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Development of a Multifunctional Cosmetic Prosthetic Hand

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Abstract—**An innovative artificial hand is presented, which can help to restore both motor and sensory capabilities of upper extremity amputees. All requisite components of the revolutionary prosthesis fit into the small volume of the metacarpus. A new high-power actuating technology has been developed for maximizing the benefit in using the prosthetic hand by increasing the number of grasping patterns. An optional sensory feedback system has been designed for the prosthesis, which is based on mechanical vibration. First clinical trials with the prosthetic hand revealed a high acceptance, as the force necessary to hold an object securely was reduced significantly.**

I. Introduction

Design of the new electrohydraulic hand prosthesis was based above all on an extensive analysis of the needs from the point of view of prosthesis carriers [1]. The results of these interviews of patients were compared with other studies. Together with the experience gained by orthopedic technicians, physicians, and therapists, this information served as the basis of the development of the new prosthesis (Fig. 1).

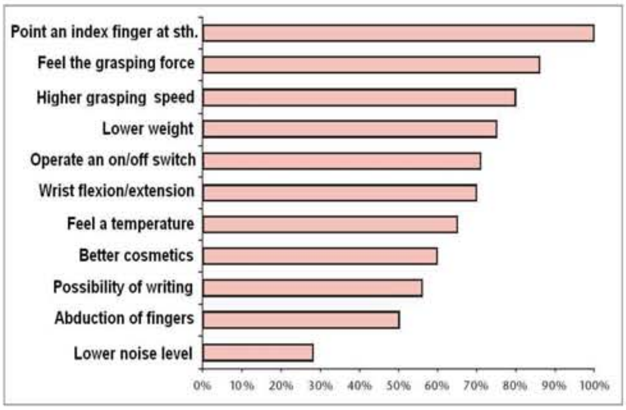

Figure 1. Results of the interviews of prosthesis users with respect to their wishes for a new generation of prostheses, displayed versus the percentage fraction of persons interviewed.

According to the interviews' results (Fig. 1), nearly all prosthesis carriers were particularly interested in additional functions of the hand prosthesis. The stretching of an individual finger and the feedback of the grasping force were considered to be of paramount importance. Moreover, the prosthesis weight should be further reduced and its grasping speed increased. The latter wish was met by introducing the "SensorHandSpeed" [2] by the company of Otto Bock. According to the manufacturer, grasping speed amounts to up to 300 mm/sec. However, an advantage for one user may be a deficiency for another, as an increased grasping speed may cause a far more difficult controllability of small hand movements. Apart from the already mentioned stretching of the index finger for operating a switch or a computer keyboard, 70% of the persons interviewed desired a wrist extension and flexion as additional movement functions. 65% of the persons interviewed expressed their wish to sense the temperature. Only every second person wanted to write with the prosthesis or to abduct the fingers. A quarter of the persons asked for more quiet prostheses. In addition, many of the persons desired a cosmetically attractive and dirt-resistant, easy-to-clean protection glove which has been offered by several producers in the meantime. When improving the functionality, however, it must be taken into account that reliable functioning is crucial to the acceptance, since the prosthesis carrier does not want to do without his aid in daily life. Other prosthetic hand prototypes with extended functionality have been presented recently by [3, 4]. The experience gained with a novel multifunctional hand prosthesis developed by the Forschungszentrum Karlsruhe in close cooperation with the orthopedic university hospital in Heidelberg and the certified suppliers of health care equipment Pohlig and Brillinger shall be reported below. This development was based on the results of interviews of patients. The interview results were taken into account when conceiving the hand. Partly, they have already been implemented.

II. Development Objectives

The research project has been funded by the Federal Republic of Germany and the state of Baden-Württemberg since 2000 under the "Regenerative Medicine Program" of the Forschungszentrum Karlsruhe. It was launched to analyze the current supply situation in the field of myoelectric hand prostheses and to design a prosthesis on this basis, which offers a maximum functionality according to the current state of the art. Increase in the separate movability of the finger joint groups was considered to be of paramount importance. In conventional hand prostheses, all prosthesis joints are usually moved simultaneously in a single group. The new prosthesis to be developed was to allow a separate movement of up to five different finger

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groups and, hence, to perform all basic grasping patterns of the human hand. The grasping speed was specified, such that the hand could change from the open state to the completely closed state within one second. A special feature of the hand is the force feedback function. With it, the patient can sense the grasping force at the finger tips of his prosthesis. Another special feature of the hand is its external appearance. It represents a combination of a cosmetic and a myoelectric functional prosthesis. A silicone glove modeled after the human hand and adapted to the special movability of the new hand prosthesis provides for life-like optics of the hand.

