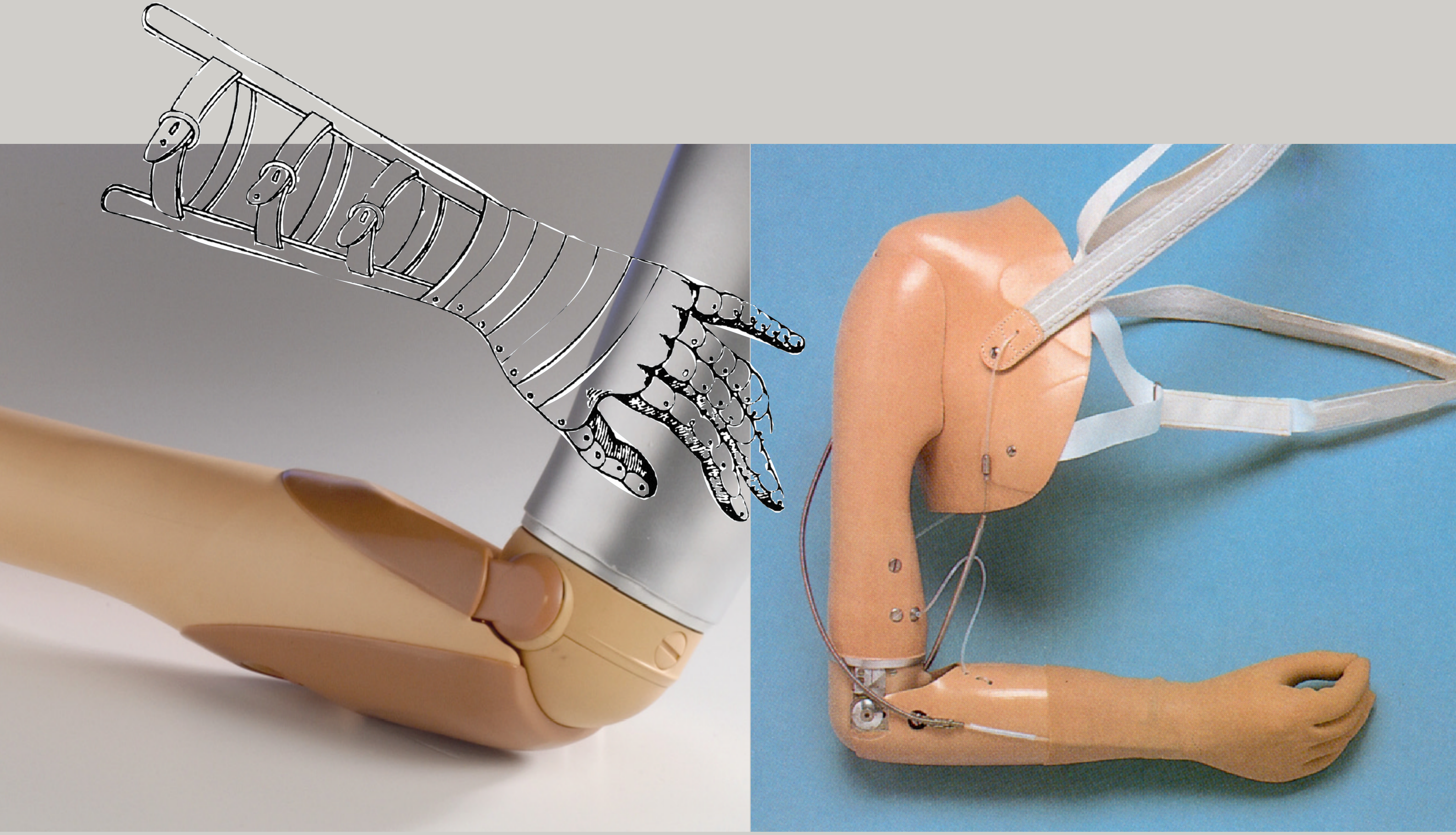
UPPER EXTREMITY PROSTHETICS

CURRENT STATUS & EVALUATION



Dick H. Plettenburg

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PREFACE

In writing my PhD-thesis 'A sizzling hand prosthesis. On the design and development of a pneumatically powered hand prosthesis for children' [Plettenburg, 2002a], it was thought to be appropriate to include a chapter on the current state of the art in upper extremity prosthetics. When finished, this chapter turned out to be a book on its own. Although being illustrative and informative within the scope of the thesis, it was decided to separate this chapter from the actual thesis, and publish it as a separate book.

The book contains three chapters. The objective of the first chapter, entitled Current Status in Upper Extremity Prostheses, is to familiarize the reader with the world of upper extremity prosthetics. This chapter reviews the prostheses presently available, their means of control and their sources of power. The second chapter, Evaluation, investigates the actual use of prostheses. In general the use of prostheses is cumbersome. The reasons for this are explored. Also some basic requirements needed to achieve better prostheses are presented in this chapter. From these basic requirements pathways for future research are derived. The third chapter, Discussion, Conclusions & Recommendations, concludes the book.

