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ULTRA-LIGHT PROSTHESES FOR BELOW-KNEE AMPUTEES

A PRELIMINARY REPORT[1]

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It seems self-evident that for the older lower-limb amputees the lightest limb possible, consistent with safety, is desirable. Recommendations to this effect have been made from time to time but little attention was paid to them. Dr. Joseph Barredo, a physicist retired from the Atomic Energy Commission, and a below-knee amputee owing to trauma, has been emphasizing the importance of weight reduction to research and development laboratories, since 1972 (*1*). Actually a method for producing an extremely light below-knee prosthesis was reported by Wollenstein in 1972 (*3*) (Fig. 1), but the method is expensive in that the labor required is quite high relative to conventional practice.

At first glance, it appears that the so-called pylon, or endoskeletal, prostheses would be lighter than the crustacean type, but closer scrutiny reveals that the crustacean type, when properly engineered and fabricated, can be much lighter and provide the same strength characteristics.

Two factors make the crustacean type superior with respect ot the strength-weight ratio. First, the further away the outer fibers of a structure are from the central axis, the larger is their lever arm, and therefore the greater is their resistance to bending about the central axis. Furthermore the need for a separate foot-ankle unit can be eliminated, resulting not only in weight reduction but in less need for maintenance. Obviously, weight reduction reduces suspension problems.

Advances in vacuum forming of sheet plastics in orthotics and prosthetics show promise of making it practical to provide an extremely light, all plastic, crustacean-type, below-knee leg similar to the Wollstein design. Some development work to achieve this goal has been started at the Rehabilitation Engineering Center at the Krusen Center for Research and Engineering.

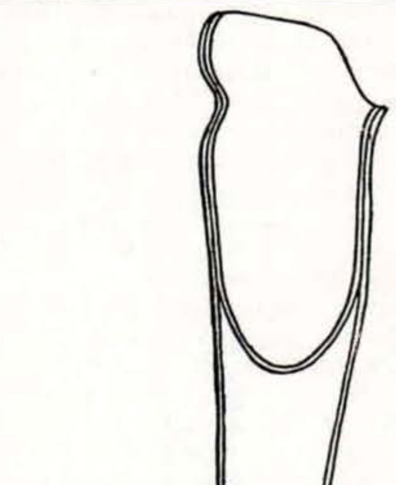

Fig. 1. Cross-section view of the Wollstein below-knee prosthesis. Wollstein used standard laminating techniques to achieve a crustacean shell. The functions of the SACH foot are provided by the cushion heel and sole that are added. The shape of the foot section can, of course, be altered to provide any function that can be provided by the SACH foot concept.

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Although, it was felt that the older patients with medical problems other than amputation would appreciate the reduction in weight the most, two young healthy male below-knee amputees were chosen as subjects because they were reliable, and could be counted upon to give their reactions clearly and without bias.

The basic approach of Wollstein has been used, but new materials and fabrication techniques have been introduced.

A hollow polypropylene foot-ankle unit (Fig. 2) with removable sole and heel is used for alignment trials with a vacuum-formed polypropylene socket (*2*) and an adjustable shank (Fig. 3). The aligned assembly is placed in a vertical transfer fixture (Fig. 4), the shank is removed, the top of the foot-ankle unit is cut off (Fig. 5), and the space between the sole to the proximal area of the socket is filled with a rigid foam that is foamed in place. The polypropylene foot shell is cut away and the foam is shaped to match the contralateral shank (Fig. 6). The anterior and posterior sections of the foot and shank are molded of polypropylene (Fig. 7). These sections along with the polypropylene socket are welded together and the sole and heel wedge are secured to the foot section to form a strong but extremely light PTB-type prosthesis (Figs. 8 and 9).

The foot-ankle unit for walking trials was also made of polypropylene by vacuum forming mainly because it offers an easy way to fabricate such a unit in the laboratory. Once the shapes for various sizes are standardized, they can probably be mass-produced for sale to individual facilities to be used with an adjustable shank from patient to patient.

Fig. 3. Walking trials using the vacuum-formed polypropylene socket. The weight of the currently available adjustable legs requires use of the conventional supracondylar strap.

Fig. 2. The hollow polypropylene foot-ankle unit used in the experimental work. Units that will not require fabrication in the individual facility will be practical when the various techniques involved in the total system are refined.

