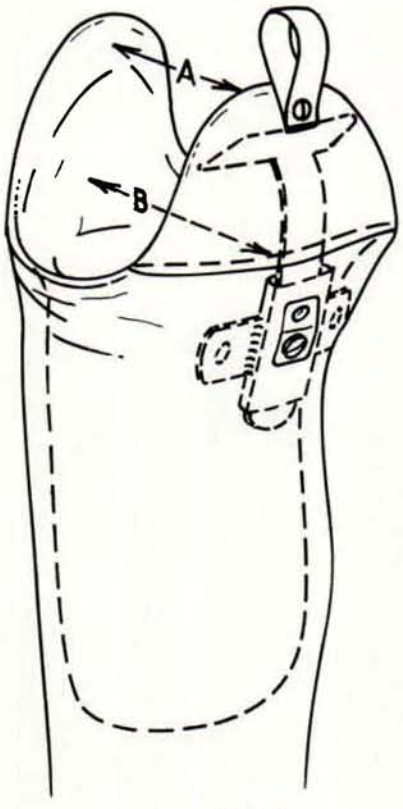


Fig. 12. The Fillauer removable brim system

or to change the angle relative to the sagittal plane. Further, the height of the wedge can be changed in a similar fashion. When properly finished the brim of the prosthesis presents a very acceptable cosmetic effect both sitting standing. While intended to be used with hard socket supracondylar PTB's it can be used with liners or in supracondylar-suprapatellar sockets. In this latter configuration the medial horizontal cut is extended anteriorly and meets with a vertical cut that splits the patella. The only problem that may be encountered with this variation is gapping of the vertical cut when the patient's knee goes into hyperextension in late stance phase. This gapping can be minimized by being certain that the bar and channel assembly are properly positioned on the midline of the medial wall or even slightly anterior to it.

Inflatable Medial Wedge

In March of 1973 (33) and again in December of 1973 (28) Timothy Staats described the development of inflatable medial wedge (Fig. 13) which he ascribed to Lincoln Baird. Basically two fluid filled bulbs are used with a short length of tube connecting the two and a needle valve used to control the passage of fluid between them. One, an ordinary rubber squeeze bulb as used in measuring blood pressure, is secured in the popliteal area of the prosthesis. The other resembles the removable medial wedge as described by Carlton Fillauer and is placed inside the prosthesis proximal to the medial femoral condyle. In use fluid would be pumped into the suspension wedge to affect suspension and evacuated to permit donning and doffing. The critical feature is that it permits the patient to adjust the suspension so suit himself and to accommodate fluctuations.

Fig. 13. The inflatable medial wedge

Mr. Staats mentioned that a limited number of patients were fitted with very encouraging results, but that numbers were limited by the number of units available. Leakage apparently was a problem with the first units fabricated but this was subsequently eliminated. Since these early publications little or no information is available in print nor do the units seem to be commercially available.

A telephone conservation with Mr. Staats in January of 1979 elicited the following facts. The inflatable wedge continued to be used for some 2 or 3 years after 1973 and some 50 patients were fitted with it. Contrary to the early expectations leakage continued to be a problem and eventually the Removable Medial wall supplanted it. The inflatable wedge is no longer available and the remaining stock of some 50 units was donated to the prosthetic curriculum and UCLA where its use is still taught as one of the options to be considered for suspension of the PTB.

Conclusion

A general overview of Below-Knee Prosthetic suspension techniques has

been conducted. In general, three broad trends can be discerned. First, a group of older suspension techniques have remained static and been supplanted by new ones since the introduction of the PTB and variants. Second, another group of techniques abandoned when the PTB was introduced have recently gained fresh appreciation. Third, an entire new group of suspension variants, all employing common principles, have emerged and gained widespread acceptance. It may very well be that the ultimate suspension technique is skeletal attachment but in the meantime there is no lack of options to be considered. What apparently is lacking is a universally accepted set of clearly enunciated guidelines to illuminate the situation.

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