I am very indebted to my thesis supervisor Prof.dr.ir. Henk Stassen and my adjunct thesis supervisor Ir. Peter Pistecky for their valuable comments in proofreading this book. Likewise I am grateful to the other members of my thesis examination committee, Prof.dr. Hans Arendzen, Prof. Dr.med. René Baumgartner, Prof.ir. Adriaan Beukers, Prof. Dudley Childress Ph.D., Prof.dr. Frans van der Helm, and Prof.dr.ir. Peter Wieringa, for devoting their time, not only to review my thesis, but the manuscript of this book as well.

Dick H. Plettenburg
March 2002

PREFACE to this edition

As a result of the continuous interest in the book 'Upper Extremity Prosthetics. Current Status Evaluation', an annex to my PhD-thesis, it was decided to make an updated version widely available. The new edition now contains four chapters: Chapter 1, Prostheses in Historical Perspective, was added to set an historical perspective. The other three chapters are updated with the newest developments within the field.
I hope this book will offer something for anyone interested in upper extremity prostheses. I am interested in any comments or remarks the readers and users may come up with after reading this book. Please refer them to the publisher; it may help improve future editions.

Dick H. Plettenburg
October 2006

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PROSTHESES IN HISTORICAL PERSPECTIVE

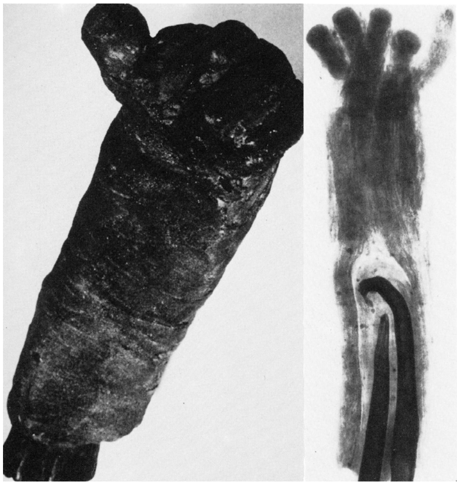

Figure 1.01 The prosthetic hand found on an Egyptian mummy, 330 B.C. The X-ray image at the right shows the deformed bony structure of the wearer.

Figure 1.02 The first hand of Florence; second half of the 15th century.

This work is about arm prostheses. The word prosthesis stems from the Greek. It is a compilation of the words *pros*, meaning *to*, and *tithenai*, meaning *to place*. Hence, *prosthesis* means *to place something to* or *to place something against* [Van Veen, 1990]. In the medical world it denotes to put, or fit, artificial parts or devices to the body, and the word also refers to such an artificial device [Simpson & Weiner, 1989; Allen, 1990]. According to the Encyclopædia Britannica [1985, 2006] a prosthesis is an:

> artificial substitute for a missing part of the body. The artificial parts that are most commonly thought of as prostheses are those that replace lost arms and legs, but bone, artery and heart valve replacement are common, and artificial eyes and teeth are also correctly termed prostheses. The term is sometimes extended to cover such things as eyeglasses and hearing aids, which improve the functioning part.[1] The medical speciality that deals with prostheses is called prosthetics.

For centuries mankind has tried to provide people with an arm defect with some kind of a replacement for the limb parts missing [Löffler, 1984]. One of the oldest examples known, dated back to 330 B.C, is a prosthetic hand found on an Egyptian mummy, Figure 1.01. This hand prosthesis is a cosmetic hand prosthesis, i.e. without moving parts, primarily aiming at the restoration of the wearer's outward appearance.

From the subsequent ages no examples of prosthetic hands are left. Written tradition mentions only one hand prosthesis belonging to the Roman general Marcus Sergius [± 210 B.C.], however, without providing technical details. The oldest physically remaining hand prosthesis goes back to the second half of the 15th century, Figure 1.02. It is a passive hand prosthesis, i.e. the fingers of the hand are moved by the sound other hand or by pressing the prosthetic fingers against a fixed object in the environment. Dating from mediaeval times and some later ages, several examples of passive hands remain.

1 In the field of rehabilitation devices that improve the functioning part where the anatomical structure is still present are usually referred to as orthoses.

Some of them with a moveable thumb only, some with the four fingers moving together in one finger block, and others with passive, individually adaptable, fingers. In these hands the thumb and finger configuration can be locked in a chosen position by the activation of a knob. A few examples are the famous hands of Götz von Berlichingen and the hands made by Ambroise Paré. Götz von Berlichingen [1480 – 1562] was a German imperial knight who lost his right forearm in the siege of Landshut, Germany, in the year 1504. His first hand prosthesis, Figure 1.03, had a moveable thumb and fingers moveable in pairs. Activation of a knob at the backside of the hand unlocks the fingers and the thumb and permits a leaf spring to return the hand to an open position. This hand is made entirely from steel and has a mass of approximately 600 grams. The second hand of Götz von Berlichingen, Figure 1.04, [1509], was revolutionary at the time as it has adaptive fingers that can be adjusted and locked individually. The hand is again made entirely from steel, and has a mass of approximately 1500 grams [Romm, 1989]. Again, like in Götz's first prostheses, the activation of a knob unlocks all the joints and permits springs to return the hand into the flexed position.