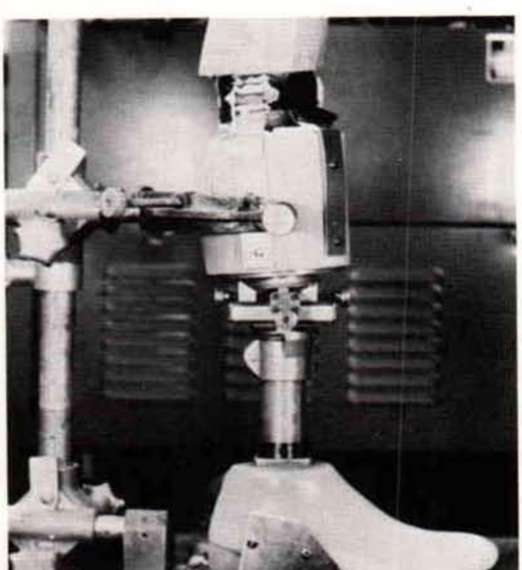

Fig. 4. Trial unit in the vertical transfer fixture.

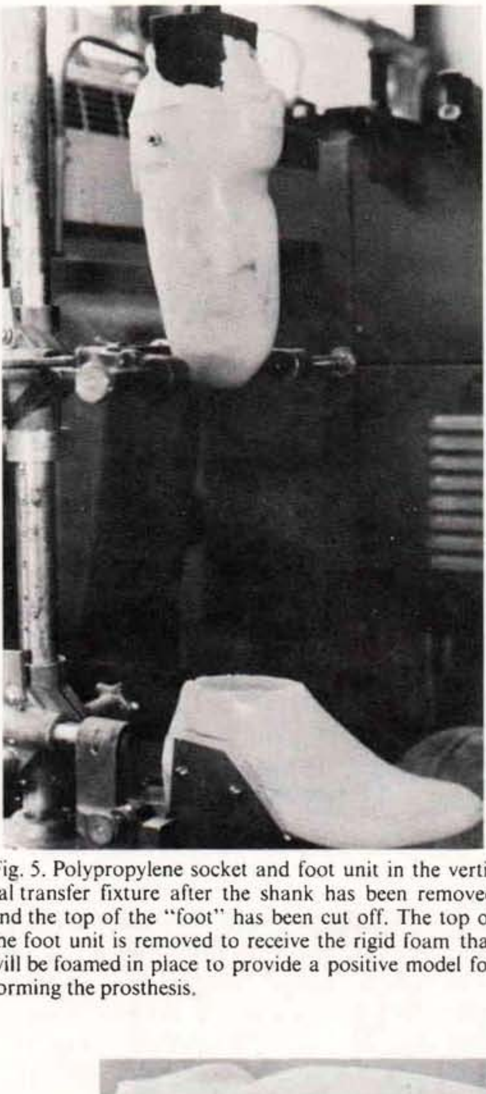

Fig. 5. Polypropylene socket and foot unit in the vertical transfer fixture after the shank has been removed and the top of the "foot" has been cut off. The top of the foot unit is removed to receive the rigid foam that will be foamed in place to provide a positive model for forming the prosthesis.

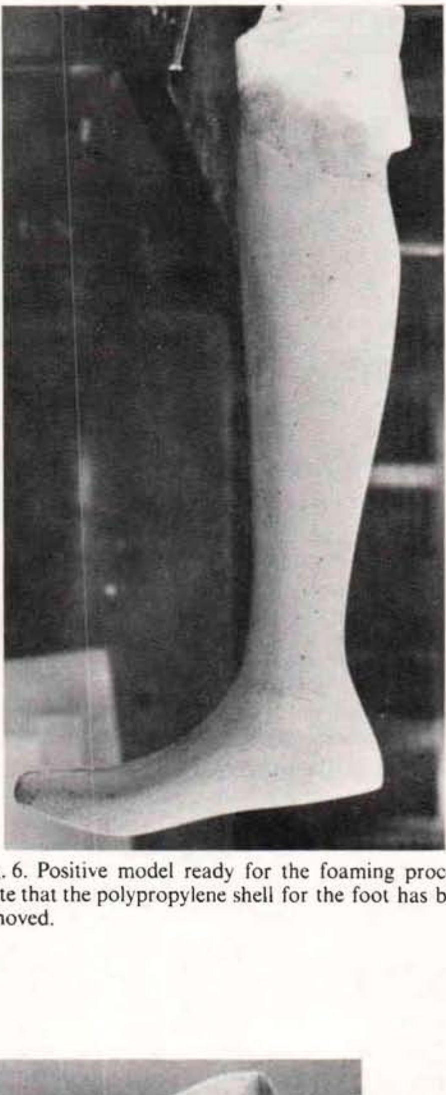

Fig. 6. Positive model ready for the foaming process. Note that the polypropylene shell for the foot has been removed.

