The Control of Electrically Powered Hand and Arm Prostheses:

Electromyogram or Residual Skeletal Movement?

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Introduction

During 1977, Dr Rolf Sörbye of the Regional Hospital, Örebro, Sweden, reported upon his experiences with the fitting of electromyographically controlled ("myoelectric") hand prostheses to young children.(1) The impact of his work was considerable; in the United Kingdom the general news media gave it extensive coverage, reporting the results with varying degrees of accuracy though, most usually, with that excess of enthusiasm over objectivity which has become such a standard feature of the presentation of medical and bioengineering advances in the lay press. One happy consequence of the episode was that a decision was made to conduct a trial of the hand prosthesis in the UK (under the auspices of the Department of Health and Social Security) by which an objective assessment might be made of the clinical benefits which the hand might have to offer, the technical aspects of reliability, maintenance and repair and, finally, the training techniques required

The Princess Margaret Rose Hospital was one of the three centres in the United Kingdom selected as a base for this trial. Since this Hospital has been one of the most active in the design of (pneumatic) powered limbs for high-level congenital limb-deficient children the trial has afforded us an opportunity to compare the patients' ability using prostheses controlled via the electromyogram with those controlled by movements of remaining, natural body segments

Control System of Pneumatic, Multifunctional, Powered Prosthesis

At an early stage in the development of a multifunctional powered prosthesis (during the 1950's and following the startling increase in the incidence of severe, bilateral, congenital limb-deficiencies consequent upon the use of the drug thalidomide by the mothers during pregnancy) it was realised that control by simple on-off switches would present an overwhelmingly difficult task to the user.[(2)] The use of "proportional" gas control valves was (correctly) advocated; these would provide a movement of each actuator which was linearly related to the movement of the control cable. Later developments by many workers who had become involved in the control problem led to a variety of "force-demand" valves which reflected the force generated by the actuator as a proportional tension in the control cable.

