A MYOELECTRICALLY CONTROLLED PROSTHETIC HAND FOR
TRANSMETACARPAL AMPUTATIONS.

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INTRODUCTION

We have developed a new externally-powered, myoelectrically controlled partial hand prosthesis that is suitable for fitting those persons with amputations at or more proximal to the level of the metacarpophalangeal (MCP) joint. This hand mechanism is capable of reasonable pinch forces (12 lbs) and fast opening and closing (2 rads/sec). In a partial hand mechanism there is very little space available for the drive mechanism if an aesthetic result is to be achieved and any residual motion of the wrist is to be preserved. The challenge is to be able to fit all the requisite mechanisms and electronics in the highly confined volume that remains after accommodating the residual limb and still have reasonable performance.

CURRENT STATUS OF RESEARCH IN THE AREA

Prosthetic solutions for partial hand amputations are considered only after surgical procedures have failed. With an intact thumb, even if the metacarpals have been somewhat shortened with an oblique amputation, an orthotic device can be fitted that will provide a post for the uninjured thumb to oppose. Alternatively a static cosmetic prosthesis can be fitted. A review of the current surgical and prosthetics practice for partial hand amputations can be found in the Atlas of Limb Prosthetics [1, 2]. In general, only those cases where all digits (thumb and all four fingers) have been lost at a level equal or proximal to the metacarpophalangeal joint is a functional hand prosthesis recommended. Functional partial hand prostheses may be body-powered or externally-powered.

Body-powered prostheses for persons with partial-hand amputations fall, for the most part, into one of two groups, those devices that are powered by bicipital abduction and/or gleno-humeral flexion, and those devices that are powered by flexion or extension of the wrist. A shoulder-driven device is often the system of choice for the persons with bilateral partial-hand amputations. The control mechanism consists of a figure-of-nine harness that fits about the shoulders and a cable that runs from the harness to an appropriate terminal device. The most usual terminal devices take the form of a hook. The disadvantages are poor cosmesis and the requirement for a harness and control cable to be worn; however, these devices do preserve the residual motion of the wrist and provide feedback to the user about the state of their prosthesis.

One such device used a hook attached to the palmar surface of a partial hand prosthesis socket. The attachment was made through the use of a “Handy Wrist” that used to be available from USMC (United States Manufacturing Corp.). The combination of hook and wrist became known as the “Handy Hook”. This was one of the most functional prosthetic fittings for this level of amputation because wrist motion was preserved to assist the prehension process. Another system that attempted to provide both function and cosmesis for body-powered partial hand fittings was the Robin Aids Hand. The Robin Aids Hand consisted of mechanical fingers that had interchangeable components that were mounted on a very short frame. The Robin Aids hand remained the device of choice in the fitting of partial hand amputations for many rehabilitation centers until it was discontinued in 1990.

The second type of body-powered partial-hand prostheses is the wrist flexion and extension device. These devices are functional cosmetic hands that operate in a manner similar to a tenodesis
type of hand orthosis (“Tenodesis action” is a method by which prehension of the index finger, middle finger, and thumb is achieved through active wrist extension). Essentially these devices operate by way of a linking mechanism that translates wrist flexion into finger pinch and wrist extension into finger opening. The user can tell where the fingers are and the forces involved through the wrist. This method is used in Europe to fit persons with partial hand amputations. The shortcomings of this type of device are that any remaining motion of the wrist that would normally be used to position a prehensor in space must be sacrificed to drive the opening and closing of the mechanism. Also while these devices are in general statically aesthetically pleasing, their operation can result unnatural appearing motions.

**Externally-powered prosthetic devices** are few and far between. Only Otto Bock, GmbH., Germany, has a commercially available partial hand mechanism. This device is suitable for persons with wrist disarticulations and short trans-carpal hand amputations. The majority of the other commercially available mechanical hands for persons with trans-radial and trans-humeral amputations are not suitable for persons with wrist disarticulations or partial-hand amputations because the resulting prostheses are too long. A couple of exceptions are the powered hand from Centri System, Sweden, which can be shortened by a creative prosthetist to enable its use in some short trans-carpal cases and Motion Control, Salt Lake City, UT, claims that its new hand can also be shortened for use in short trans-carpal cases. Of the commercially available mechanisms none is short/compact enough to be used in transmetacarpal cases.

In the area of ongoing research, Gow et al. [3] in Scotland developed an externally-powered device based on a wrist flexion/extension type prosthesis. This system evolved into the REACH hand [4] and more recently into a small externally powered partial hand prosthesis, named ProDigits [5]. A custom made cosmetic silicone glove is worn over the mechanism, giving the hand an aesthetically pleasing result. This main limitation of the device is the limited overall pinch force and speed. The actuators can generate gripping forces of about 20 N (4.5 lbs), for adult-sized fingers, at speeds of around 1 rad/sec. RSLSteeper, England, has conducted limited clinical trials of the ProDigits system but as yet it is not commercially available.

