CLINICAL TRIALS OF A HYDRAULICALLY POWERED PROSTHESIS

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Introduction

A hydraulically powered arm prosthesis, together with portable power unit, was described in the previous Dubrovnik proceedings (1). This arm was based on the Edinburgh E.P.P. arm and had 5 degrees of freedom (2) (Fig 1). It was decided to obtain further experience by hydraulically powering another more simple but robust arm, the pneumatic powered B.R.A.D.U. 'radius vector' arm designed by the late Dr Alistair Bottomley (3). The arm has a radius of 400 mm with a powered reach motion, wrist rotation and T.D. grip. Shoulder elevation is provided by a body powered motion which is ratchet locked.

Component Construction

The control valves for the wrist rotation and reach motions were placed alongside the actuators in an integral body, unlike the previous pneumatic system which utilised on/off valves mounted on the harness. The hydraulic system was arranged to have closed loop position controlled reach and wrist rotation with closed loop force control of the T.D. grip. The valve for grip was mounted remotely on the harness. All control valve input motions were obtained using levers attached to Bowden cables. The actuators for reach and wrist rotation were made double ended so that pulley drive cables could be attached in line. The limited space made it difficult to install the valves and actuators and allow the linear stroke required for the Bowden cable input motion.

The T.D. grip was arranged to allow disconnection of the T.D. without breaking hydraulic supply lines. This was achieved by placing a single acting hydraulic actuator with a spring return on the end of the arm and using a mechanical push rod coupling to the T.D. which could be readily unlinked. Quick release and multiple location features were also provided.

The portable hydraulic power unit which had been mounted for the Edinburgh prosthesis in the upper section of the body powered arm was too long to fit into the B.R.A.D.U. counterpart and so for the clinical trials it was temporarily mounted on a back panel. The power unit supplied oil at 34 bar (500 lb_f/in^2). Rechargeable nickel cadmium cells worn on a waist band provided the primary energy source.

Clinical Trials - 1st subject

The first subject was a male bilateral amelic with normal leg function who was left handed. For some time he had worn a closed loop position controlled Edinburgh gas powered arm on the left side and a body powered arm on the right side which utilised a gas powered Edinburgh hand. The right side configuration was retained but shortened to conform to the hydraulic powered B.R.A.D.U. arm worn on the left. To comply with the input sites previously used by the subject a cap on the left acromion joint was used as an input for the reach motion and a backward movement of the right shoulder for wrist rotation. The valve controlling T.D. grip was mounted on the left hand side of the harness and operated by chin nudge. A further valve, also operated by chin nudge, was mounted on the right side of the harness to

control the pneumatically powered right hand T.D. (Fig 2). All valves were sprung to one end of their travel so that with no input to the valves the reach motion was fully extended, the wrist rotation fully pronated and the T.D. grip closed.

Assessment - 1st subject

It is difficult to distinguish effects due to the subjects having previously used a different type of arm structure from those due to the use of a different actuation media. However, some subjective comment is possible, particularly as the gas powered 'Edinburgh' arm and the hydraulic B.R.A.D.U. arm both used closed loop position control.

The most frequently voiced comment from subject, occupational therapist and technical staff, was the increased stiffness of the system compared with gas power. With a blunt knife, the subject was able to slice an apple having a tough skin and slice a fruit cake. He could also operate switchable power sockets. All these activities were not previously possible due to the compliant nature of the gas powered system. The subject and O.T. thought the control more precise than for gas systems, being able to position the arm accurately and also move it slowly and smoothly. The subject gradually increased in confidence until able to bring the T.D. quite close to his face whilst previously, for tasks such as eating, he had compensated by making large head and trunk movements.

The T.D. used in the trial was a hydraulic version of the gas powered 'Otto Bock' hook. The patient's previous experience had been using the Edinburgh gas powered hand which has a powered 'thumb'. The hook was biased to the normally closed position and opened by a spring return mechanism. With the high viscous losses in the hydraulic pipe, opening speed was much lower (1.8 secs) than for the Edinburgh hand. The time taken to close the hook was 1 sec. The pinch force (70N) and opening distance (65 mm) were larger than for the Edinburgh hand. The subject expressed a preference for the hydraulic hook, particularly its positive grip and was not frustrated by the slow opening speed, a feature which tends to be inherent in single acting, small hydraulic systems. A redesign of the actuator making it bidirectional rather than spring return would overcome these limitations.