III. SETUP OF THE HAND PROSTHESIS

As a rule, conventional prostheses are driven by an electric motor. Via a gear, it moves the thumb and long fingers of the prosthesis towards each other or opens them simultaneously. To actively move individual finger joints with this technology, small motors would have to be integrated directly in the finger joints or the force of small motors located in the metacarpus would have to be transmitted to the finger joints via Bowden wires, rods, gear wheels, etc. Functioning of the new fluidic hand is based on a different approach. A single motor in the metacarpus is connected with a miniaturized hydraulic pump that presses an oily liquid directly into the finger joints at a pressure of up to 6 bar. In selected finger joints, small bellows of a flexible, but difficult-to-strain material are located [5]. If these drivers are pumped up with oil, the corresponding finger joint is bent by up to 90°. One advantage of a using actuators with inherent compliance is that passive adaptive

Figure 2. Fluidic hand from 2002: The lower arm shaft accommodates the hydraulic pump and control computer, the wrist is rigid without a rotary joint.

grasping is possible; the area of contact is increased and the required grasping force decreased compared to stiff fingers in conventional myoelectric prostheses [6]. Via small valves, the driving medium is passed specifically to the different finger joints, and the force and speed of the movements are controlled. The instructions for the control of the hydraulic pump and valves are given by a microcontroller that evaluates the analog initial voltages of the myoelectric sensors. Here, development goes towards an intuitive prosthesis control. Already today does the control program of the microcontroller automatically adapt to the constantly

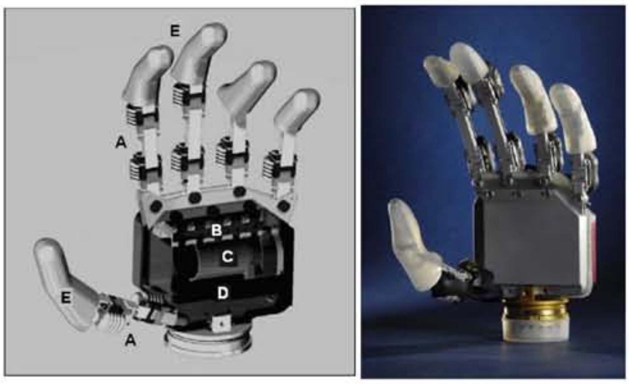

Figure 3. left: CAD model of the new prosthesis with all components: A) = flexible fluidic actuators, B) = miniaturized valves, C) = miniaturized pump, D) = microcontroller, E) = elastic fingers (right: first prototype).

changing maximum and minimum signal amplitudes of the myoelectrodes in order to respond to the constantly changing physical state of the prosthesis carrier and ensure reliable control. The prosthesis hand possesses an artificial skeleton, consisting of a metacarpus frame and the individual finger joints that are connected by small hinges. The hand skeleton largely consists of highly stable aluminum, axles, and connection elements of steel. For the first models of the fluidic hand prosthesis, part of the lower arm shaft was used to accommodate the hydraulic system components [7] (Fig. 2). In contrast to these first models, the latest prosthesis allows for an integration of all system components in the metacarpus. This compact setup can also be used for patients after a distal transradial amputation. The shorter setup of the hand prosthesis for the first time allows for the integration of a standard hand closure adapter. Hence, myoelectric hands or electric grippers of other manufacturers can be exchanged without a separate shaft being needed (Fig. 3). The support construction of the new hand prosthesis is designed in a modular manner. In this way, individual hand sizes and finger lengths can be implemented easily, depending on the anatomic features of the patients. To increase the grasping speed compared to the previous model and minimize noise development, a new miniaturized pump was developed and the corresponding valve and tank technology was optimized (Tab. 1). The number of active joints was reduced from 11 in the previous model to 8, which ensures an optimum movability and

TABLE I
TECHNICAL DATA OF THE FLUIDIC HAND P4.

Weight	353 g
Maximum holding force	110 N
Grasping patterns	5 (lateral grasp, index position, tripod pulpa grasp, hook grasp, cylinder grasp)
Grasping speed	for complete hand closure in < 1 s
Noise	< 45 dB(A) at 1 meter distance
Active finger joints	8
Maximum opening width	active: 90 mm, passive: 120 mm

grasping speed. As a result, five grasping patterns and the function of "stretched index finger" are possible (Tab. 1) (Figure 4). It is now easier to operate a computer keyboard or the number panel of a telephone with the index finger.

