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Artificial Limbs

A Review of Current Developments

ADVISORY COMMITTEE on ARTIFICIAL LIMBS

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CONTENTS

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Harnessing—Here and Hereafter

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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 an 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 IBM 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-

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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.

The Biomechanics of Control in Upper-Extremity Prostheses

CRAIG L. TAYLOR, Ph.D.[1]

In the rehabilitation of the upper-extremity amputee, structural replacement by prosthetic arm and hand is an obvious requirement, and it poses a comparatively easy task; functional replacement by remote control and by substitute mechanical apparatus is more elusive and hence infinitely harder. For the purposes of functional utility, remaining movements of upper arm, shoulder, and torso must be harnessed, and use must be made of a variety of mechanical devices which amplify remaining resources by alternators, springs, locks, and switching arrangements. The facility of control attained through this apparatus is the key to its ultimate value.

The future of upper-extremity prosthetics depends upon an ever-increasing understanding of the mechanics of the human body by all who minister to the amputee—prosthetist, surgeon, and therapist alike. It must always be stressed that the final goal is an amputee who can function. Too often there is a tendency to put undue faith in the marvels of mechanism alone, when in fact it is the man-machine combination that determines performance. It is in this broad frame of reference that the biomechanical basis of upper-extremity control must be approached.

Prosthetics Anthropometry

SURFACE LANDMARKS

If successful control is to be obtained, the various components of the prosthesis must be positioned with a good degree of accuracy. To do so requires reference points on the body, of which the most satisfactory are certain bony landmarks. Most of these skeletal prominences protrude to such an extent that location is easily possible by eye. Others require palpation, and this method should be used to verify observation in every case. The bones most concerned in upper-extremity anthropometry are the clavicle, the scapula, the humerus, the ulna, and the seventh cervical vertebra. Surface indications of protuberances, angles, or other features of these bones constitute the landmarks, the locations and definitions being given in Figure 1.

ARM AND TRUNK MEASUREMENTS

The typical male torso and upper extremity are shown in Figure 2, which, together with Table 1, was derived from average measurements on Army personnel (*16*). Such an average form serves to establish harness patterns and control paths. The arm, forearm, and epicondyle-thumb lengths[2] constitute the basis of sizing prostheses (*2*). Arm length places the artificial elbow; forearm length locates the terminal device. The epicondyle-thumb length is an important over-all sizing reference because in the unilateral arm am-

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[2] In everyday language the word "arm" is of course taken to mean the entire upper extremity, or at least that portion between shoulder and wrist. In anatomical terms, "arm" is reserved specifically for the segment between shoulder and elbow, that between elbow and wrist being the "forearm." Although in the lower extremity the word "leg" commonly means the entire lower limb, whereas anatomically the "leg" is that segment between knee and ankle, confusion is easily avoided because we have the special word "shank." No such spare word is available to describe the humeral segment of the upper limb.—Ed.