The force demand valve to release the T.D. grip was located on the harness and operated by chin nudge. This arrangement was not suited to eating food held between the hook blades as when the subject lowered his head to operate the valve, his mouth was a long way from the T.D. Also, a continual force was required on the valve to limit the grip applied when holding crushable items, such as a paper cup, with the result that such items could not be presented to the mouth. These problems could be overcome by relocating the valve on the right shoulder, using the control site previously required on the Edinburgh arm for powered shoulder rotation. The forces required to operate the position control valves were similar to the subject's gas powered arm and were not considered excessive. The subject, who had normal leg function, did not find the arm and the power unit heavy (total weight, excluding body powered arm, 3.4 Kg). The primary energy store consisted of 10 Nickel cadmium rechargeable cells in series to form a 12 Volt, 1.8 Ah. battery pack worn on the waist band. The battery was adequate for a day's use and was recharged at the end of each day's testing.

Clinical Trial - 2nd subject

The second subject was a female bilateral amelic with no legs who

was also left handed. She had previously worn an open loop, on/off controlled, B.R.A.D.U. gas powered arm on the left side with a body powered right arm having a gas powered T.D. and wrist rotation. The subject was seated in a wheel chair and had found the body powered ratchet shoulder elevation of the B.R.A.D.U. arm too cumbersome to operate and had for some time been using a gas powered actuator to pull on the cord of the ratchet release mechanism. This system was also utilised for the hydraulic arm trials, together with the body powered arm configuration and control sites. To conform with previous control sites a forward motion of the right acromion was used for controlling reach and an upward motion of the left acromion for wrist rotation. In view of the difficulty experienced by the first subject in utilising the chin nudge control for the T.D. grip, the T.D. control site was relocated on the seat of the wheelchair under the patient's left vestigial foot. The power pack was hung on the wheelchair.

Assessment - 2nd subject

The clinical trials for the second subject were strongly affected by her previous experience of the B.R.A.D.U. on/off valve control. During the testing period, she was unable to fully adapt to the new position control system and found it difficult to maintain the constant input signal, necessary when using position control, to keep the arm stationary. However some ability to sense position of the arm from the known position of the input lever was gained towards the end of the trial. The increased stiffness compared with the gas powered system was also favourably commented upon (Fig 3). Valve operating forces and movements were considered large compared with on/off valves.

The restricted range of motions that can be realised with the B.R.A.D.U. arm prevented many of the test tasks from being carried out. The subject was seated in a wheelchair with limited opportunity for using compensating trunk motions. For example the lack of any prosthesis shoulder rotation, or compensating trunk rotation, prevented the subject placing rectangular blocks in similar shaped holes (Fig 4).

Conclusion

The limited clinical trials indicate that it is difficult to compare, in isolation, the relative merits of the actuation media. The first subject had been used to an arm having 5 degrees of freedom and yet, because he had good leg function and trunk mobility, did not feel restricted when using a 3 degree of freedom B.R.A.D.U. arm. The fact that he was used to position control was also important in being able to realise any potential advantage due to a different actuation media. As an active male, he appreciated the increased stiffness and stability of the hydraulic system and could use the arm fairly intensively for a day on one battery charge compared with several changes of gas bottle using the pneumatic system. The second subject had many years experience using the B.R.A.D.U. arm, but as a velocity control system. However the change to a position control system, with its higher valve forces, proved to be the dominating factor. This, together with the restricted range of movements possible for a wheelchair subject when using the B.R.A.D.U. arm, resulted in only limited utilisation of the potential merits of hydraulic power.

However the hydraulic powered version of the B.R.A.D.U. arm was thought to provide a more rigid, precisely controlled system than its pneumatic counterpart. The system was robust and had a reliability commensurate with its prototype development phase. The battery pack could provide energy sufficient for a day's energy needs and then be cheaply and

easily recharged.

The clinical tests indicate that there are potential advantages in using a hydraulic system compared with pneumatics which can justify the increased complexity and cost of using hydraulic components. Further tests are required with a larger number of subjects to indicate those patients who can most benefit from a hydraulic powered system.

