CANADIAN DEVELOPMENT OF AN ELECTRIC ARM PROSTHESIS FOR CHILDREN

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Thalidomide and Child Prosthetics

In 1962, the ingestion of the Thalidomide drug by pregnant mothers caused 125 cases of congenital deformities in Canada, many of them with severe limb involvements. While these deformities are by no means unique, this gross episode emphasized the need for sophisticated and highly functional prosthetic appliances suitable for very young amputees.

Three institutions were selected by the Canadian Government to care for the survivors of this group. The Rehabilitation Institute of Montreal is presently responsible for 36 children in Eastern Canada. Realizing the need for early prosthetic treatment, conventional body-powered devices were adapted and applied to children by the Prosthetic Laboratories of the Institute.

The Department of Research of the Institute was charged with the task of finding new methods and materials, and to develop advanced prosthetic equipment for children. Gas-operated arms became available commercially from Germany. To date, 12 children, mostly bilateral upper-extremity amputees, have been fitted with various models of the Bock pneumatic prosthesis.

The advantages of external power in extensive prosthetic applications were readily recognized. It was decided to investigate all aspects of this field, especially myoelectric control, which seemed to show versatility and promise.

Experience With External Power

Scientific literature indicated a number of research activities investigating the possibilities of external power in prosthetics and orthotics, and the associated problems of control, i.e., man-machine communication. Mechanical and electronic developments since World War II produced a variety of components and technology, adaptable to

this purpose. Fundamental research, device development, and clinical applications were reported in increasing numbers[2—8].

In 1964, a Soviet hand prosthesis with myoelectric control became available. Through a grant by the Ministry of Health, Province of Quebec, the manufacturing rights and several prototypes of this device were purchased by the Institute, and placed into clinical practice as a pilot project. A number of modifications improved the comfort, reliability and packaging of the prosthesis, and our clinical experience was reported in several publications[9,10]. Further development is presently under way in Montreal, mainly in the area of electronic miniaturization and consolidation of equipment.

Preliminary experimentation with children, using the U.S.S.R. equipment, indicated that, as originally assumed, it was indeed possible to train young amputees in the use of myoelectric control. Functional prostheses were required in very small sizes to investigate the technical and clinical problems of such applications.

Medical-Industrial Cooperation

Development work was commenced at the Institute to produce a small externally powered hand, suitable for children four years of age and older. With the Thalidomide group inevitably approaching school age, it became essential to parallel the technical development with clinical experience, in order to hasten the availability of the final design. Functional devices were needed immediately.

It soon became evident, however, that the existing facilities of the Institute could not handle service and research work simultaneously. It was decided to seek help from Canadian Industry, preferably a private firm with a mature research establishment where multi-disciplinary talent and adequate laboratory facilities existed.

The Northern Electric Company, the tenth largest firm in Canada, manufacturers of communications equipment, offered to assist through their Research and Development Laboratories in Ottawa. When the clinical and technical staff of the Institute outlined the problem and showed samples of previous work, Northern Electric engineers became deeply and personally interested. Excellent cooperation with mutual contribution was established, resulting in the development within six months of the prototype electric arm described in this paper. It may be fully expected that other important developments will follow, from the ideal spirit of cooperation between industry and medical research.

Selection of Power and Control: Immediate Objectives

Since the initial concept of control was that of myoelectrics, an all-electric system was favoured to avoid the necessity of duplicating energy sources, as would have been required in an electropneumatic hybrid device.

Experience with adult patients indicated that a very intimate communication may be established between the human operator and an

externally powered prosthesis, by means of myoelectric control. The cost and complexity of such systems will become tolerable in multifunction, high-level prosthetic applications, in which myoelectrics will be needed to develop the large number of control input signals required, with electronics to perform complex signal processing.

The advantages of the pneumatic system are fully realized; actuators are lighter and cheaper at present than electric motors and drives, and the control is quite simple. However, the rechargeable battery is a more efficient source of energy than the pneumatic cylinder. It is more conveniently installed on the body, and may be serviced by nontechnical personnel without difficulty. It seems reasonable to state at this time that electric power will probably be employed in the multifunction, sophisticated prostheses of the future.

Very little work has been published on the electromyographic patterns of children. The myoelectric control capabilities of very young amputees are largely unknown. In the light of urgent and immediate requirements, it was decided to use a group of switches, as the first stage of control development, with the prototype electric arms. This decision was facilitated by the fact that the first prospective amputee had functional phocomelic fingers at both shoulders. However, myoelectric control will be substituted as soon as possible, to accommodate patients with complete absence of the upper limb.

The actuators of the control switches were made to resemble pneumatic valves, with which the child had some previous experience, having seen them on others in the ward. The control system is presently under revision, to render it smaller and simpler to operate.

