Hydraulics and Above-Knee Prosthetics

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Some of the highlights in the history of the use of hydraulic systems in artificial legs might be useful in understanding the present status and influencing the future application of hydraulic principles in lower-limb prosthetics.

One of the prime objectives of the designers of artificial legs for above-knee amputees is control of the knee joint, and, thus, the shank to provide the amputee with the means to stand and walk safely, efficiently, and gracefully. Sporadically since 1918, and possibly before, hydraulic principles were proposed as a means for locking or braking the knee to enhance safety, but none of these ideas seem to have reached a practical stage until after World War II.

When the National Academy of Sciences (NAS) initiated a research program in limb prosthetics in 1945 at the request of the Surgeon General of the Army, surveys of amputees indicated that the above-knee amputees felt that their greatest need was a knee lock that would prevent stumbling. This "finding" prompted a number of designs in the United States that used hydraulic systems to provide knee locking or braking on demand. Concurrently, a team in Germany, Ulrich Henschke, a physician, and Hans Mauch, an engineer, developed a leg prototype that used a hydraulic lock activated by motion of the abdominal wall. After Dr. Henschke and Mr. Mauch moved to the United States at the invitation of the United States Air Force, they were encouraged by their host to continue development of their design, and they became active in the NAS Artificial Limb Program.

During the 1940's, Mr. Jack Stewart, an AK amputee and inventor, devised, to meet his own needs, an above knee leg which used a hydraulic system to not only provide knee locking, but also to provide shock absorption at the heel, co-ordinated motion between knee and ankle joints, and adjustability of the height of the heel. Swing phase control was provided by hydraulic fluid being forced through a single orifice, a serendipitous sort of circumstance.

About 1951, leaders in the research program came to the conclusion, based on data developed at the University of California, that perhaps, more important than control in the stance phase, is control during the swing phase. Mr. Mauch was requested to give high priority to the design of a mechanism that would provide control of the knee during swing phase so that the amputee could vary cadence without changing the friction control setting. At about the same time it was recognized that the characteristics of a fluid flowing through an orifice had the possibility of providing automatically the change in resistance to knee flexion and extension needed to compensate for changes in the walking cadence.

Using many of the same parts designed for the stance-control system as well as data provided by the University of California Biomechanics Laboratory concerning knee movements during swing phase, Mr. Mauch produced a unit with a number of orifices arranged to provide changes in resistance to rotation at the knee corresponding to the "normal." This design, known as the Model "B," after some years of testing and field use, was combined with the stance-control system to produce the Model "A," which when modified was marketed as the Henschke-Mauch S'n'S (Swing and Stance) knee unit. During the development of the Henchke-Mauch units several less complex hydraulic and pneumatic units were also developed by others and marketed commercially with some degree of success.

During the early 1950's 18 units of the Stewart design known as the Stewart-Vickers Hydraulic Leg were evaluated by a team at New York University, who found good amputee acceptance, and recommended that the locking feature be eliminated since the cost could be reduced appreciably and the test subjects didn't seem to make use of that feature. This recommendation was followed by Mr. Stewart, who a short while later sold all rights to U.S. Manufacturing Co., who manufactured and marketed it as the Hydra-Cadence Leg. The Hydra-Cadence Leg has been a commercial success, but in spite of a great deal of experience no one can be sure of the relative importance of its many features.

The development of hydraulic mechanisms for artificial legs has been plagued by leakage and breakage, which is only natural in an effort that tries to arrive at the optimum compromise between cost, weight, and function. Whether or not this optimum has been achieved is not yet known. We do know, however, that active above-knee and hip-disarticulation amputees appreciate the swing-phase control function afforded by hydraulic mechanisms and that the present day costs are not prohibitive for a substantial number of amputees. No definitive studies have been made that would delineate the efforts of the various factors and features involved, singly or in combination. With the availability of 4-channel 24-hour physiological surveillance systems and other sophisticated instrumentation, such studies seem to be quite feasible now and certainly should be considered.

For at least thirty years the need for voluntary control of the knee joint has been recognized, but until the advent of the microcomputer it was difficult to conceive of a practical method to accomplish this. When microcomputers became available, the first reaction of some designers was simply to add the microcomputer to present hydraulic systems, but these efforts failed most probably because the systems available were not designed for control by computer. At any rate, it would

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seem that the weight alone of present systems would make voluntary control impractical, and thus any project in this area should begin anew.

At present, very little work seems to be going on in the area of voluntary control systems. Some work at the Massachusetts Institute of Technology has been reported for nearly a decade. More recently, the REC at Moss Rehabilitation Hospital started a project where pattern recognition techniques are used to obtain subconscious control of a knee mechanism by EMG signals about the hip joint, which shows a good deal of promise.