Figure 1.03 The first hand prosthesis of Götz von Berlichingen, known as the first Jagsthäuser Hand.

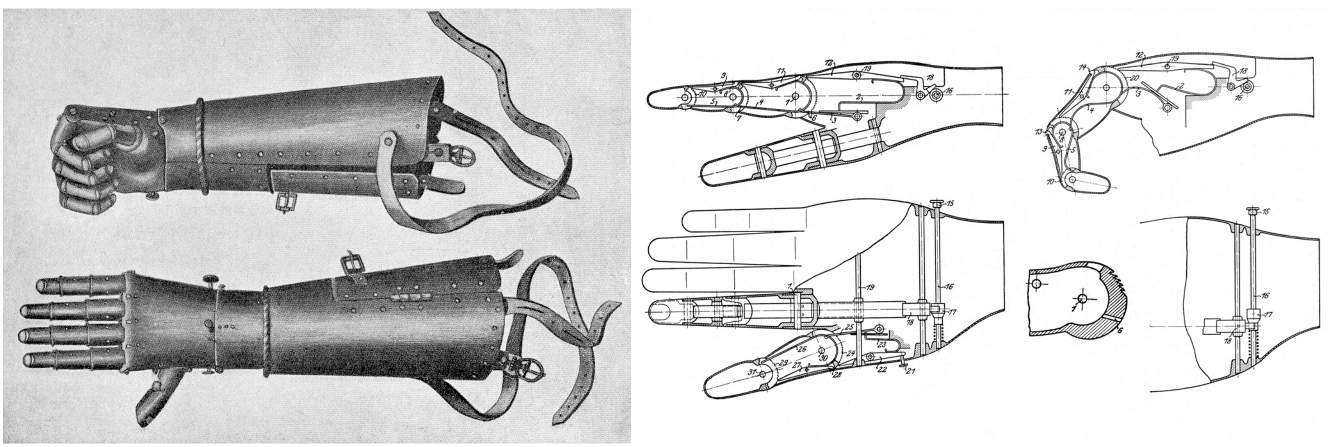

Figure 1.04 The second hand of Götz von Berlichingen, 1509, known as the second Jagsthäuser Hand.

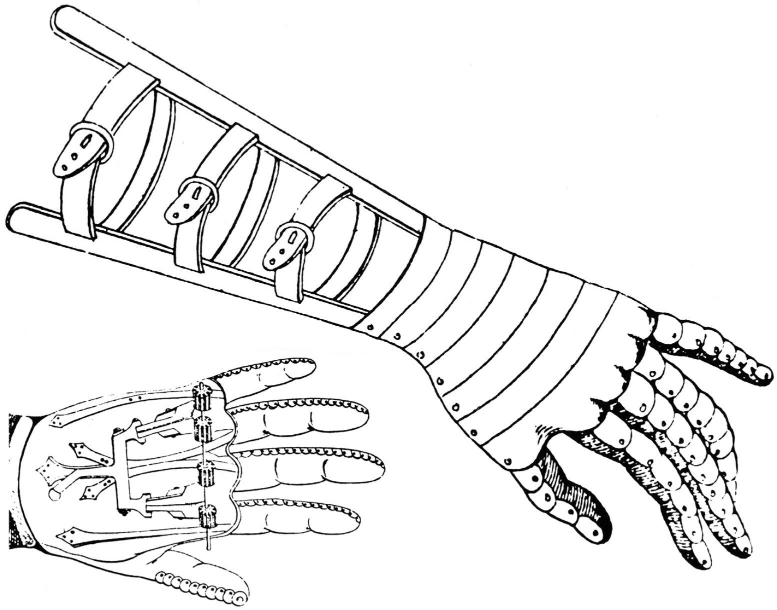

Figure 1.05 Prosthetic hands made by Ambroise Paré, second half of the 16th century.

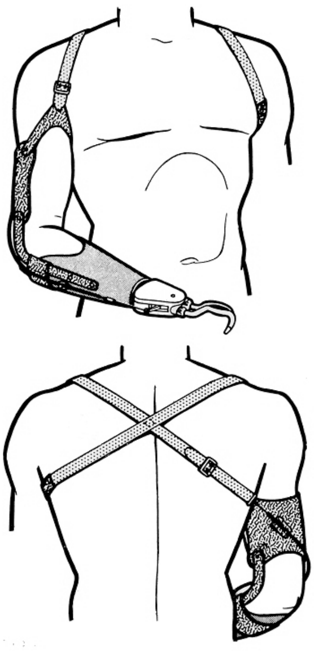

Figure 1.06 Configuration of a standard harness for the suspension and the control of a below-elbow prosthesis. The terminal device is opened and closed by movements of the shoulder.

The hands made by Ambroise Paré [1510 – 1590], a French physician who is generally acknowledged as the founder of prosthetics as a science, date back to the second half of the 16th century. These hands, Figure 1.05, have fully adaptable fingers, and are built with many small interconnected metal strips resembling the way in which the armour of knights was built. The palmar side of the fingers and of the hand was made of leather. A locking mechanism enabled the user of the prosthesis to maintain a grasp.

