# DEVELOPMENT OF MYOELECTRIC UPPER LIMB PROSTHESES: A GLANCE AT THE PAST AND A GLIMPSE OF THE FUTURE

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The principle of using myoelectrics for prosthesis control is already 50 years old. We have long left the experimental stage behind us - commercial production of components is now quite common and the myoelectric prosthesis has become the general standard. But one can still feel something of the early day pioneer spirit, perhaps because the fundamental ideas have not changed.

The interest in finding a replacement for the human hand is guided by two principles:

1.) Never lose your respect for nature.

2.) Never harbour the illusion of being able to even approximate the quality of the natural hand by any technical replacement. In order to create an acceptable aid for the amputee, always keep abreast of the newest technological developments. Do not be afraid of treading new paths.

This lecture will illustrate how the most significant developments, based on the principles stated above, came into being.

The first design engineers already had at their disposal a vast pool of hand models to study. Generations of technicians had struggled with the problem of replacing the human hand. As an example of the manual skills used for creating artificial hands, I would like to mention the hand of Götz von Berlichingen and an invention from the 16th century by the famous universal genius, Ambrose Paré. Conventional cable-operated hands and hands for muscle tunnel Kineplasty by SAUERBRUCH were the foundation for development of an electrical hand prosthesis. A high degree of efficiency was essential due to the limited muscle force of the amputees.

The logical step was to use such developments as a basis for more advanced work. Another field in arm prosthetics from which one could draw ideas were pneumatic devices. These first externally powered prostheses allowed researchers to study of the problems of power supply and storage, as well as the lack of control signals. The use of electrical energy as an external power source for prosthetic hands was first reported in 1919. SCHLESINGER of Berlin presented an electromagnetically powered hand which he himself described as "a construction with very poor prospects". When the circuit was switched on, a conical gear wheel system moved the index finger towards the thumb. Technically, this was a very interesting approach. But it was never used for prosthetic purposes, mainly due to problems with proper control and energy supply.

In 1945 reports mention an electrically powered hand developed by FRIESECKE and HÖPFNER. No documents survive and it was never used for prosthetic purposes. The same applies to a hand patented in 1949 by LAUMER and DANKLEFSEN.

The first electrically powered hand used for prosthetic purposes was the VADUZ HAND presented in 1949 by WILDS.

 

The drive assembly was built into a wooden HÜfNER HAND which caused problems with durability later. Control was achieved via the stump muscles. The circumferential difference between the contracted muscle and the relaxed muscle was used as control signal. Shortly afterwards the IBM ELECTRO ARM was constructed.

In 1957, at the Technical University of Hannover, BINDER developed an electrical prosthesis with an on-off control system.

Characteristic to all these developments was the lack of an appropriate control system. In 1945 ROLAND REITER, then a student at the University of Munich, wrote the first report about experiments with myoelectrically controlled arms.

In 1948 he published his first paper on myoelectrically controlled prostheses, whereby the current arising from muscle contractions was used for controlling an electric hand. This was a sensational idea at the time, even though GALVANI in the 18th century had already been aware of existing electrical activity in the muscles. DR. REITER used the amplified muscular action potentials as electrical trigger impulses for the electromechanical control of movements. The slides show the control amplifier, naturally built in tube technology. The transistor had not yet been invented. On the right hand side is a HÜFNER HAND with a built-in control magnet.

This was the birth of myoelectrics. And it occurred in the period after the 2nd World War when there was widespread interest in the advancement of prosthetic design. Some research centres began to specialise in this field. As an example I would like to mention the myoelectric control system presented in 1955 by DR. NIGHTINGALE at GUYS HOSPITAL, London.

The 1959 Brussels World Exhibition brought the myoelectric arm prosthesis greater publicity. A Soviet research team under KOBRINSSKY presented a workable forearm prosthesis. The use of transistors, state of the art technology for that period, as well as the size reduction of the control system and batteries with sufficient capacity put myoelectrics, for the first time, into the realm of reality. The control system still was the size of two cigarette packs and had to be worn externally on a belt. This system was adapted and improved in 1965 by MCKENZIE in England and by DR. GUSTAV GINGAS in Montréal. This construction became very well-known thanks to exaggerated media reports. For the first time in the history of myoelectrics, public expectations were raised. As detrimental as this later proved to be, in retrospect one can say that in this case it was of advantage for the consequent development of myoelectric components.