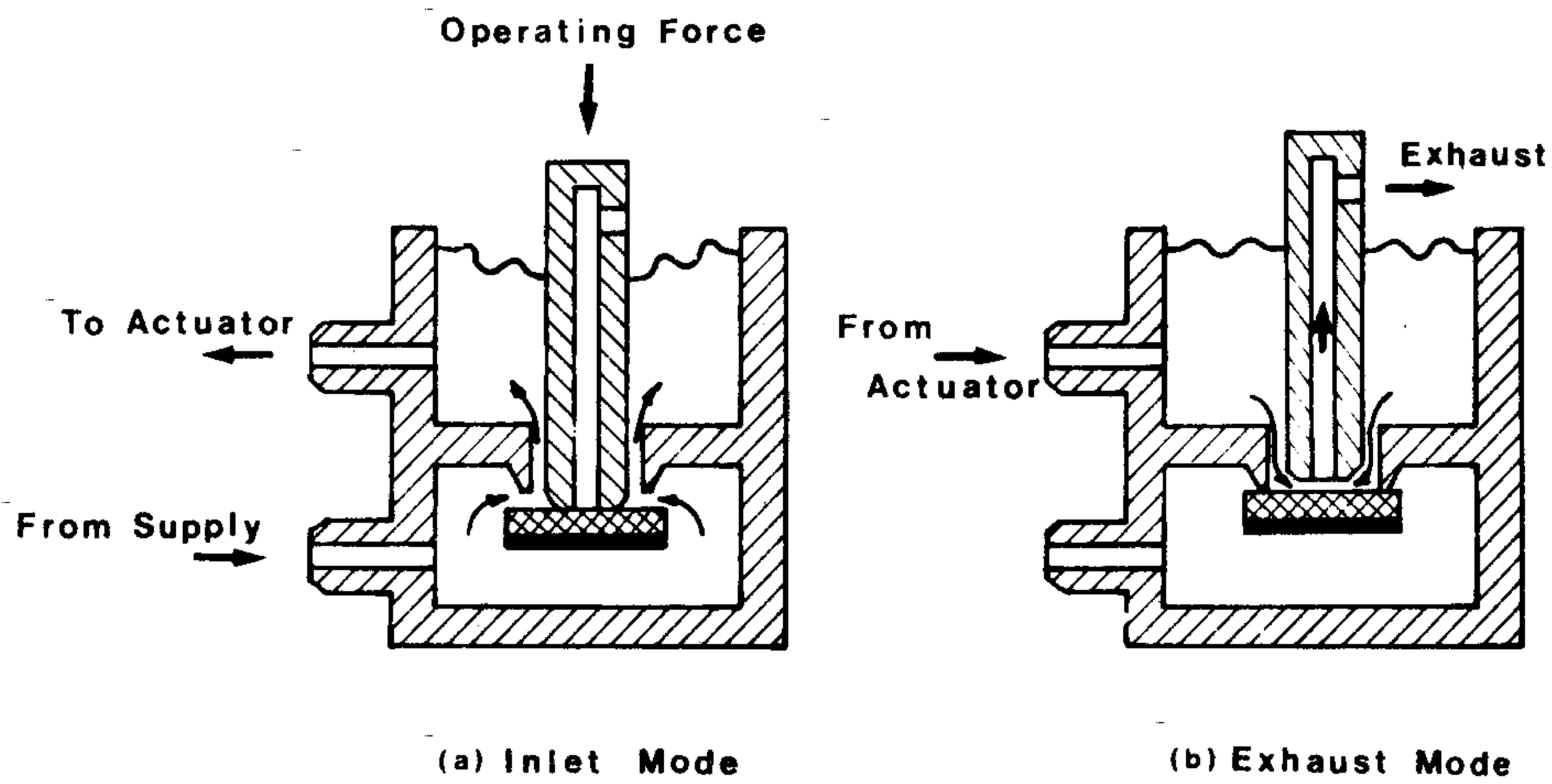

Fig (1) .Schematic Illustration of Force-Demand Valve
The gas pressure at the outlet port acts on the upper diaphragm and hence on the operating shaft.

A schematic illustration of such a valve is shown in Fig (1) and an example of the manner by which the "proportional" behaviour may be obtained in Fig (2). The device is recognisable to control engineers as a follow-up servo incorporating force feedback.