The beginning of the 19th century brings about a tentative start with actively operated prostheses. Harnessing gross movements of other body segments operates these prostheses. Hence, this type of prostheses is called body-powered. Commonly, the user wears a shoulder harness made of webbing, from which a cable extends to the terminal device, i.e. a hand or a hook. When the person shrugs the shoulder, thus tightening the cable, the

terminal device opens and closes. A typical, somewhat more modern - early 20th century - , example is shown in Figure 1.06.
The development of body-powered prostheses over the subsequent decades has resulted in a wide variety of designs, all characterised by a traditional and a more or less non-recurring nature. Some examples.
In 1844, Van Peetersen from The Netherlands was the first to employ a combination of abduction and antefexion movements of the upper arm to simultaneously operate the elbow mechanism and the hand mechanism of the prosthesis, Figure 1.07.

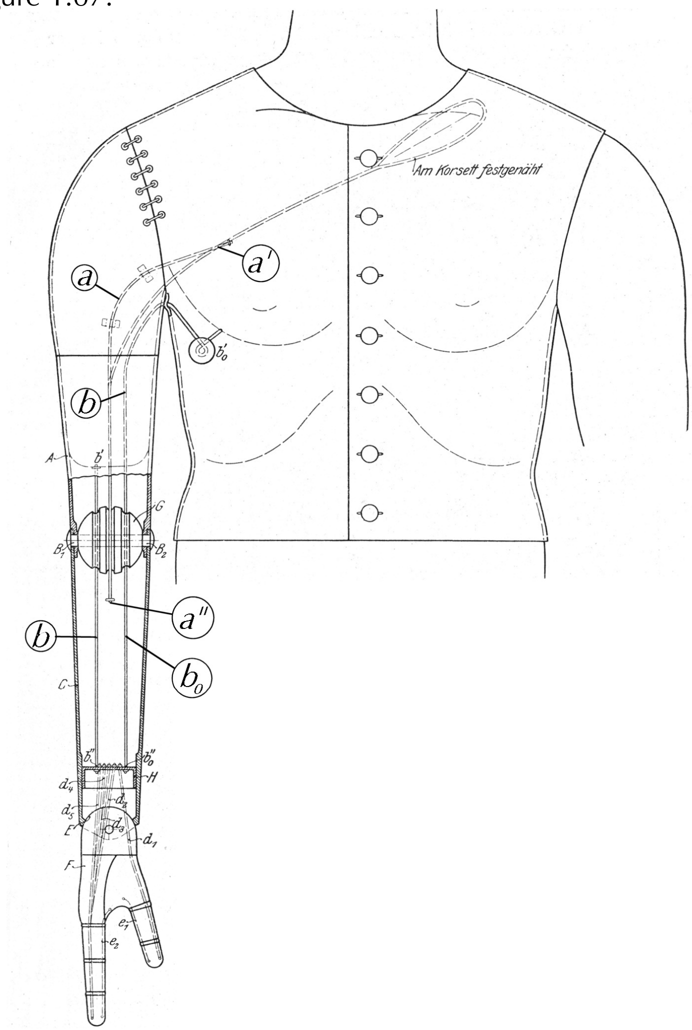

Figure 1.07 The prosthetic arm designed by Van Peetersen in 1844 for above elbow defects. Flexion and extension of the elbow is controlled by anteflexion of the shoulder and the upper arm shortening the cable a that is fastened to the suspension corset at a' and to the prosthetic forearm at a''. The fingers of the hand are in the rest position extended. Flexion of the fingers is accomplished through cable b that shortens as a result of the flexion of the elbow. Hence, elbow flexion is coupled to the closing of the hand. Furthermore, flexion of the fingers can result from an abduction movement of the upper arm shortening the cable b_0.

In 1860, the Count of Beaufort, from France, made a surprisingly modern looking prosthesis, Figure 1.08, [please, compare with the picture of Figure 1.06!]. The hand, made of wood and with a moveable thumb only, is controlled by a cable attached to a simple shoulder harness. Both the abduction and the anteflexion of the upper arm enable the operation of the hand mechanism.