Tentative Specification for a Powered Arm

The scope of tentative specifications written for the experimental protshesis was to establish a set of basic requirements, reasonable when considered in comparison with the present state of the art, in order to produce a working model, with which clinical experience could be gathered, and on which further development and inmprovements could be effected. The basic component of the prosthesis would be a powered hand, generally corresponding in size and function to the Size 1 Prosthetic Hand, developed by the United States Army Prosthetics Research Laboratory, (now Army Medical Biomechanical Research Laboratory). This hand design has been field tested, and commercial prosthetic gloves are available in this size.

The following general guidelines were established:

a) The prosthesis is to have a substantial design in terms of reliability, finish and safety.

b) A metallic, hard hand design is to be used, with a soft hand to be developed later.

c) A modular system is to be used throughout, with simple, interchangeable parts and adequate accessibility for maintenance.

d) Materials used must be easy to clean, must not produce sharp splinters when damaged, must not react with one another or with tissue. The device should be strong and reliable, and able to withstand occasional exposure to sand and water.

e) Independent application and removal by the patient should be possible with provision for interchangeable terminal devices. The drive should be free of objectionable noise and there should be no interaction between functions.

f) Mechanical components should be compatible with the principles of current prosthetic design. A service life of not less than one year or 100,000 cycles of operation without major repairs will be considered acceptable. The device should function satisfactorily from 0° C. to 40° C. All heavy components should be mounted in the line of gravity of mechanical support.

Development and Description of the Canadian Arm

Several hand designs were considered, but the simplest one had to be adopted to save time. Design specifications called for a hand with a grip force of 2—4 lbs, capable of handling objects greater than 1/4 inch and less than 2 inches in diameter, opening or closing in approximately one second.

Hand components were individually machined from aluminum for the two prototypes. The four fingers move together, hinged about the metacarpophalangeal joint. The flexion at the first finger articulation increases angularly as the fingers close in on the thumb. The distal joints are fixed and slightly flexed. The top digits are padded, and the finger tips forming the pinch are grooved.

Design objectives include a thumb moving laterally. This function is most important to achieve a true palmar grip, and to reduce the silhouette of the hand for insertion into pockets and other close quarters. On the prototype, the left thumb may be moved passively in a lateral direction. The right thumb may be positioned close to the palm, but it will resume its opponent position when the fingers start to close.

A short study indicated that a single motor, energizing all functions through gearing, would yield the optimum function to weight ratio. A twenty-four volt motor with a no-load of 20,000 rpm, weighing 3 1/2 ozs., was readily available. The windings of the motor designated the system potential at 24 volts.

Two different power transfer units were developed. In the left arm, the motor is coupled to a gearbox, (ratio 1 : 30) which drives a pinion in the center of a cluster of four gears. Any one of these gears may be made to engage the pinion by a system of levers activated by four solenoids. Individual solenoids may be energized by switches or relays. In the right arm the motor was arranged to drive four clutches through a speed reduction gear. These clutches may be engaged by

energizing an appropriate solenoid. In both systems, a reversal of motion is obtained by reversing the polarity of the power supply as it appears at the motor terminals.

Mechanical shafting transmits the power from the gear or clutch to the appropriate arm or hand functions. A preset friction clutch in the transmission chains protects the motor from overloading in a stalled condition.

A new gear reduction unit is now available with double-acting engagement mechanism obviating the necessity of reversing the motor. This system will considerably simplify the switching and control equipment.

Components of the drive were hand-made in Ottawa, assembled with the motor and installed in the upper arm region, on aluminum structural members.

The wrist units were designed to rotate continuously, approximately 120 deg. per second. The right wrist has been limited to a range of approximately 170 deg.

The elbow extends or flexes 120 deg. in 1.5 second lifting approximately 2 lbs in the hand, with the upper arm vertical.

The shoulder articulation presented a difficult problem. This is a complex joint, with three degrees of freedom; loading forces are applied to it through long moment arms. In order to permit coordinated operation with the elbow in the future, the function of flexion and extension was powered. Humeral rotation and lateral upper arm movement were provided through passive positioning. The motorized function is independent of the position of the passive joint. A spring loaded safety point is provided at the shoulder, with adjustable brakout force, to permit flexion at the shoulder in the case of a heavy fall.

The control system of the prototype arms employs four sets of switches per side. These are single-pole, double-throw switches, operated by a rocking lever. Functions are selected by choosing the appropriate switch, the direction of operation is controlled by depressing the proper end of the lever. Simultaneous operation is prevented by an electrical lockout. With the modified control system, coordinated operation will be possible.

Two standard battery units, as developed by the Rehabilitation Institute of Montreal for use with myoelectric prostheses, were combined to form a 24-volt supply. Each of these units consists of 11 nickel-cadmium rechargeable cells, Eveready N46T, encased in Vitrathene — plastic material universally used in prosthetics by the Institute. Overnight charging provides ample energy for one day's training.

The prosthetic components were manufactured and fitted by the Prosthetic Laboratory of the Rehabilitation Institute of Montreal. A body vest made of Vitrathene provides the suspension points for the shoulders. The forces created by the weight and the operation of the arms are evenly distributed and no pressure points have developed on the skin. Flesh-coloured covering shells were applied to both upper

and forearms to cover the mechanism and prevent injury. Prosthetic gloves were applied over the metallic hands.