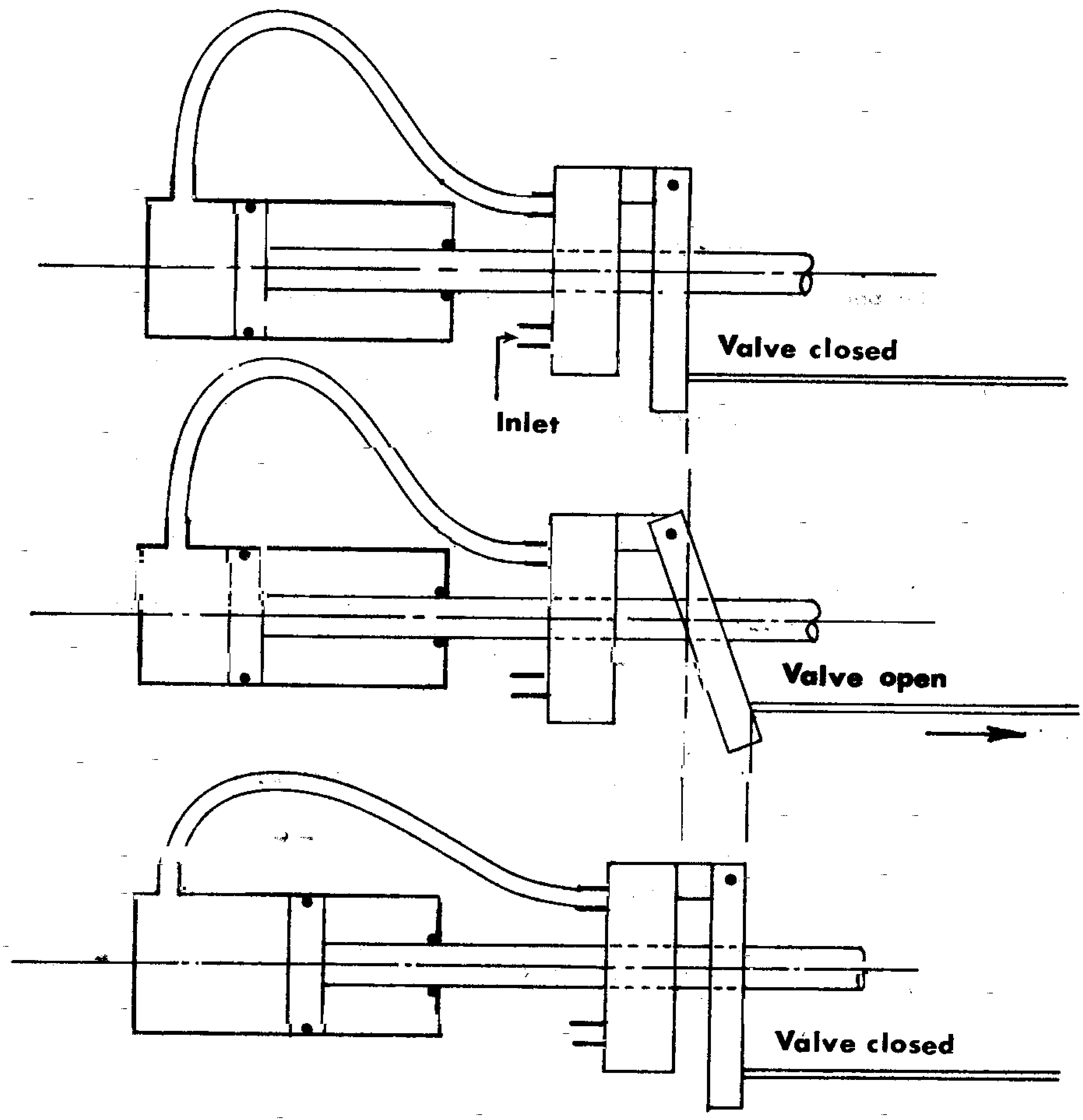

Fig (2)

By mounting the valve on the output shaft of the actuator proportional action is obtained.

Operation of the numerous control cables by bilateral, amelic children was achieved by movements of the scapulae. Protraction, retraction, elevation and depression provide for four different movements of the prosthesis (only one arm of which incorporated powered articulations). These could be exercised independently or in a coordinated manner. Other movements could be controlled by vestigial limb buds or by body bands. It was found that the young children mastered the control of their prostheses (initially three-functional, later with five or six functions) in a remarkably short space of time.

Since linear relationships had been established between the position of the prosthesis and the position of the control site it appeared that the natural proprioceptive mechanism of the user was being mobilised in the control of the artificial arm. The concept of "extended physiological proprioception" emerged.[3]

It is perhaps interesting to note that every mechanical control linkage provides this inherent bi-directionality which is central to the concept of e.p.p. The "joy-stick" of a light aircraft is a good example. When powered controls have to be used as in larger, faster aircraft, it becomes essential to provide a substitute means of feedback of the forces acting on the flight control surfaces. Even with careful design it is difficult to achieve the same precision of "feel" as is demonstrated by the simple mechanical linkage.

Control by the Electromyogram

When myoelectric (e.m.g.) signals are used as a control input no afferent nervous pathways are involved. There is no physiological apparatus to make us aware of the electrical activity of our muscle tissue, though of course, we are aware of the related, mechanical contraction of the muscle. There can be no recruitment of e.p.p., therefore, when electromyographic control of the prosthesis is used.

The Response of the Patients

The Princess Margaret Rose Hospital has been involved in over 300 fittings of pneumatic prostheses to 18 patients. The more recent trial of the myoelectric hand prosthesis has involved 17 fittings to 7 patients.

It is of course extremely difficult to make a completely objective comparative assessment of the way in which those two patient groups learned to use their prostheses. All of the children fitted with the myoelectric prosthesis were able to master the control system. One child, however, came close to being a failure, successfully resisting all efforts to train him for six days. Thereafter he became a good user of the prosthesis.

A questionnaire sent out to the parents of the 75 children fitted (at all three centres) drew a 95% response. Questions which reflect on the child's attitude to the control system, and the responses to these are:

1. How many days a week is the hand worn?

7 days/week	78%
4-6 days/week	20%
1 day/week	2%

2. How many hours a day is the hand worn?

More than 10	63%
More than 8	29%
Less than 8	8%

3. Does your child use the hand

Spontaneously?	47%
With a little thought?	37%
Only with prompting?	14%
Not at all	2%

4. When using the hand functionally, does your child appear to operate it

Automatically?	70%
With a little thought?	16%
With some concentration?	9%
With total concentration?	5%

All in all this reads as a favourable commentary on the hand and the control system. Acceptance is not complete, however, and we must bear in mind that we are studying a single function prosthesis.