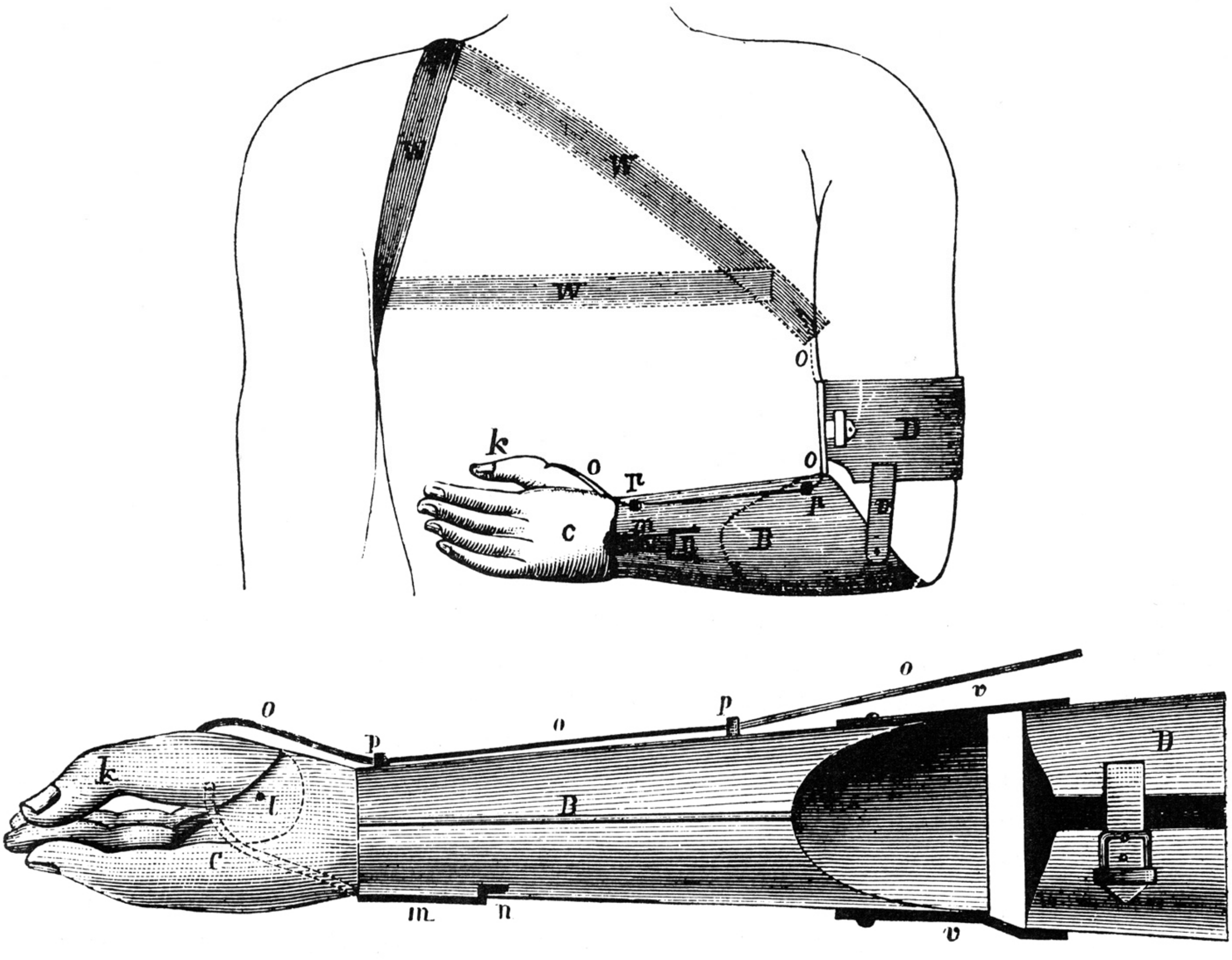

Figure 1.08 Below-elbow prosthesis by the Count of Beaufort, 1860. The hand is controlled by a cable, indicated with O, attached to a shoulder harness.

Also in 1860, the French prosthetist Charrière made a prosthesis for an opera singer who had lost his right arm through the elbow joint, Figure 1.09. In this prosthesis, in an attempt to enable dramatic gestures, a coupling was made between flexion of the elbow, supination of the wrist, wrist flexion and the closing of the fingers of the hand.