The control switches were arranged in a semicircle, within reach of the phocomelic fingers, and secured to an auxiliary panel, which in turn was fastened to the body vest.

Initial Clinical Experience

The Occupational Therapy Department has the responsibility of developing training methods and the conditioning of child amputees to externally powered prosthesis, and evaluation of performance.

Initial clinical experience shows that the four-year-old patient with high bilateral phocomelia accepts the prototype prosthesis eagerly, even to the extent of possessiveness. She understands the purpose of the device and has mastered its control quickly.

The little girl was equipped with conventional prostheses at the age of 18 months. She became well-adapted and quite functional. She has seen gas-operated equipment on others but was not equipped herself. This patient displays great initiative, learns quickly and likes to experiment.

The weight of the prosthesis causes balance problems since the child was born without arms. The equipment in its present form is deemed to be too large and bulky for her size.

The hand limits the patient to the use of larger toys than she is able to handle with hooks. Wrist flexion may reduce this limitation.

The functional freedom gained through external power is significant even with the prototype arms, although control is difficult and slow with the present switches. The shoulder function is essential and often used for extended reach.

Discussion and Conclusions

The prototype arms represent a reasonable approximation to the tentative specifications, in spite of a greatly accelerated development.

The power and speed of functions are acceptable at this stage, but both should be increased on future models. The weight of the prosthesis is excessive, mainly due to the gear and clutch units.

The hand functions are comparable with other existing hand designs, but the lateral operation of the thumb must be developed and perfected. The continuous wrist rotation is an advantage.

The integration of the prosthesis with the body image of the patient seems to be quite real, although a large part of the acceptance must be due to the »new-toy« aspect represented by the prosthesis.

In conclusion, it may be stated that a functional externally powered prosthetic device will, in all probability, be acceptable to young amputees, especially when the technical imperfections have been eliminated.

It is planned to produce a total of 16 working units with detail improvements within the next 14 months, for clinical application. A

14-year-old congenital amputee is considered for the next set of equipment available.

Further development will render these prototype arms a useful addition to the prosthetic armamentarium.

Summary. The Thalidomide tragedy in Canada initiated new efforts to produce functional prosthetic appliances for very young amputees. The Rehabilitation Institute of Montreal commenced fitting a group of 36 babies with adapted conventional and gas-operated devices.

Practical experience with the Soviet electric prosthesis proved the feasibility of myoelectric control, and indicated the possibility of using it with children.

Industrial assistance was sought and secured through the Northern Electric Company, whose Research Laboratories produced the prototype arms described in this report.

An all-electric system was developed with a single motor powering four functions. Control is effected by switches but myoelectrics are directly applicable.

Modular construction and at least one year's service life between major repairs were specified. Details on design and performance are outlined in this report.

Initial clinical experience indicates complete acceptance by a little patient, in spite of excessive weight and inconvenient control. Four powered joints give the child greater function freedom than she has ever known.

Future plans include an older subject and a total of eight bilateral installations within the next 14 months.

A mature version of this device will be a useful piece of prosthetic equipment.

Acknowledgments. The authors express their sincere appreciation to General H. Keefler, President, and Mr. A. B. Hunt, Vice-President in charge of the Research Laboratories, Northern Electric Company, and Mr. John J. F. Bancroft, President of the Rehabilitation Institute of Montreal, for their good offices in establishing the cooperative program which made this development possible. Similarly, Mr. Fortier, Director, Mr. Duffy and Mr. Perron, of the Public Relations Department, Northern Electric Company, and Mr. Guy Lefebvre, Director of Public Relations, Rehabilitation Institute of Montreal, merited special acknowledgment for their efforts in managing the publicity connected with the project.

Mr. Bela Arnoti, Mechanical Engineer, Messrs. James Lowe and Helmut Lucas of Northern Electric, Mr. Camille Corriveau, Prosthetic Consultant, Mr Yves Lozach, Electronic Technician, Mrs. Debrabander and Mr. Courtemanche of the Protshetics Department of the Institute formed the technical section of the team. It was through their invaluable efforts that design ideas could be turned into working models.

Clinical members of the team, Miss J. Hutchison, Chief Occupational Therapist, and Miss Denise Mauger, had the difficult task of training the little patient and of evaluating the performance of the prosthesis. Their professional observations provided much useful information for further development. Special thanks are due to the Nursing Staff of the Institute, who care for child amputees around the clock.

Mr. Bennett Wilson, Jr., Executive Director, and other members of the Committee on Prosthetics Research and Development, Washington, U.S.A., have rendered great assistance by making hand models and information available. Professor Rajko Tomović of the University of Belgrade, and Mr. Colin A. McLaurin, Ontario Crippled Children's Centre, provided most useful advice through personal communication.

Last but by no means least, Miss Denise Lafrenière, research secretary and Mr. Gaudette, Medical Photographer, have patiently and faithfully recorded the events of the project and helped produce this report.

To all these and many others, the authors are truly grateful.

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