Harnessing—Here and Hereafter

JOHN LYMAN, Ph.D.[1]

However well designed the other parts of an artificial arm may be, the functional success of the upper-extremity prosthesis must ultimately depend upon the adequacy of the coupling between the human being and the inanimate mechanism. Since this man-machine linkage is intended to hold the arm on the stump and to secure from residual body sources the mechanical power necessary for operation and control of the prosthesis, the technique of constructing it has come to be known simply as "harnessing." Because body harness is such ah intimate piece of apparel, and because arm amputees exhibit the same kinds of individual differences as characterize the rest of the population, it seems likely that proper harnessing will long remain a tribute to the personal skill of the prosthetist, despite all advances in prefabricated components. Although the clinic team may prescribe the specifications for a prosthesis within the existing framework of medical and engineering knowledge, the final result depends largely upon the prosthetist's talent for constructing and fitting the harness in such a way as to meet anatomical, physiological, and functional requirements.

Functionally, the harness may serve one or more of three purposes: it may hold the prosthesis in place; it may transmit power and excursion to produce force and movement in operating components; it may convey to the wearer the intelligence needed for arm control. In conventional construction of upper-extremity prostheses, it has been customary to rely upon the harness for the performance of all three of these services and, further, to obtain them all from a single harness system. Such an arrangement is of course grossly unlike that of the normal limb, where the control function, mediated by the nervous system, is clearly separated from the functions of suspension and of power transmission. Only in externally powered prostheses, as for examples the TBM Electric Arm and the Vaduz hand, has an attempt been made to separate the control function from the power and suspensory functions. Although to date such devices have not proved to be as useful or reliable as simpler ones, they are representative of an approach which may, in the long run, lead to far more refined limb substi-

[1] Assistant Professor of Engineering, University of California, Los Angeles.

tutes than can be contemplated by further development of a harnessing philosophy which stresses the combining of suspension, power transmission, and control.

The use of body power for operating an artificial arm forms an inherent control link between the neuromuscular system and the prosthesis. To the extent that a "closed loop" is effected via the sensory feedback available to the power-producing muscles, control of force and excursion through the power-transmission system is possible without the aid of external sensory-feedback loops such as vision and hearing. While the latter cues are generally present, they can at best serve only in an auxiliary capacity. The rich sensations of touch, pressure, pain, and temperature, which have been lost with the natural limb, have no substitute beyond their dim reflection in the signals from harness strap or cineplasty muscle pin of present-day prosthetics technology.

One can argue, with considerable sustaining evidence, that the modern arm prosthesis is quite functionally adequate in most respects and that the addition of refinements in the form of further sensory cues for improved control would only complicate harnessing unnecessarily. But to take this viewpoint is paying tribute to the adaptability of the human mechanism rather than to the adequacy of today's prosthetics research and development. As facts currently stand, it appears that no clear-cut assessment has been made of the importance of sensory losses to the amputee. The effort has been to achieve prosthetic replacement of motor function, and it still is not generally recognized that this goal has been approached with the present degree of success only because sensory control loops are established incidentally in the course of harnessing for power transmission. The major inadequacies leading to failure in externally powered prostheses can be traced directly to shortcomings in the design of control loops—loops which are intrinsic even in the crudest of body-powered prostheses.

Since in the present state of the art the optimum connection between the amputee and the operating mechanism is still so indispensable to the proper functioning of the upper-extremity prosthesis, this issue of ARTIFICIAL LIMBS is devoted to a summary of current harnessing technology as developed under the auspices of the Advisory Committee on Artificial Limbs. Although progress in the improvement of body harness has been substantial since World War II, even the latest techniques fall far short of duplicating the neuromuscular mechanism of the normal arm. And consequently there is still a great deal of forward-looking to be done in the research, development, and production phases of upper-extremity prosthetics.

Where will the technology come from that may make possible "sensory prostheses" with attendant refinements in the present "motor prostheses"? Probably not directly from current trends in artificial-limb research. As is common knowledge, a very real and dynamic revolution is under way in the modern engineering sciences. It is accompanied by a plethora of popular terms like "cybernetics," "servomechanisms," "information theory," "digital and analogue computers," and "automation," to name a few. From the developments that are taking place, many new materials and processes are becoming available. Just as the aircraft industry, through the Northrop design studies, has contributed the present lightweight plastic artificial arm and the Bowden-cable transmission system, so it may be anticipated that within a relatively few years the electronics and missile industries may make even greater contributions. Compact, reliable, and lightweight items like the famed transistor may become as commonplace in the control systems for artificial arms as is presently the case in hearing aids. New products from metallurgy and chemistry may eventually make it possible to realize direct attachment of prosthetic devices to remaining skeletal members of the body through the skin and surrounding tissue, with consequent elimination of the socket and of the suspensory elements of harness. Much of the theory and much of the methodology for accomplishing the direct coupling of man to mechanism, including the all-important link to the nervous system for control, are either available already or else are promised within the foreseeable future.

Because in the field of amputee rehabilitation there are never apt to be available the amounts of research money now characteristic of other fields of science and invention, it is fortunate that a systematic plan for the advancement of limb prosthetics has become so well established in the decade since World War II. The Artificial Limb Program furnishes an organized means of following progress in other areas and of adapting to limb substitutes new approaches and new techniques that would otherwise lie far beyond the purse of prosthetics research itself. The future in design of limb replacements is thus perhaps now greater than ever before. Even so, no matter how sophisticated upper-extremity prostheses may become, the actual utility of any given artificial arm will continue to reside largely in the degree to which the fitter can attain the optimum sensory-motor association through accomplished harnessmaking. In no other known way can so much satisfaction be afforded the individual arm amputee.