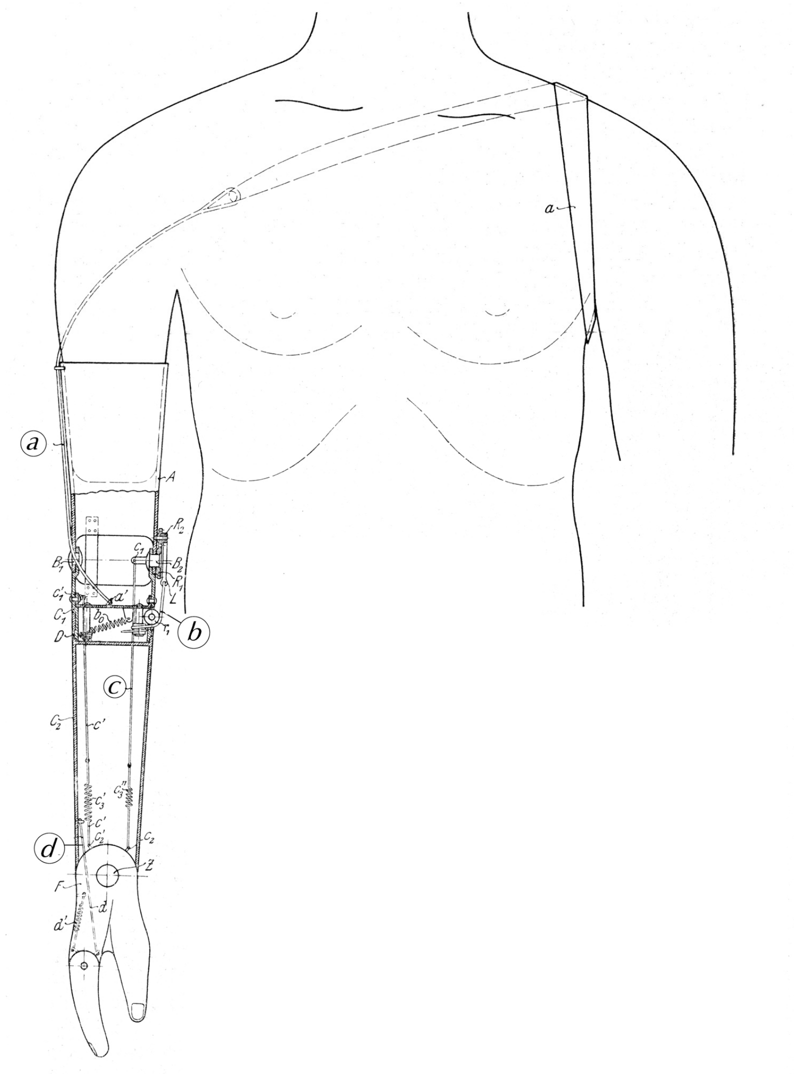

Figure 1.09 Elbow disarticulation prosthesis by Charrière, 1860. Shortening of the cable a flexes the elbow. As a result the cables b, c, and d are shortened as well, resulting in supination of the wrist, wrist flexion, and the closing of the hand, respectively.

Carnes, an American mechanical engineer, who had an above-elbow defect himself due to an industrial accident in 1902, made in 1911 a set of prostheses that is said to be the first clinically useful body-powered prostheses [Schlesinger, 1919]. Carnes was the first to use the shoulder shrug on the affected side to control the hand mechanism, Figure 1.10.

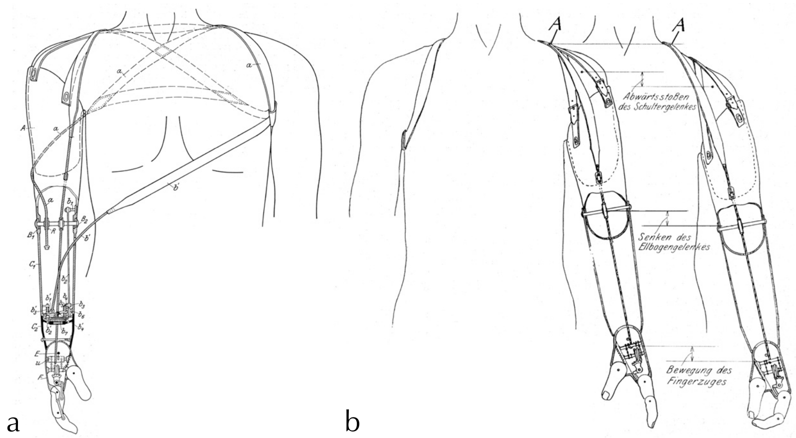

Figure 1.10 The prosthesis built by Carnes in 1911 for above elbow defects. Figure 1.10a shows the complete prosthesis. Figure 1.10b illustrates the shoulder shrug control for the operation of the hand mechanism. With the shoulder in the normal rest position the hand is open. Depression of the shoulder pulls the cable anchored at point A and closes the hand.

For forearm defects Carnes also employed the shoulder shrug control, Figure 1.11. The hand mechanism requires an active operation for opening [bi-scapular abduction and/or shoulder flexion] and closing of the hand [shoulder shrug].

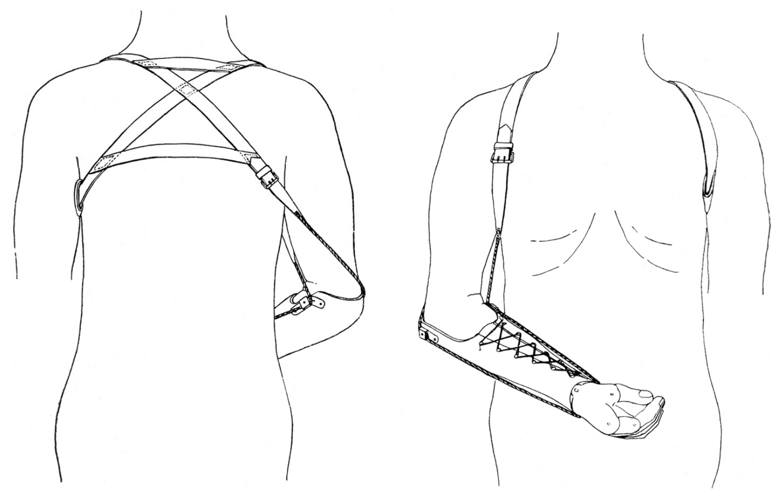

Figure 1.11 The prosthesis built by Carnes in 1911 for below-elbow defects.

The great number of amputees resulting from World War I boosted the development and use of body-powered prostheses. Although originally designed just before the war in 1912 [Fryer and Michael, 1992], the split hook, Figure 1.12, found wide application. The hook has two fingers, one stationary and one moveable, operated by a control cable attached to an extension of this finger. The moveable finger is opened against a spring, usually a rubber band. This spring provides the return action and the pinching force.

