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A preliminary clinical evaluation of the Mauch hydraulic foot-ankle system

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Abstract

A preliminary clinical evaluation was conducted by the United States Veterans Administration on eight prototype Mauch hydraulic foot/ankle systems over a period of two years (June 1977–October 1979). One above-knee, three below-knee, and one bilateral above-knee/below-knee subjects were fitted. Both of the above-knee amputees were Mauch S-N-S hydraulic knee users. The purpose of this study was:

1. To determine if this system provides the functions of the natural anatomical ankle around all three main axes; mediolateral, anteroposterior, and vertical.
2. To determine its applicability as to level of amputation, its benefits to bilateral amputees, and its compatibility with crustacean and pylon prostheses/standard knee designs.
3. To determine ease of installation, alignment, and adjustment procedures by a prosthetist and any new gait training techniques by a therapist. The results of the study revealed that this system does simulate the anatomical ankle in activities such as walking on uneven terrain, descending stairs step over step, running, ascending and descending inclines step over step, and a variety of sports activities including skiing. Fifty units have been produced and are being clinically tested in a nation-wide clinical application study conducted by the VA Rehabilitation Engineering Center (formerly V.A.P.C.).

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Introduction

In 1956, shortly after the Veterans Administration had assumed the sponsorship of Mauch Laboratories work in the field of artificial limbs, Hans Mauch of Dayton, Ohio, invented an ankle control principle with an automatically adaptable dorsiflexion stop, enabling an amputee to walk uphill and downhill without loss of stability (Fig. 1).

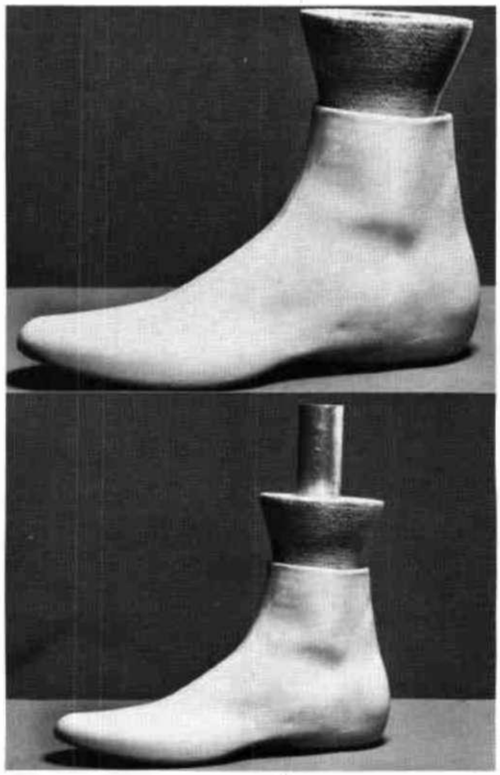

Fig. 1. Mauch Hydraulic foot/ankle system, top exoskeletal, bottom endoskeletal.

Between 1956 and 1963, there followed a pause due to other higher priority work, mainly the swing and stance (S-N-S) hydraulic knee unit development.

In 1963 work on the hydraulic ankle was resumed and the design of an advanced prototype was initiated. This design included, in addition to the variable hydraulic dorsiflexion stop, a mechanical eversion/inversion control as an integral part of the ankle structure. In 1965 this prototype had been completed and was test worn by an amputee in Dayton. It was recognized that provisions for transverse rotation (around the vertical axis) should be added. In 1966, the hydraulic unit was completely redesigned, in addition to eversion/inversion and transverse rotation, hydraulic toe-slap damping and toe pick up were incorporated. In 1967, work on a production prototype was started but again there were delays, due to higher priority projects. The design was finally completed and a production prototype unit became available in 1970. The next year was spent in resolving many persistent difficulties such as wear and noise.

By 1974, all redesigning was completed resulting in a simpler, sturdier, more versatile system, compatible with wooden setups as well as pylon type legs. At this time, preparations for a preliminary clinical evaluation by the V.A. in New York of eight prototype ankles was initiated.