Subsequently research and development projects were initiated in Austria and in Italy. In 1965, at the Federal Vocational School for Orthopaedic Technology in Frankfurt, Mr. HANNES SCHMIDL, with his team from the I.N.A.I.L. of Budrio/Italy, presented the first really efficient myoelectrically controlled prosthesis.

He used HÜFNER HANDS modified by OTTO BOCK. But it soon turned out that converting proven conventional artificial hands was sufficient. The wooden hand's interior space was too small. The hollow hand became too fragile and could not take the strain. Therefore completely new hands needed to be designed for this new generation of prostheses.

In 1965, OTTO BOCK began with the development of special electric hands. Starting point for the SYSTEM ELECTRIC HAND was the normal system hand consisting of three components: the hand mechanism, the inner hand of soft plastic and the cosmetic glove.

The hands, TYPE S, developed for I.N.A.I.L. were given by a direct current motor connected to a self-locking spindle drive mechanism.

At the same time in Austria, DR. ZEMANN was working on a myoelectric control system. He contacted OTTO BOCK for a suitable electric hand. The result was the OTTO BOCK SYSTEMHAND Z1. Naturally the newest non-ferrous direct current motors were used. The hand was subsequently built by the VIENNATONE company who also continued developing myoelectric control for DR. ZEMANN. This hand was also the basis for a later development on behalf of the VETERANS ADMINISTRATION in the United States.

The slides on the left-hand show the ELECTRIC HANDS S1 to S4, on the right-hand the development of the Z-TYPES. The present OTTO BOCK SYSTEM-ELECTRIC HANDS are based on TYPE Z6.

Crucial disadvantages of the Z1 hand drive soon became apparent. Hand movement was too slow, gripping action too fast and grip force too limited. There was no possibility to passively open the hand in an emergency situation, presenting a problem for the patient as in those days the low-capacity batteries were not exchangeable and still full of technical bugs.

The decision to develop a new model was soon made and in 1967 work on this model began.

The design created was to result in the most widespread electric hand, the Z6.

A concept for the gripping movement was proposed that today is the standard for electric hands. The gripping movement was divided into phases based on the physiology of gripping. The fingers rapidly approach the object and then the object is gently gripped, with little force. As soon as the drive senses that the object has been gripped, it switches over the augments the grip force until the myosignal stops or the maximum grip force of the hand is reached. An analogous concept for gripping movement was presented in 1974 by PROFESSOR CHILDRESS. This concept was executed with a double motor drive and is known as SYNERGETIC PREHENSION. A safety release was integrated and the gears were optimised for the electrical device.

The Z6 cannot be viewed alone. It is part of a whole concept developed in 1967 and still valid today:

- modular design for making the prosthetist's work easier
- optimal esthetic appearance
- easy after-sales service through interchangeable modules
- education of technicians by seminars and workshops
- creation of an international after-sales service

The Z6 was developed as a component of the MYOBOCK-System to fulfil the high demands of this concept. Basic elements are the active electrodes and integrated control electronics. All cable connections are to be quick-connect and integrated into the prosthesis.

Years of experience brought a number of additions and improvements that refined the system.

In 1973 OTTO BOCK introduced the 6V-BATTERY SYSTEM achieving the complete integration of the energy source into the arm prosthesis. New battery technology made a considerable reduction in size possible and paved the way for the integrated interchangeable battery.

This meant a considerable improvement in prosthetic quality. The patient did not need to wear the battery externally anymore and it could be exchanged quickly and easily. The prosthesis became more reliable as the external battery cables had been one of the greatest sources of trouble.

In 1975 the WRIST ROTATOR was completed providing electromechanical pronation and supination, 1979 brought the introduction of the ELECTRIC GREIFER with myoelectric control.

In 1985, in order to provide an optimum in children's hand prostheses, a new compact active electrode was developed. This type of electrode soon became standard for adult prostheses as well.

Strong pressures for new developments in the field of myoelectrics came from the prosthetic fitting of children. A sad occasion for even greater efforts in arm prosthetics was caused by the Contergan catastrophe.

DR. ROLF SÖRBYE has performed valuable work in Sweden leading to the development of a children's hand with SYSTEMTEKNIK.

The first children were already fitted in 1971. The purchase of this development by the company STEEPER created the basis for further developments there.

At the Ontario CRIPPLED CHILDREN'S HOSPITAL an adolescent was already fitted in 1965 with a myoelectric prosthesis. At this hospital, that has since developed into one of the most important centres for child prosthetics, further models were constructed that today are developed and produced by VARIETY ABILITY SYSTEMS.