Due to the fluidic drives, all movements are smooth, which makes them appear very natural. This impression is enhanced by the cosmetically attractive protection glove made of silicone rubber. The wrinkling of the glove to be expected, above all in the range of the metacarpus, was minimized to an optically acceptable extent. As the mostly small wrinkles are located in the closed inner hand, they hardly affect the aesthetics of the hand. The functionality of the hand is not limited by the silicone glove in any movement state of the prosthesis. In case of a successful introduction of the fluidic hand in practice, the gap between cosmetic hands and prostheses focusing on the grasping

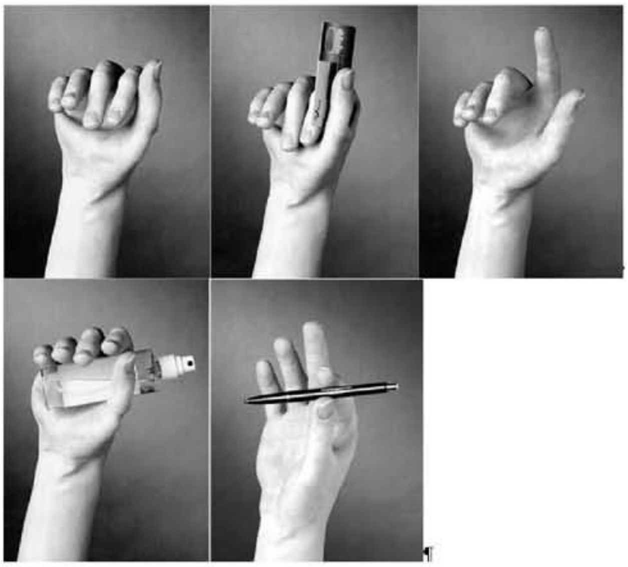

Figure 4. Grasping patterns of the fluidic hand prosthesis with silicone cosmetics: Hook grasp, lateral grasp, index position, cylinder grasp, and pincers grasp (from left to right).

function could be closed successfully. To reach the required reliability of the hand prosthesis, the individual components are first studied in a laboratory and then checked by test persons as parts of a complete prosthesis. Clinical evaluation of the new prosthesis takes place with practical tasks of an established hand functioning test [8]: Writing of sentences, turning around of cards, the lifting and stacking of small objects, e.g. crown caps or draughtsmen, eating and drinking, and lifting of large, heavy objects.

IV. Sensory Feedback

In contrast to body-powered prostheses, a major drawback of conventional myoelectric prostheses lies in the fact that no sensory information on the grasping force and finger positions has been transmitted to the prosthesis user so far. Consequently, the grasping process is strongly dependent on visual control. Use of the hand force is relatively unprecise. In most cases, grasping is accomplished with far more force than required for the reliable holding of the object. To develop an adequate haptic system, various force feedback methods were analyzed. For the setup of a first system, a vibrotactile functioning principle was chosen [9]. It consists of a vibration motor as it is often used in mobile telephones, control electronics, and one or several force sensors in the finger tips. With the force feedback system, the test patients needed only about half of the grasping force to lift an object. Furthermore, the test persons rapidly improved their capacity of adjusting the force needed for grasping without visual control. The compact system is characterized by a small power consumption and a good acceptance by prosthesis carriers. In principle, any myoelectric functional prosthesis can be backfitted with the feedback system developed.

V. Prosthesis Control

Communication between the aid and the user still is one of the biggest challenges in the development of arm prostheses with extended functionalities. Arm prostheses of the 21st century are expected to allow for a reliable control of several active movable artificial joints. The spectrum of movement patterns shall be extended without the patient being tired by a very complicated control task. By means of modern signal analysis methods, five different grasping patterns or five actively movable joints can be driven reliably by the signals of two surface myoelectrodes. This control has the advantage of being non-invasive. It may adapt to the strongly varying individual capabilities of the patient [10]. After five minutes of training already did the patients operate the new prosthesis reliably and select among five grasping patterns without any errors. Control is accomplished individually for each patient. The fluidic hand prosthesis is equipped with an electronic module that transmits the patient's parameters from a service computer to the microcontroller of the prosthesis in a wireless manner by bluetooth technology. Hence, the prosthesis can be adjusted under optimum conditions directly during use by the patient.

VI. Connection to Peripheral Nerves

Figure 5. The new hand prosthesis with hand closure adapter.

In the future, contacting with peripheral nerves or individual target muscles may gain importance in prosthesis control in order to generate a far higher number of control signals. However, these are invasive methods that cannot be applied to any patient. In case of an electrode defect or a dislocation of the electrodes, another surgical intervention will be required, which will be associated with the risk of traumatizing the nerves. Fortunately, research in the field of hand prostheses will gain importance in the future. In autumn 2005, a large funding program was launched by the American Research Association DARPA to develop new prostheses and their control units for more than 200 upper extremity amputees, above all professional soldiers from the Afghanistan and Iraq wars [11]. In the next two to four years, these activities will give rise to considerable progress and major findings in the field of neural prosthesis controls. If it will be possible to develop an interface with peripheral nerves or individual muscles that is stable in the long term, the new fluidic prosthesis of the Forschungszentrum Karlsruhe will allow for separate movements of individual finger joints.

VII. Acknowledgement

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