Multifunctional Myoelectric Prostheses

Numerous workers have tackled the problem of providing control of a multifunctional prosthesis by electromyographic signals. The methods used can be grouped together into two main categories:

1. Detection of changes in the electromyogram from a single site so as to obtain multiple functions (usually two) from a single site.[4], [5] Dillner and Hägg[6] define three methods,

   (i) Sequential operation, each movement alternating with the other (for example, hand open, close) on each occasion the e.m.g. activity exceeds a certain threshold value.

   (ii) Transition from one movement to the other when the e.m.g. exceeds a second, higher, threshold value (so-called "three-state control").

(iii) Selection of function by examination of the initial slope of the rectified, integrated e.m.g.

2. The use of multiple sites and pattern recognition techniques.(7), (8), (9)

Reports from all of these workers comment on the difficulties of control, the lengthy and demanding training period, and the need for visual and tactile attention to the movements of the prosthesis. Several workers look to the provision of some sensory feedback to palliate these problems.

The writer's own view is that an electromyographically controlled prosthesis is limited to, at most, two functions. The prosthetic establishment INAIL in Italy, (Professor Hannes Schmidl) which has fitted by far the largest number of patients with e.m.g. controlled prostheses, regularly fits two-functional hands (prehension and wrist-rotation) using the three-state control system. Dr Sörbye and co-workers have accumulated over two years of experience with a two-functional arm (prehension and elbow flexion). Even at this level the mental load on the user is clearly perceptible and in sharp contrast to the startling ease of adaption to the pneumatic three- and five-functional prostheses.

Several reasons for this comparative failure can be identified.

1. The statistical nature of the e.m.g. waveform and the low upper limit to its frequency spectrum prevent any precise measurement of its amplitude unless the signal is sampled for an extended time. For control of a prosthesis, 0.5 s is the maximum measuring time available. In this time the measurement accuracy is only just adequate to quantify the signal into three levels, the three-state control is extracting the maximum quantitative information possible.

2. The electromyographic output from the various sites is not stable with time. It is not clear to what extent the changes result from variations in electrode position, electrode contact pressure, contact resistance and so on, artefacts which must be present when surface electrodes are used, as has been usual. The variations in amplitude are considerable and make analysis of the signals from multiple sites by pattern recognition extremely difficult.

3. Intrinsic feedback is completely absent. (The adjective "intrinsic" is used to differentiate with other sensory feedback channels, for example, visual and auditory clues).

Control by Residual Skeletal Movement

If the prospects for multifunctional e.m.g. control are poor then we must seek ways by which the characteristics of the pneumatic control system are replicated in an electrical system.

Fig (3) shows such a scheme. The potentiometer R_{V1}, linked to the movement of the prosthetic hand, is compared with R_{V2}, linked to the input shaft. The output motor M_1 is driven from the difference signal between the two potentiometers, to give the required position servo action. Strain gauges R_{S1} and R_{S2} are incorporated in the fingers of the prosthesis to measure prehensile force. The difference signal from these drives the motor M_2 in the direction shown, giving a force feedback proportional to the closing force of the hand.