A further milestone in the development of hand mechanics is the development of the children's hand 2000 by OTTO BOCK.

This project applies all available new materials and technologies. Enough experience and data existed concerning the assessment of electric hands to allow a thorough analysis of the weak points of existing hand constructions.

Main tasks for improvement were:

- reduction of weight
- optimised gripping characteristics
- optimisation of the handling capability of small objects.

With conventional hands functionality is generally sacrificed for visual appearance. The passively moved fingers are a hindrance when gripping. The movement axes of the gripping movement are poorly designed for picking up small objects off flat surfaces. Gross compensation with the arm and torso is necessary. And parts of the hand conceal the object - a pronounced disadvantage with electric hands where the feedback for grasping is primarily visual.

The CHILDREN'S HAND 2000 was developed on these findings. By placing the power unit in a sealed chassis made from a special aluminium alloy, weight could be saved by doing without the inner hand. The choice of hand kinematics removed most of the disadvantages of previous grip geometry. The use of modern materials made room for a double-motor-drive with noise reducing friction gear drive. The CHILDREN'S HAND 2000 proves that the force-grip principle still has room for improvement.

The first developers all had a background in prosthetics. Despite their enthusiasm for complex techniques and technologies they backed the well-used Greifer construction with "force based" grip characteristics instead of the so-called adaptive or multiple-joint hands with "shape based" grip characteristics.

Much has been written about the wonders of adaptive electrical hands. This is not the forum to discuss the development of this technically very interesting construction so I will limit myself to regard its position in every day prosthetics.

Allow me to quote PROF. DR. SCHLESINGER, whose 1919 electromechanical hand I mentioned at the beginning of this speech:

*"The more precisely a designer knows the specific needs of life, the more effectively he has restricted the movements of artificial fingers to those movements which are really indispensable, the more useful and solid his designs are. A real master reveals himself in restriction".*

We believe that part of the success of the MYOBOCK-SYSTEM comes from adhering to this insight. Our research group continually assesses the feasibility and reliability of multiple-joint hands.

Thus far, OTTO BOCK has not been able to justify developing a multiple-joint hand. The following reasons discouraged us from doing so:

- reduced reliability
- reduced ergonometry
- increased power consumption
- reduced esthetic appearance
- increased production effort
- high costs

That is why the "force-grip" concept was developed further and optimised.

Allow an elderly gentleman a few comments on the subject of multiple-joint hands: When leafing through project reports made by ambitious and highly funded research teams such as TIDE MARKUS, I cannot help the feeling of having seen this information before.

Around 1970 many research institutes dedicated a lot of energy to the development of multiple-joint hands and their control. As an example, I would like to mention the Swedish SWEN HAND, and BELGRADE HAND, or the development by DR. KARAS in Austria.

Many of these projects were far ahead of their time. In Japan KATO already used electro-stimulation as force-feedback. I would like to recommend that all young engineers interested in this field first study the reason why previous projects did not bring any results. That could save them a lot of time and energy. I also am reminded of something else - a quote from Professor KUHN: *"Inventions in the field of orthopaedic technology are the proof of a missing reading list."*

In the early years of myoelectrics, the North American continent preferred "cable operated terminal devices". Developments for higher amputation levels were made that are of importance for myoelectric fittings. These are the HOSMER ELECTRIC ELBOW, the BOSTON ARM, and especially the UTAH ARM. To my knowledge this is the only product where the complexities of a university research project were successfully transferred into everyday prosthetics.

Through the development of myoelectric control systems I would like to show you how state of the art technology was applied with enthusiasm.

Even in the earliest days, interest for electronic solutions was very strong, as was the wish to construct functioning control systems using simple technology.

Many of today's ideas and insights originate from those days. Numerous control systems, simple to complex, have been designed since then.

Technology limitations made implementing the ideas so much more difficult than is the case today.

The history of myoelectrics points to the designers eagerly awaiting the invention of the transistor. Only the transistor allowed the realisation of their ideas.

In Italy the team of HANNES SCHMIDL had already started in 1963 with the development of a digital control system. In response to the patients needs and to the unique capabilities of the I.N.A.I.L. institute, a multi-channel system with proportional control was also developed. The construction was still relatively simple and energy consumption enormous.

In 1968 Viennatone patented the first proportional control system with pulse width modulation.

In 1970 CHILDRESS and LOZACH in Montréal presented further proportional control systems.