Perhaps what we need most at this point is more information concerning the contribution of each variable, such as swing-phase control, stance-phase control, ankle action, weight, and weight distribution, singly and in combination, for designers of the next generation of above-knee legs. With the technology now available to us, this appears to be possible as well as practical.

Physical Therapy and Hydraulic Knee Units

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Without a thorough understanding of the principles of operation and functional benefits engineered into the sophisticated hydraulic knee mechanisms, the therapist will be unable to help the amputee gain maximum benefits and to use the system effectively. It is important that the prosthetist ascertain that the therapist knows what adjustability is incorporated into the prosthesis. Much of the adjustment will be done during dynamic alignment at the prosthetic facility, but modifications will need to be made as the patient gains confidence and his ambulation pattern improves.

An understanding of the fundamental differences between hydraulic control and mechanical friction will help in training the amputee to take full advantage of the flexibility of hydraulic mechanisms. Amputees can walk over a wide range of cadences instead of being limited as with mechanical friction. There are two reasons for this. First, hydraulic friction increases with speed to just balance the increase in kinetic energy of the prosthesis while mechanical friction remains essentially constant. The programmed hydraulic characteristics give little frictional resistance during initial extension and flexion, but build to a peak at terminal flexion and extension. This helps to provide a natural appearing gait regardless of cadence. The stability of hydraulic systems permits alignment nearer the trigger point and thus results in less energy expenditure required for walking. If a patient has previously used a mechanical knee, he needs to be reminded that no exaggerated residual limb motion is necessary to gain adequate flexion and extension of his hydraulic prosthesis.

For purposes of brevity I will limit my discussion to gait training with one knee unit—the Mauch S-N-S (Figure 1). The Mauch S-N-S knee unit can be set to provide 3 functions:

1. Swing and Stance phase control.
2. Swing phase control only.
3. Manual knee lock.

A stirrup shaped lever near the top of the piston rod operates as a selector switch. When the lever is in the down position, swing and stance control are both operative. This would be the adjustment chosen for normal walking. The major advantage of stance control is that it offers the patient stumble recovery. If

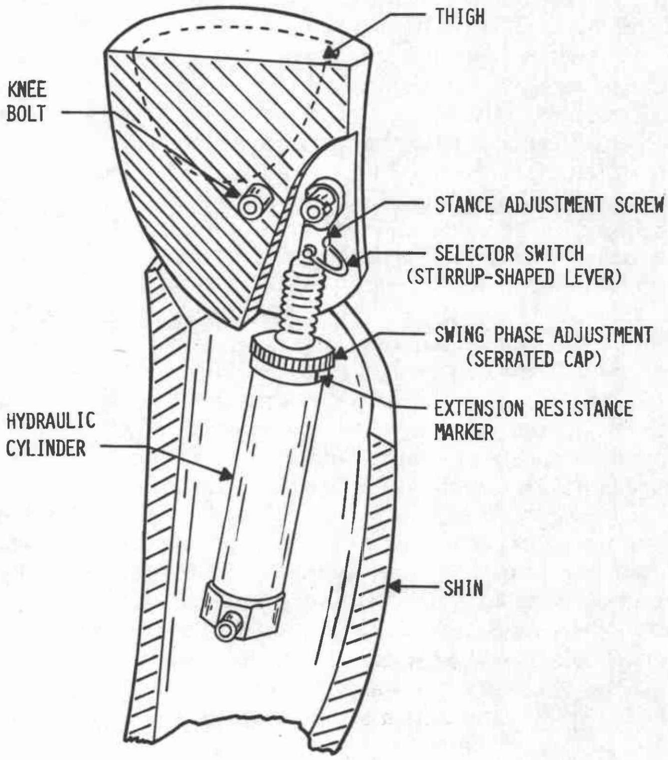

Figure 1. Cutaway diagram of the Mauch Unit

the prosthetic knee buckles, it will give way slowly enough that the patient should be able to regain his balance before falling. When training a patient with a conventional knee unit, he is taught to forcefully contract his hip extensors late in swing phase to accelerate the shank forward (with resulting terminal impact) to ensure extension of the knee at heel strike. Amputees wearing fluid-controlled mechanisms need not do this. The amputee should be instructed to swing his thigh forward, decelerate it, and end the movement with the residual limb pointing to the point on the ground where the heel should strike. The shank, aided by the built-in extension bias will swing forward smoothly, and at heel strike will be in

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