Function of the system

These prototypes now provided the functions of the natural ankle around all three axes, medio-lateral, anterior-posterior, and vertical. (Fig. 2.) These three controls are achieved from a mechanical point of view as follows:

1. *The medio-lateral axis* controls plantar and dorsiflexion. The hydraulic unit contains a gravity controlled element which closes a port in the vane piston and therefore prohibits oil flow from the rear chamber to the front chamber of the housing whenever the piston rod and the attached shank are in vertical position or inclined forward from the vertical. This dorsiflexion blocks whenever the shank, in its forward motion, reaches the vertical position no matter whether the foot is horizontal or pointing upwards or downwards. This means, compared with a standard ankle, that the dorsiflexion stop in walking uphill occurs later, thus avoiding the need for "pole-vaulting", and in walking downhill occurs sooner, thus maintaining knee alignment stability. It also means that in walking over doorsills or in stepping into a hole with the heel or the ball of the prosthetic foot, the ankle automatically compensates for these uneven portions of walking surface. The same happens when the amputee changes to shoes of a different heel height or to slippers.

A second port through the vane piston closes whenever the amputee steps on the leg (a 13·6 kg minimum load), and it opens when he takes his weight off. This means that in the unloaded condition, the foot of the ankle can assume any position from 10° dorsiflexion to 20° plantarflexion. This weight controlled port enables the amputee to walk downstairs step-over-step, without having to aim for the edge of the stairs with his prosthetic foot.

Also, due to this second weight controlled port, the amputee can sit on a chair having his prosthetic leg tucked under the chair, with the foot in a natural dorsiflexion position, or having the prosthetic shank in front of the chair, placed slightly forward, with the prosthetic foot plantarflexed and its sole touching the ground without the toe sticking up.

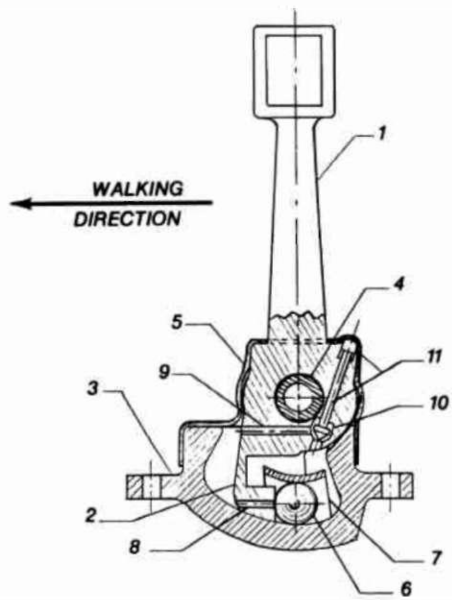

Fig. 2. The hydraulic unit. 1-piston rod. 2-vane type piston. 3-housing. 4-axle. 5-rubber boot. 6-control ball. 7-ball cage. 8-control port. 9-bypass port. 10-bypass valve. 11-valve stem.

A third port in the vane piston is spring loaded. It opens when the load on the ball of the foot exceeds 136 kg, to prevent overstress of the entire structure.

Finally, the hydraulic unit provides hydraulically controlled toe slap damping. The design of the hydraulic orifice is such that it produces turbulent flow, which means that the plantarflexion speed upon heel contact will only increase by 40 per cent if the amputee's weight is doubled.

2. *The anterior-posterior axis* controls eversion and inversion. The housing of the hydraulic unit is attached from below to the inside of a hollow keel of the foam foot by two screws. The housing pads and four rubber washers are so shaped that a 10° inversion of the foot encounters little restriction, but eversion is strongly resisted. This preserves lateral stability, but permits foot adjustment for a straddled stance, or for the downhill foot on laterally slanted surfaces.