Figure 1.12 The split hook prosthesis.

A more natural appearance was strived for in the development of wooden hands with moveable fingers, Figure 1.13, sometimes covered with a leather glove. These hands are kept in the closed position by an internal spring, and can be opened by pulling the control cable through a shoulder harness.

After the Second World War plastic materials, frequently reinforced with textile fibres, were introduced into prosthetics. The further development of body-powered prostheses to date is best characterised with a gradual evolution, with no basic innovations in the principles of operation. Some examples of contemporary body-powered prostheses are shown in Figure 1.14.

Figure 1.13 A wooden hand with moveable fingers and a moveable thumb.

Figure 1.14 *Several contemporary body-powered prostheses. Clockwise, from the top left: the WILMER central pushrod operated hand and hook combination; the WILMER appealing prehensors; and the WILMER elbow controlled below elbow hand prosthesis.*

At the end of the 19th century the first ideas to employ an external energy source for the operation of prostheses were introduced. Both pneumatical and electrical power were utilised in different designs. An early example of a pneumatic hand is shown in Figure 1.15.

Clinical use of pneumatically powered prostheses was achieved not until 1948 when Weil started to use a prosthesis designed by Häfner at the University of Heidelberg, Germany, which was powered by compressed carbon dioxide, Figure 1.16, [Marquardt, 1965]. The Thalidomide tragedy [a sedative drug causing foetal deformities when used during pregnancy] advanced the development and the clinical application of pneumatically powered prostheses in the late 50's. Over the years, the clinical use of and the research on pneumatically powered prostheses continued in several locations throughout the world. However, when the electrically powered prostheses matured around the mid-seventies, pneumatically powered prostheses fell into oblivion. This was mainly due to the cumbersome refill procedure of the carbon dioxide containers used in pneumatically powered prostheses as compared to the recharge procedure of the batteries in the electrical powered ones, and due to the fact that the myo-electric prosthesis did not require a harness anymore [Childress, 1985; Plettenburg, 1989].

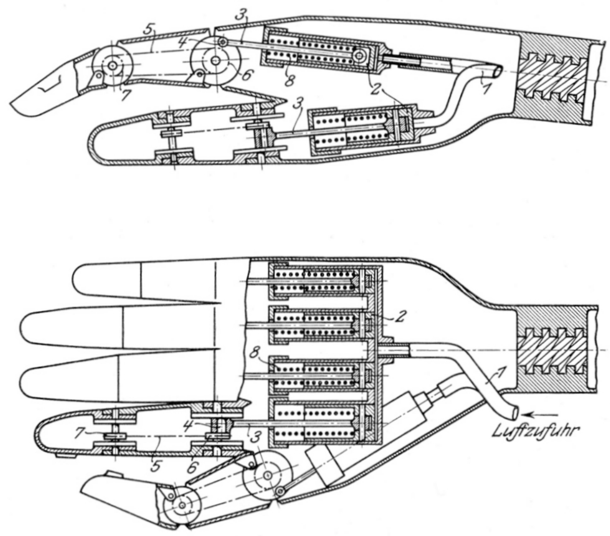

Figure 1.15 An early example of a pneumatically powered hand prosthesis. The supply pressure is presented at the gas duct #1 and displaces the pistons #2. These pistons drive the proximal phalanxes of the fingers. A mechanical coupling drives the distal phalanxes to the proximal phalanxes.

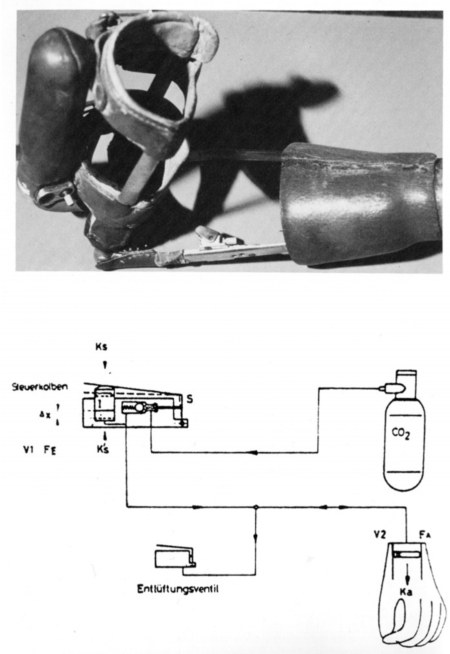

Figure 1.16 The Heidelberg pneumatic arm prosthesis, 1948. The hand prosthesis is powered by compressed carbon dioxide, contained in a bottle located at the upper arm [left in the top figure]. The gas flow to the hand is controlled by a pneumatic switch valve, operated by movements of the remnants of the forearm.

An early example of an electrically powered hand prosthesis is shown in Figure 1.17.