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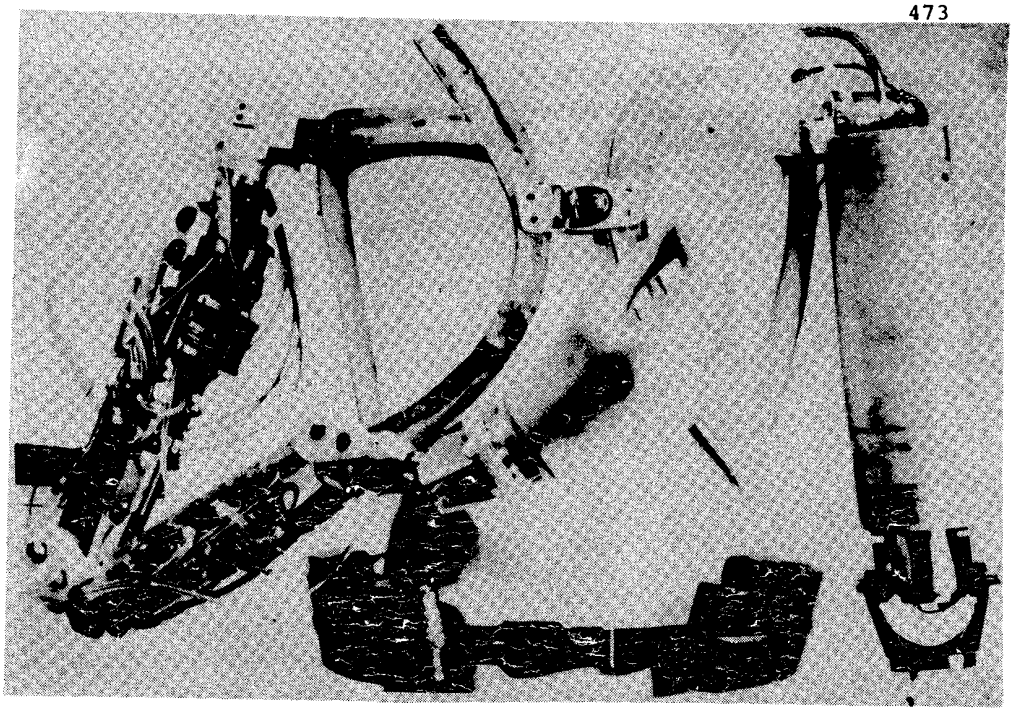

Fig. 1. Five degrees of freedom Hydraulic Powered arm with power unit in left upper arm