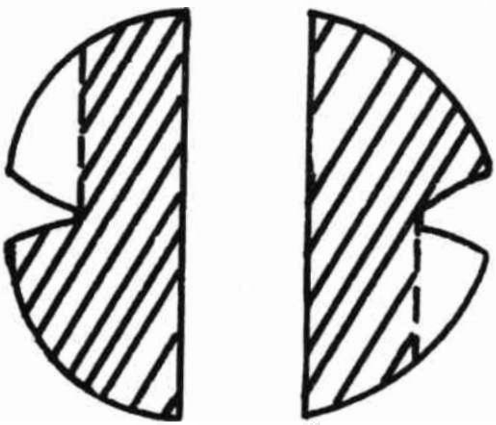

Fig. 3. Two profiled rubber bumpers which control transverse rotation around the vertical axis.

3. *The vertical axis* controls transverse rotation. Two profiled rubber bumpers (Fig. 3) are interposed between the two flat surfaces of the paddle and the inside of the shank where each bumper is kept from rotating with the piston rod. The bumpers are solid on one side of their groove and channelled on the other, providing different torque resistance for piston rotation in opposing directions. The arrangement is such that forward rotation of the pelvis is facilitated, but backward rotation is opposed. Thus the amputee, during the stance phase of the prosthetic leg, can accelerate the other leg at the beginning of its swing without his pelvis sliding backward and can stride out with his pelvis rotating forward while the other leg decelerates at the end of its swing.

Over a period of two years from June 1977–Oct. 1979, these eight prototype systems (Fig. 4), were evaluated by the V.A. Two units were held as spares.

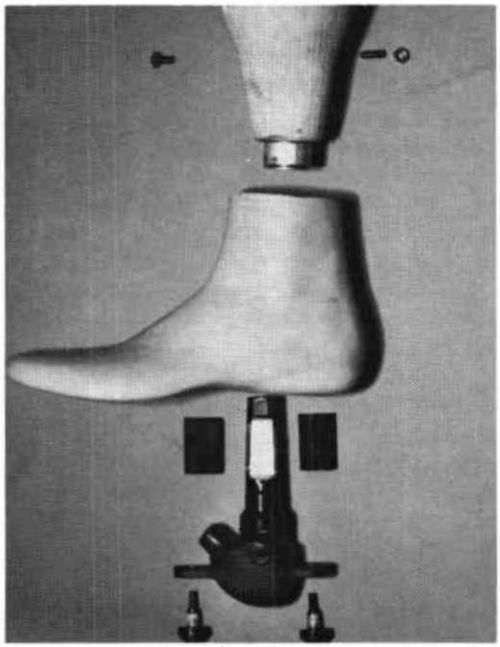

Fig. 4. The complete foot/ankle system components (bottom to top), two holding screws, hydraulic unit, two rubber bumpers, moulded foot, wood block/shin tube set-up, 2 set screws and two locking nuts.

Purpose of the study

The purpose of this study was to determine if this system provides the functions of the natural anatomical ankle around all three main axes, to determine its applicability with crustacean and pylon prostheses, and to determine its ease of installation, alignment, and adjustment procedures by a prosthetist and any new gait training techniques by a therapist.

Table 1. Subject data
(5 subjects, 6 systems, 2 spares)

No.	Sex	Age	Weight (Kg)	Height (m)	Occupation	Etiology	Amputation Level/Side	Suspension Type	Foot Type	Time System Used
1 G.P.	M	55	72·7	1·78	Truck Driver	Traumatic	BK-Left	PTB	Sach	1/7/77–9/8/77
2 M.D.	M	53	97·7	1·78	Prosthetist	Traumatic	BK-Left	PTS	Greisinger 3-Way	2/8/78–2/2/79
3 J.S.	M	43	79·5	1·82	N.Y. Policeman	Traumatic	AK-Left	Suction (S-N-S Knee)	Sach	26/5/77–Present
4 C.K.	M	55	72·7	1·75	Public Utility Work	Traumatic	BK-Right	PTS	Sach and 4 Rotators	7/11/77–Present
5 J.M.	M	28	95·4	1·75	Orthotist	Traumatic	AK-Left	Suction (S-N-S Knee)	Sach	2/3/78–10/4/78
5a							BK-Right	PTS	Sach	2/3/78–10/4/78

Subject data

The participating subjects were one unilateral above-knee, 3 unilateral below-knee, and one bilateral above-knee/below-knee amputees. The two above-knee amputees were Mauch S-N-S hydraulic knee users.