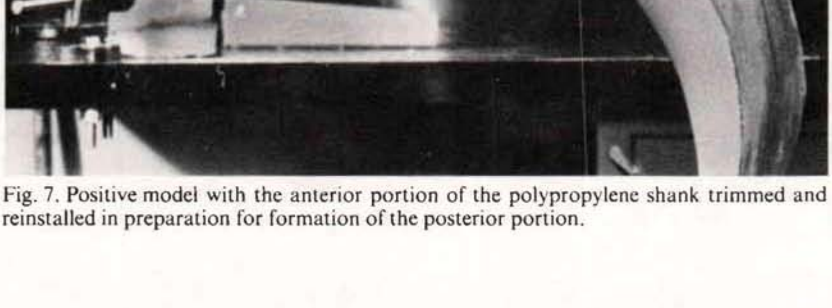

Fig. 7. Positive model with the anterior portion of the polypropylene shank trimmed and reinstalled in preparation for formation of the posterior portion.

Fig. 8. The completed polypropylene ultra-light below-knee prosthesis ready for fitting.

Fig. 9. The ultra-light below-knee prosthesis worn by patient. Note the light suspension strap.

SOME RESULTS

Experiences with the two subjects to date follow:

Case No. 1

Case No. 1 is a 21-year-old male, 5'10" in height, 145 lbs. in weight, with a right below-knee amputation as a result of a motorcycle accident. The stump is scarred and has been difficult to fit comfortably. His conventional prosthesis weighs 4.25 lbs and he has worn it for 2 1/2 years. He has been provided with 3 different polypropylene prostheses during the development period so far. The first experimental prosthesis failed structurally because of poor forming technique. The second experimental prosthesis weighs 2.7 lbs, and he has worn it 3 months because he prefers it to his conventional PTB. The third prosthesis weighs 1.5 lbs. but the socket does not fit as well as the socket in the second one, so he wears it only on special occasions. The subjects initial reaction was that it felt much lighter and required less energy to use. The subject wears his prosthesis daily for work and during sports activities such as football and swimming. Although waterproof, the buoyancy causes difficulty in swimming. This problem can probably be overcome without too much difficulty.

Case No. 2.

Case No. 2 is a 21-year-old male, 6'4" in height, weighing 181 lbs., with a left below-knee amputation as a result of an industrial accident. He has a well healed stump with no scar tissue. He has been wearing a conventional BK prosthesis weighing 4.6 lbs, for 2 1/2 years. His first and only light weight prosthesis weighs 2.2 lbs. and he has worn this prosthesis for 3 months. His initial reaction was that the prosthesis was so light that he might have trouble controlling it, but he has accommodated to it nicely. Subject is a basketball player and he was instructed not to play basketball with the prosthesis because fatigue levels of the material in this configuration had not been determined. At last report, subject was playing basketball without apparent damage to prosthesis.

Each of the light weight prostheses is suspended with a simple elastic strap worn above the patella (Figs. 8 and 9). Attempts will be made to develop a socket with supracondylar suspension. Expert prosthetists are being consulted in order to develop techniques that will insure quality fit between the limb and the socket.

DISCUSSION

A reduction in weight in prostheses seems to be highly appreciated by active, young unilateral below-knee amputees. Aside from energy savings, less suspension problems are encountered and control seems to be improved.

It seems obvious that the older below-knee amputee will benefit as well, if not to a greater degree. To what extent weight reduction is useful, of course, is not known, and needs to be determined. It might well be that a below-knee prosthesis can be too light, but weight reduction over standard practice certainly seems to be in order.

Polypropylene is an adequate, easily available, relatively inexpensive material for use in making below-knee prostheses. The fabrication technique needs further refinement. Wall thickness can be reduced, and better welding techniques will provide for improved appearance.

A series of patients—children, young adults, and older patients—should be provided with ultra light limbs and the results compared with the current "best" practice.

A study of the effects of the change in configuration of the foot needs to be made. This study would involve gait analysis. Should reduction in weight for some reason not be the goal, the introduction of an integral foot-ankle-shank seems still to be desirable in order to eliminate problems encountered with present foot designs.

The Rehabilitation Engineering Center will welcome the cooperation of other centers who would like to participate in a collaborative study.

LITERATURE CITED

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