Still a Long Way to Go[1]

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IT IS probably a common experience to those of us who work in the field of artificial limbs to receive odious comparison between the relatively primitive prostheses and the sophisticated hardware deriving from space technology, nuclear physics, and the like. The implication usually is that, if similar expenditure on research were made in our field, similar dramatic advances would be made. I do not think that the problem is as simple as this reasoning would imply, and there is some evidence to support my view. I am told that, once upon a time, a great American aviation company undertook to develop an artificial arm and that, some years and a million or two dollars later, they reverted with relief to the relatively simple matter of designing aircraft.

And yet we must acknowledge that the externally powered upper-extremity prostheses of today are poor things. It is very doubtful indeed whether the unilateral arm amputee can obtain from them any functional or emotional gain over that deriving from the conventional body-powered prosthesis; indeed, in some respects there may be a loss. It is even doubtful whether any bilateral amputee with measurable humeral stumps would be improved, except perhaps by making it possible to superimpose an additional degree of freedom such as pronation-supination on the existing body-powered prostheses. Indeed, I would go so far as to say that the amelics and bilateral shoulder-disarticulation patients would be better off functionally if they only had sufficient sites available for harnessing with sufficient power and excursion for body-powered control. Currently available externally powered limbs are acceptable to these patients only because a little function is better than none at all. How little that is, is exemplified by the readiness with which the children with upper-extremity amelia and normal lower limbs revert to using their feet for prehension and manipulation.

It is of more than passing interest to attempt to analyze why these things should be so, and I think there are a number of reasons.

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First, the power-weight ratio of available actuators and power storage components is still not advantageous enough for us to provide truly acceptable responses.

Second, we have not yet discovered enough control sites capable of providing a sufficient number of degrees of freedom to position the hand or terminal device in space, to put it in the optimum attitude in relation to each task to be performed, and still leave an adequate reserve for prehension.

The problem of simulating normal prehension has not been solved, nor, in my opinion, has a truly acceptable compromise been attained. Most writers agree that a well-designed hook is more functional than any of the many so-called functional hands, and yet few would claim that the hook contributes anything to cosmetic restoration or that it is likely to be emotionally satisfying to more than a small proportion of patients. Various ingenious hands purport to provide a selection of different types of grasp, such as the power grasp, precision grasp, "three-jaw chuck," and so forth, and some even achieve this. But none of them, nor of the hooks for that matter, is capable of manipulation within the grasp. This results in the exasperating experience for the user that any object he picks up is seldom immediately in a position of function; he is unable to manipulate it into such a position and has to resort to inelegant procedures such as transferring the object to the mouth and back to the hand again. Furthermore, many tasks that we do are achieved by manipulation—screwing, modeling, squeezing, and a host of others—which, for the amputee, have to be done by energy-consuming gross arm movements or even gross body movements, and he cannot feel what he is doing. It is not surprising that the unilateral amputee elects to use his remaining hand, and the amelic his toes.

The foregoing difficulties apply in the main both to externally powered and body-powered prostheses, and I have said little about sensory feedback, a degree of which is available to the users of the latter systems. The control cable offers a built-in position servo, while a great deal of information about the forces applied at the output can be derived from the reactions of the harness against the body and those of the socket on the stump. When external power is used, these afferent channels either cease to exist or are severely attenuated, and it becomes necessary to consider the provision of artificial sensory loops which in their turn introduce difficulties in interpretation.

We are thus confronted with what I believe to be the main barrier to progress in externally powered prostheses—the man-machine interface. This should be taken to mean not only the physical attachment of the prosthesis to the wearer, but also the boundary through which all command signals from the biological system of the wearer must pass to the mechanical system of the prosthesis and through which all information relating to the output of the prosthesis must return to the biological system if the wearer is to make the best use of such information to modulate performance.

It is on these channels of communication that the effective control of externally powered devices depends. I am quite certain that we do not know enough about their mechanism to exploit them to best advantage. No one has yet attempted to measure the "goodness" of the channels—for example, in terms of communication theory—and yet I believe that effective systems design would follow on such data as surely as night after day.

One of the greatest virtues of biological systems is that they are highly adaptive. The human control system—and in particular the computer as represented by the central nervous system—is no exception to this. The pattern of manual activity which we require in order to enjoy a full life is so infinitely variable that I have very serious doubts whether any form of programmed operation within the prosthetic system will satisfy a user for any length of time. The concept of programming the trajectory of the terminal device so as to limit the decision-making demand upon the user to commanding the system to move it from *A* to *B* is open to this criticism. Even if provision were made for the user to override the program and revert to voluntary control, I suspect that the switch would soon be left permanently in the override position. In any event, the case for this sort of programming seems to me to be accepting that the interface is inevitably poor in a communications sense. It may be that a better understanding of the interface will make this an unduly pessimistic view.

Reverting to the adaptive properties of the biological system in general, and of the central nervous system in particular, it seems to me that significant progress in externally powered limbs will be made only when it becomes possible to link the central nervous system "on line" with the prosthetic control system. Servo loops crossing the interface would make an integrated and adaptive system. It might be said that a start had already been made on this by exploiting the myoelectric discharges for control. In such an integrated system, however, the command signal is being derived by tapping the middle of the efferent loop. Such sensory information as returns by afferent channels is derived from the muscles and their tendons. Essentially, this is a backwater of the main stream of the afferent channel of the man-machine complex. It follows that information about the output of the man-machine system can only be inferred rather than known. In my view, Simpson's position-controlled servos and Bottomley's pressure-demand pneumatic valve have more prospects of achieving a truly adaptive output and might be regarded as among the first breaches in the man-machine interface.

Taking all these matters into consideration, besides many other difficulties which I will not discuss for reasons of space, we are in no position to be complacent about externally powered arms. Indeed, the state of the art is so relatively primitive that the only overriding indication for prescribing them at this time is bilateral high-level amputation or the equivalent—only a handful of patients out of the total upper-extremity case load of any prosthetic service and an even smaller proportion of the total case load. The difficulties are so great, and the amount of fundamental information lacking is so formidable, that one is continually surprised at the surge of interest in the field and the amount of effort that is going into it. Indeed the budget for prosthetics research and development in Great Britain for next year envisages that over 30 per cent of the total expenditure will go to work on external power. From what I saw when I visited the United States in May 1967, I would think that a similar proportional expenditure is being made there. Taking into account the tiny number of immediate beneficiaries—although admittedly they are among the most severely disabled—it is proper to take stock and consider whether this level of expenditure of money and effort is justified. Have we got our priorities right? Of course, there is much common ground in the orthotics field, and many developments arising from purely prosthetics requirements would have direct application here. This would increase the number of potential beneficiaries, but they would still be a small proportion of the total disabled population. I think the justification as well as the reason for the interest in the subject is the fact that we believe the possibility of introducing a new order of function to *all* upper-extremity amputees lies in external power and possibly to lower-limb amputees as well.

May I use these pages to make a plea, if not that hardware development should cease, at least that some of the effort should be put into fundamental research into problems such as those I have indicated? Indeed, all of us already engaged in such work should devote sufficient time to discovering what the patient really needs, rather than to providing him with what we think he ought to need.