During this period the most daring visions were developed - the technical realisation of these dreams is only becoming possible nowadays. WIRTA and TAYLOR were already working an arm prosthesis control with the help of pattern recognition. GAWRONSKY in Poland applied a neuronal network. Implantable sensors were developed by REILLY in England and KAISER in Sweden. TODD and NIGHTINGALE developed a multiple-sensor concept that today is the basis for the TIDE MARKUS project. Of course the many control systems did nothing but fill up valuable laboratory space - most never got beyond the stage of a laboratory sample.

The limited amount of space forced developers to adopt a very compact construction style. The introduction of integrated circuits was welcomed and instantly put to use. By using energy efficient components and new housing technologies, especially Surface Mounted Device (SMD) Technology, the available restricted space could be used more effectively for electronics.

As an example of this development you can see in the on the left of left side the first active OTTO BOCK electrode dating back to the year 1967. It is made completely out of discrete components. As you will notice silicium transistors are already in use. In the middle you can see a 6V electrode from the year 1973. For the first time operation amplifiers are used as integrated components. On the right see the child hand's electrode from the year 1985. It is completely built in SMD-technology.

A revolutionary component concept was chosen for the UTAH ARM. The employed CHIP ON BOARD TECHNOLOGY was, when introduced at the end of the seventies, way ahead of its time and is still considered advanced technology today. And now suddenly I find myself in the present.

Whereas in the past transistors and individual integrated circuits handled the job perfectly, nowadays circuits, so-called ASIC's, that can be programmed according to the client's needs, micro-controllers and memory elements have taken their place. Micro-controller technology has been available for quite some time, but until now size and energy consumption were the barrier against an application in prosthetics.

Micro-controller application achieves a:

- reduction of electronic components
- simplified testing during production
- easy adaptation by changing of software

Thanks to progressive size-reduction the conditions for applying controllers have fundamentally changed.

These new intelligent components offer complex functions that with traditional technology could only be realised with many components and therefore needed excessive space.

By including testing algorithms into the software, self-testing and auto-adaptive systems can be designed.

In signal analysis totally new ways and methods are created for a better interpretation of myo-signals.

The Dynamic Mode Control (DMC) System, presented in 1994, uses all advantages of the micro-controller technology. With this control system we hope to give the patient a maximum of comfort combined with a minimum of complexity.

Direct connection between muscle signal and speed or grip force has always been the objective in myoelectrical prosthetics. The various mentioned proportional control systems show how this objective was pursued. All systems try to control the energy supply directly proportional to the myo-signal. DMC-Control takes another path. Numerous experiments established an optimal sequence of allocating the myo-signal to the energy supply of the drive. It must be taken into consideration that the sequence varies depending on whether the gripping movement is taking place or if contact with the object has already been made. The results were programmed into a micro-controller that translates the myo-signals and then operates the hand in a matter that the correlation between muscle and hand movement is seen and felt to be natural.

Now allow me to take a glimpse of the future:

The new technologies that already are so soon will be at our disposition allow an optimal adaption to the needs of the patient.

On the one hand this adjustment process can take place on its own thanks to adaptive technology. This will considerably simplify the prosthetist's job. For instance DMC-Control setting only requires a correct adjustment of the electrodes.

On the other hand a number of functions can be made available from which the optimal setting for each individual patient can be chosen. An example for this is the new 4-Channel-Processor, presently undergoing a field test. Various control patterns are available for controlling the hand function as well as for pronation and supination. A rotary switch selects the desired function.

One of the biggest challenges in prosthetic electronics will continue to be a grip force FEEDBACK-SYSTEM for the patient.For years great efforts have been made in this field. Think of the work by SCHMIDL in 1969 or SCOTT in 1978. Recently, the results achieved by SABOLICH received a lot of press coverage.

I myself think that in order to realise a mature Feebac-System a lot of hard work still lies ahead of us.

The development of internal Feedback-Systems, such as "Slip Detection Systems", have a better chance of soon being ready for production.

The development of such special sensors for orthopaedics could, with the help of micro-controller technology create, closed loop feedback. This technique helps to bypass the prosthesis' missing tactile feedback signal to the patient.

Preparing this paper gave me pleasure in several respects: I became conscious of the fact that concepts developed years ago were still valid. Therefore our models still have a modern look whereas contemporary products from other industrial fields can nowadays be viewed only in museums.

I also realised how strongly innovations in myoelectrics are connected to technical advancements and how effectively new products and technologies were put to use.