Another externally powered device for persons with partial hand amputations was developed at the University of New Brunswick, Canada [6]. This mechanism used a single transverse motor in the line of the knuckles to open and close finger armatures. This system had a range of finger motion of approximately 60°. The opening and closing speed for the unloaded unit was approximately 200 ms, which corresponds to a speed of 5.2 rads/sec. The device had a stall torque of 9 in-lbs, which equates to a pinch force at the finger tip of about 2.5 lbs (11.1 N). Both the ProDigits and the New Brunswick system should be capable of being fit to persons with trans-metacarpal amputations.

**OUR MECHANISM**

The motivation for our interest in externally-powered partial hand mechanisms stems from a temporary fitting our laboratory performed for a patient of the Rehabilitation Institute of Chicago (RIC). This patient had partial-hand, shoulder disarticulation, and trans-femoral amputations. This fitting was performed to give the patient some hand function for the duration of his stay at the RIC. The prosthesis fitted was self-contained, self-suspended, and used myoelectric control. The muscles of the thenar eminence provided the myoelectric control site. The importance of this fitting was the observation of the exceptionally functional movements, which were made possible by the unrestricted motion of the wrist. Most impressive was that his movements were not “amputee-like”, which was attributed to the conservation of nearly normal wrist function.
The availability of small (10mm in diameter) DC motors enabled us to develop and build an initial prototype partial hand with powered fingers [7]. These motors were small enough to be placed within the fingers and thumb and were used in synergistic pairs to achieve reasonable speed and force. When an object is grasped a force is exerted with very little excursion while excursion of the grasping fingers usually occurs in space and requires very little force. In both cases the work involved is minimal. Childress [8] observed that this kind of prehension could be readily implemented using multiple motors that operate in synergy. One motor provides high speed and excursion but little force (fast side), another motor provides high force but little speed and excursion (force side). In this way the motors work to boost overall performance. An alternative to multiple motors is an automatic transmission as used by Otto Bock in their adult hands.

Our next prototype used three motors operating in synergy [9]. There were motors in the index and middle fingers to provide force, and a third transverse motor lying in the line of the knuckles to provide speed of opening of the fingers. The thumb was kinematically linked to move with the “Fast side”, or knuckle motor, thus achieving a large width-of-opening. The volume of the ring and little fingers housed the battery and control electronics. As with our original prototype the two motors in the index and middle fingers operate independently. The total force generated by the hand is the vector sum of the force from each finger.

The surprisingly good performance of the knuckle drive train prompted us to redesign this prototype. This effort resulted in a new single motor trans-metacarpal hand mechanism (Figure 1). In this mechanism performance is achieved through the use of a transverse knuckle drive that uses a planetary gear train. The novelty of this design lays in the use of the transverse drive housing as the axle upon which the hand’s fingers rotate and the use of an entirely planetary based gear train with a 6 planet gear final stage to distribute the output torque. Using the drive housing as the finger axle allows for a hand mechanism with a hand width of only 60mm (2.25”).

A planetary gear train was used because they are self-centering, with torque that is distributed equally on the planet gears. The use of a planetary gear train allows for a high gear ratio drive train capable of handling the high speeds and torques required to generate acceptable grip forces and hand opening speeds. As with the previous prototype, the thumb is kinematically linked to the fingers so as to provide a large width-of-opening. The weight of the current mechanism alone is 157g (0.35 lbs) and its length, in the closed position, from back plate to finger tip is 85mm (3.5”).

Proportional myoelectric control sites on the residual partial-hand are the preferred mode of control. Ideally there should be two such sites using the intrinsic muscles of the hand. For example,
closingle could be provided by a site over the thenar eminence and opening by a site over the lateral aspect of the hypo-thenar eminence. Flexing/adducting the thumb would cause the hand to close while abducting the little finger would cause it to open. This kind of control might not always be possible, but even if only one EMG site is available three-state control could be used.

IN CONCLUSION
We have developed a new externally-powered partial hand prosthesis mechanism suitable for persons with amputations at or more proximal to the metacarpophalangeal joint. This single motor mechanism is smaller and lighter than our original multi-motor prototype and is capable of attaining pinch forces in excess of 12 lbs and has a speed in excess of 2 radians/sec. This performance is achieved through the use of planetary gearing, which allows for a very compact high gear ratio drive train capable of handling the high torques required to generate acceptable grip forces. Given the compact and lightweight nature of our mechanism we believe this mechanism could also have application in the fitting of persons with high-level upper-extremity amputation where weight considerations are of paramount importance. We also believe that preservation of wrist motion for positioning of the terminal device is necessary to achieve maximum function and cosmesis.

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REFERENCES