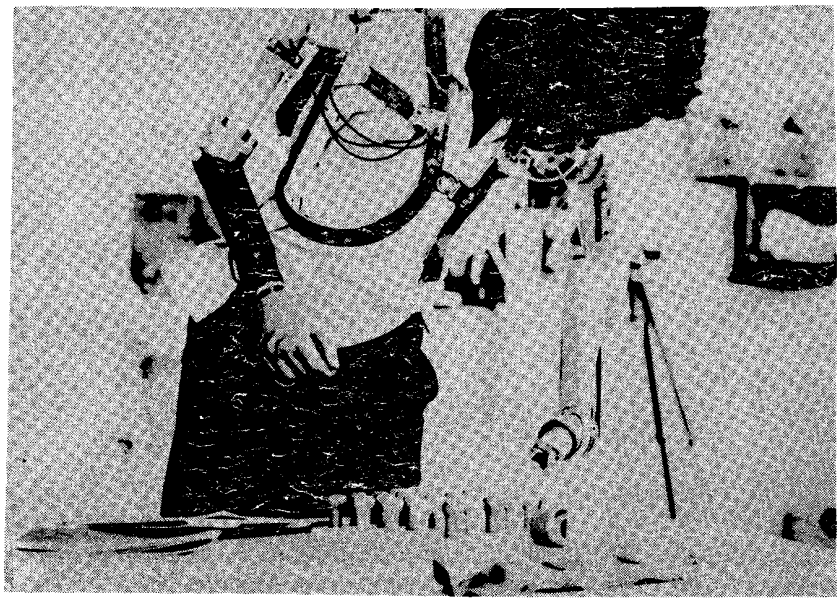

Fig. 2. Three degrees of freedom BRADU arm hydraulically powered

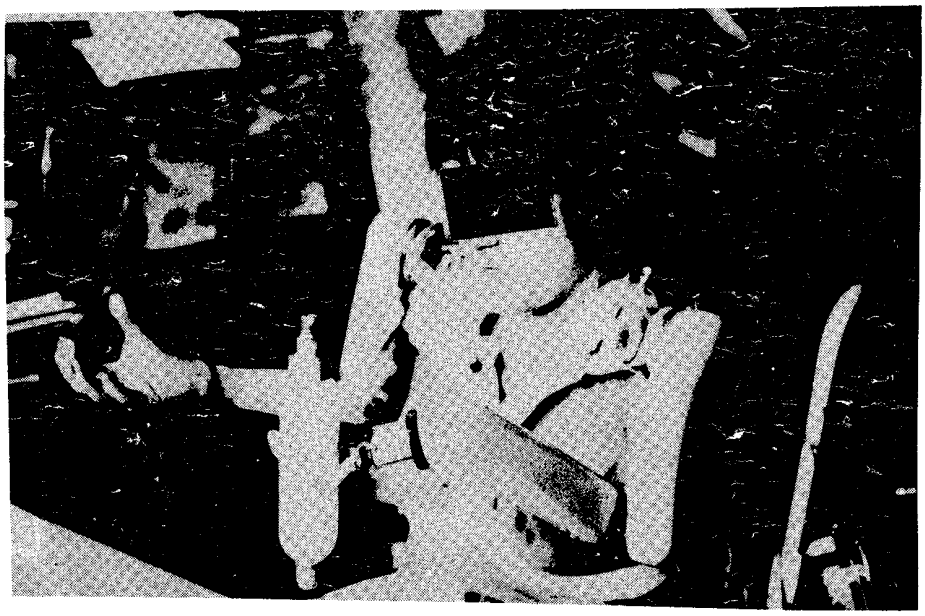

Fig 3. Hydraulic powered BRADU arm lifting 150gm CO_2 gas cylinder

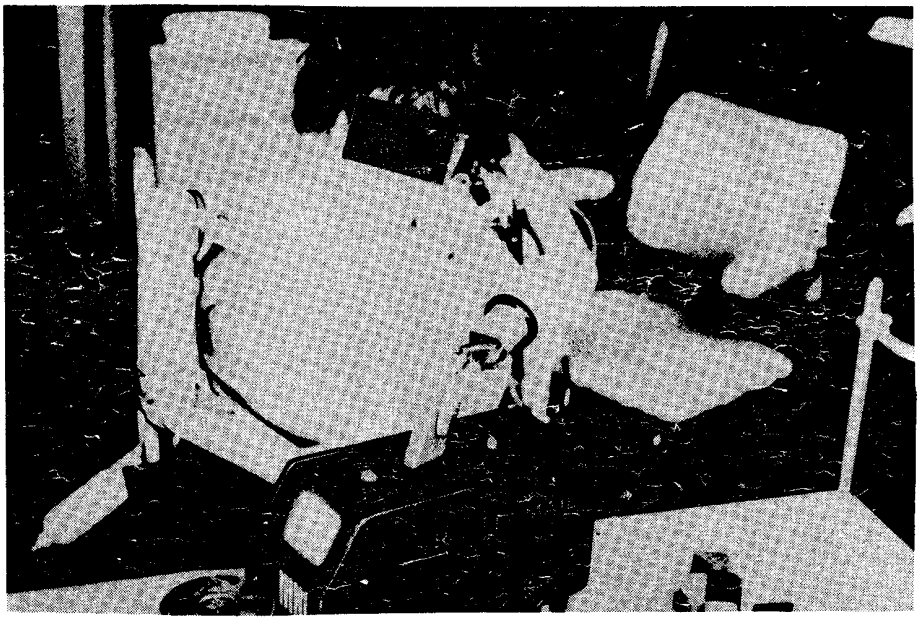

Fig. 4. BRADU arm showing restrictions due to back of shoulder rotation