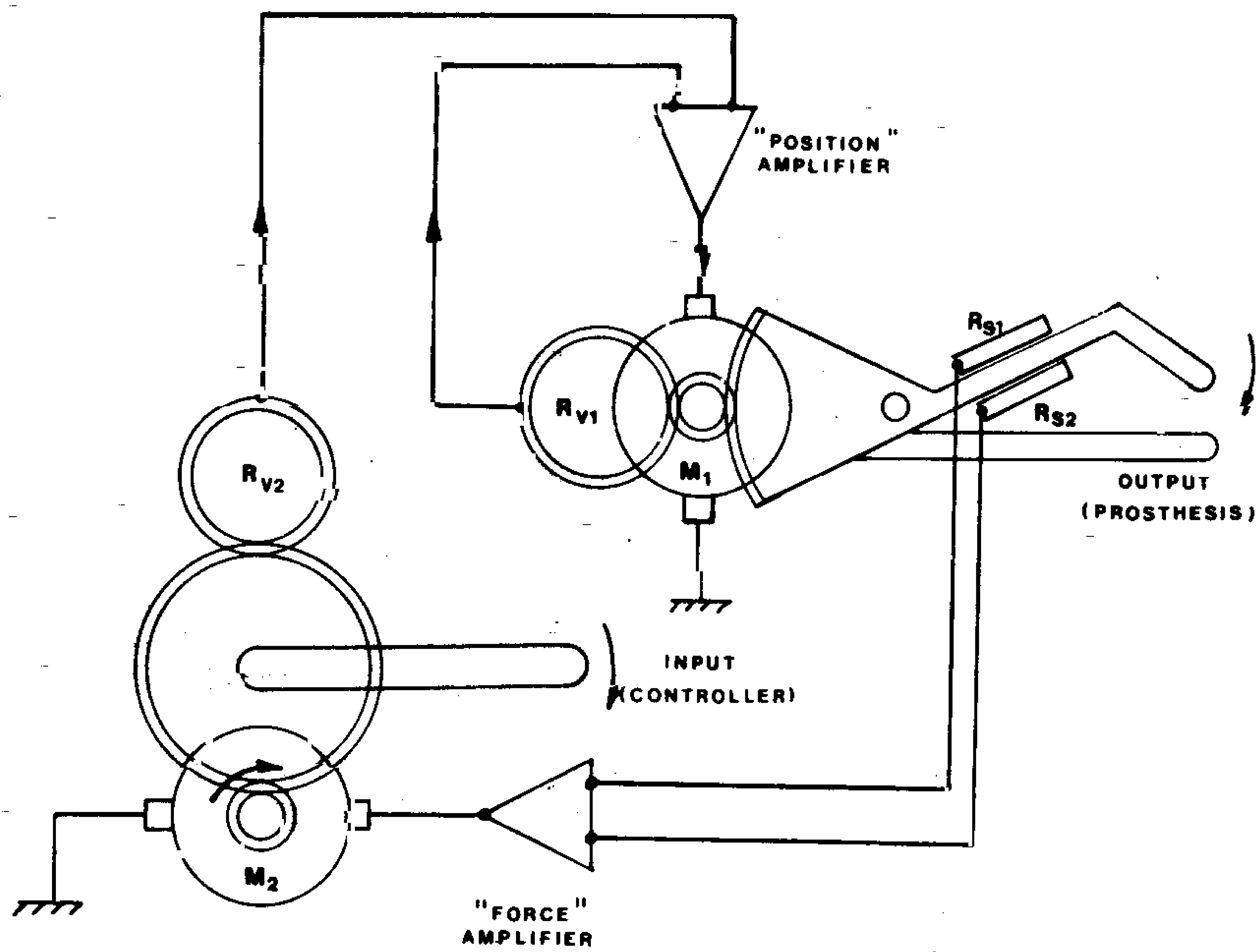

Fig (3) Electrical Control System with Position and Force Feedback

Experiments with such a system have demonstrated a surprising degree of transferred tactile acuity, the size and, to a certain extent, the texture of an object placed in the prosthetic "hand" can be assessed remotely from the controller. These are due to be described in another paper presented to this Conference.

Fig (4) shows the forearm stump of a congenital amputee suitable for fitting with this type of control. Radiographs show only a single bony segment distal to the radius and ulna, but this segment has a range of active movement (palmar/dorsiflexion) of about 140°. In addition he retains good pronation and supination. These movements are used as control inputs by fitting a plastic cup over the distal end