Table 1 describes the subjects characteristics; all were males, their ages ranged from 28 to 55 years; weight ranged from 72·7 kg to 95·4 kg pounds; height from 1·75 m to 1·82 m; and all amputations were traumatic. All of the subjects were active individuals both vocationally and avocationally.

The hobbies of subject number 4 were hiking and ballroom dancing; subject number 3 baseball, skiing, and tennis. Subjects number 2 and 4 had tried, used, and broken many of the commercially available rotators.

Results

The most common and frequent failures of the system were hydraulic leaks. The most common amputee complaint did not relate to the systems function but to a "squeaking noise".

Subject number 3 actually broke the piston rod while skiing (this activity was not recommended by the developer, however, this breakage led to the redesign and additional strengthening of the piston rod).

The bilateral amputee was a poor candidate to select, however he gave some indications as to prescription criteria. The stump on the BK side was extremely short and subject to skin breakdown. Two hydraulic systems totally unbalanced him. With the system only on the BK side, he felt more secure, however, he never quite adjusted to all the additional freedom of motion.

This subject was used to test the ease of attaching the system to a pylon (endoskeletal) AK set-up with a cosmetic cover (Fig. 5). No unusual problems were encountered.

Relating to ease of installation and adjustment of the system by the prosthetist, no unusual problems were encountered. Both AK and BK alignment procedures were standard—AK with an S-N-S knee unit followed the TKA line.

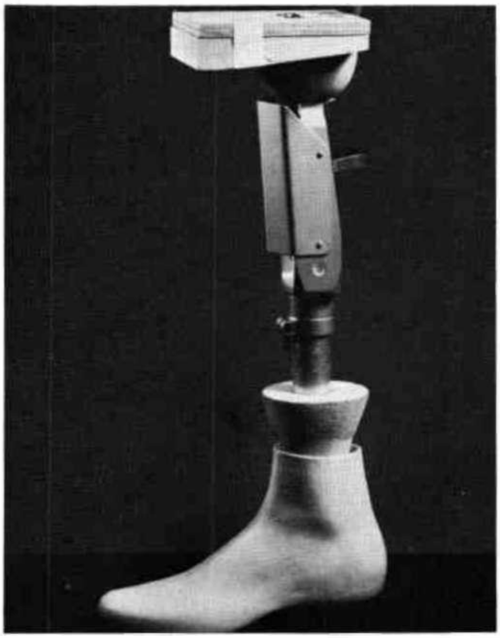

Fig 5. Above-knee endoskeletal system bench alignment with multiplex.

Regarding training techniques, it was found advisable to take the subject through stair climbing, ramps, walking in a circle, and walking out of doors on uneven ground. This was done to ensure that the subject was made aware of the multi-functionality of the system.

As of this writing two of the subjects continue to use the system (almost three years): the unilateral AK policeman and the unilateral BK public utility worker.

All noise has been eliminated from the system, however, problems still exist with leakage.

Conclusion

The preliminary study has revealed that this prototype ankle system does simulate the anatomical ankle in activities such as walking on uneven terrain, descending stairs step over step, running, ascending and descending inclines, and a variety of sports activities including skiing.

Fifty production model units have been produced and as of July 1980 are being clinically evaluated in a nation-wide full scale clinical application study, conducted by the VA Rehabilitation Engineering Center in New York.

FURTHER READING

MAUCH, H. A. (1978). Final report on development in the field of artificial limbs, VA Contract No. V100 (134) P-340, 9–11, 26.