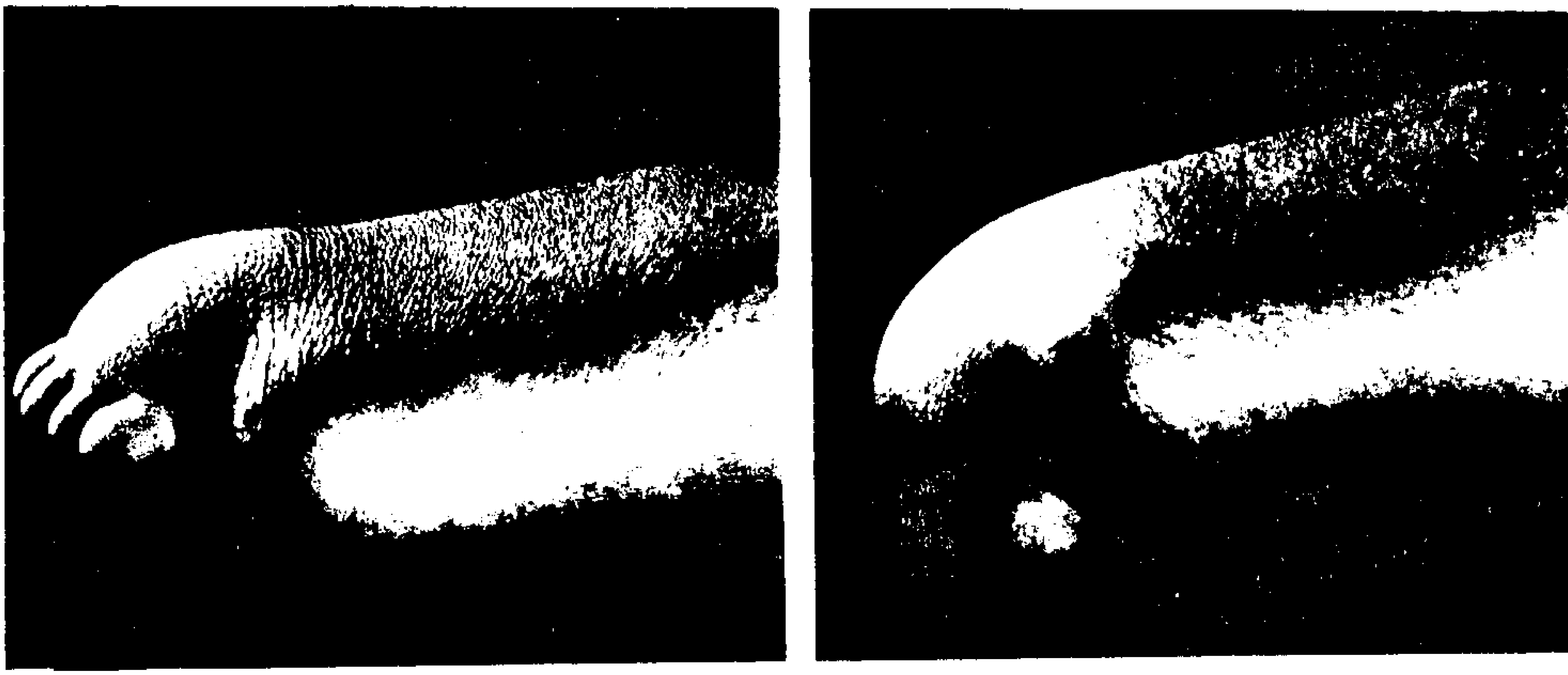

Fig (4) Stump of Young Congenital Amputee Showing Range of Movement of Dysplastic Carpus

of the stump, hinged within the outer plastic socket. Movements of the cup may be sensed by two liquid-in-rubber strain gauges (serving as the input potentiometer R_{V2}) and force feedback applied by a loop of cord passing around the capstan on the output shaft of a permanent-magnet, DC motor mounted transversely, distal to the stump.

A surprisingly large number of our young below-elbow amputees retain sufficient voluntary movement in the limb stump to enable satisfactory control by these techniques to be achieved Even when only soft tissues cover the dysplastic long bones of the stump useful voluntary movement is available. In those few cases where residual voluntary movement is not adequate it is appropriate at this stage to consider the value of surgical procedures to provide a suitable control "site" for instance by a modified cineplasty.

Conclusions

If it is accepted that the application of e.m.g. control to upper-limb prostheses is limited to, at most, two functions, then we must seek means of controlling the several other functions which are needed. Control by movements of remaining natural structures is simple and very effective (because of the extended proprioception). For electrical prostheses the design features of the early pneumatic, e.p.p. arm should be emulated.

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