The Vaduz Electric Hand, sometimes referred to as the French Electric Hand, [Wilms, 1953a, 1953b] is another noteworthy example of an attempt to introduce electrical actuation in the prosthetic field, Figure 1.18 and Figure 1.19. This hand employs a servo control which provides feedback of position and force to the user. The user controls the prehension of the hand by the tension of his forearm muscles against a pneumatic transducer located within the forearm socket.

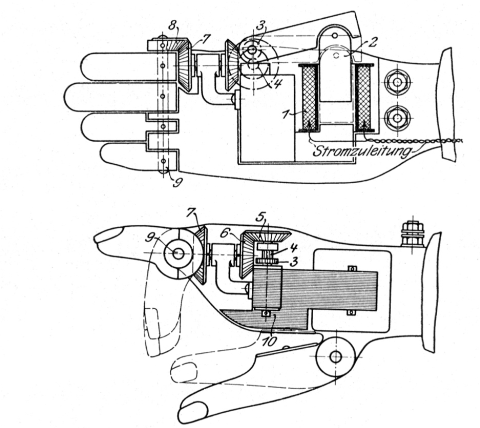

Figure 1.17 An early example of an electrically powered hand prosthesis. When switched on, the electromagnet #1 pulls the anchor #2 inward, therewith rotating the lever #3. The movement of the lever is transmitted to the fingers through a set of bevel gears # 5 – 8.

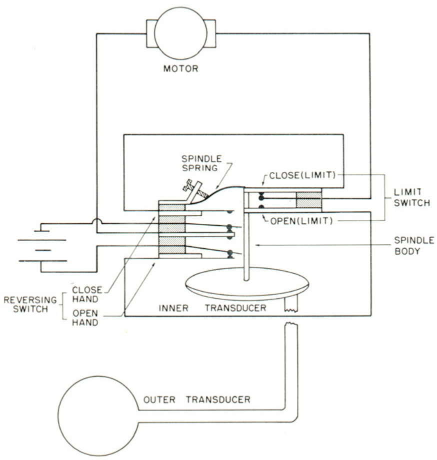

Figure 1.18 The scheme above shows the electrical circuit and parts of the mechanism of the Vaduz hand. The spindle moves the insulated ends of the 2nd and 4th leaves of the reversing switch.

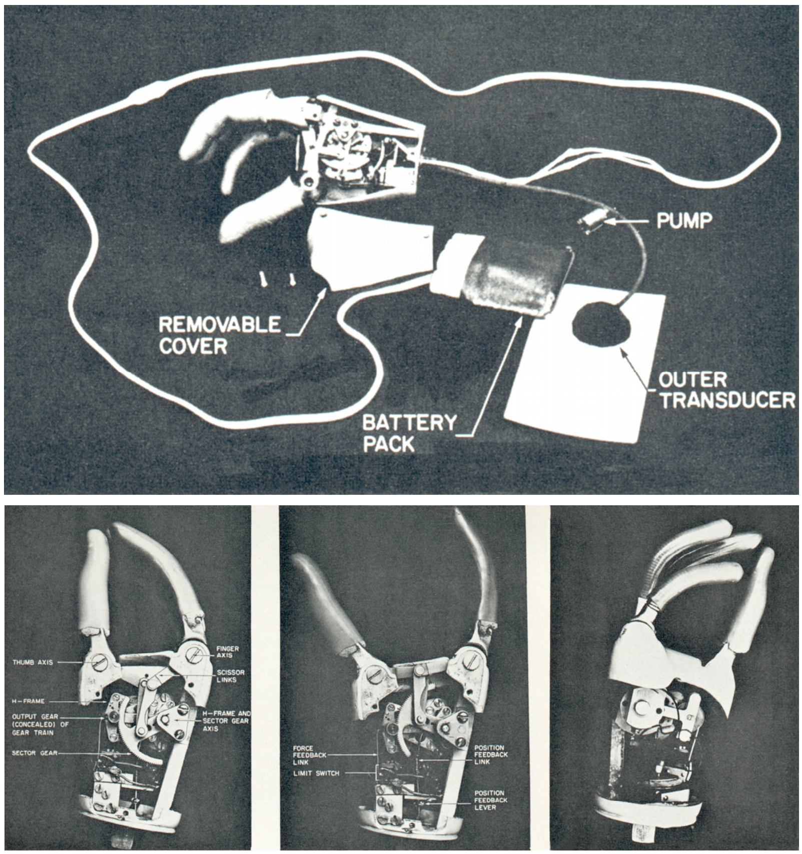

Figure 1.19 The Vaduz hand (1962 model).

An important step towards clinical application of electrically powered prostheses was the idea to use the electrical signals associated with voluntary muscle contraction for the control of the prosthetic device. These signals are called myo-electrical signals, from the Greek word *myos* for muscle. Hence this type of prostheses is called myo-electric prostheses. Reiter [1948] was the first to propose and actually build a myo-controlled hand prosthesis, Figure 1.20. Intended for stationary use at a workplace, it was powered from the mains and it made use of a vacuum tube amplifier. With the invention of the transistor, the electronic equipment necessary could be made portable. Early fifties, some initial attempts were made in Russia [Kobrinskii et.al., 1961] and in England [Berger & Huppert, 1952; Battye et.al., 1955].

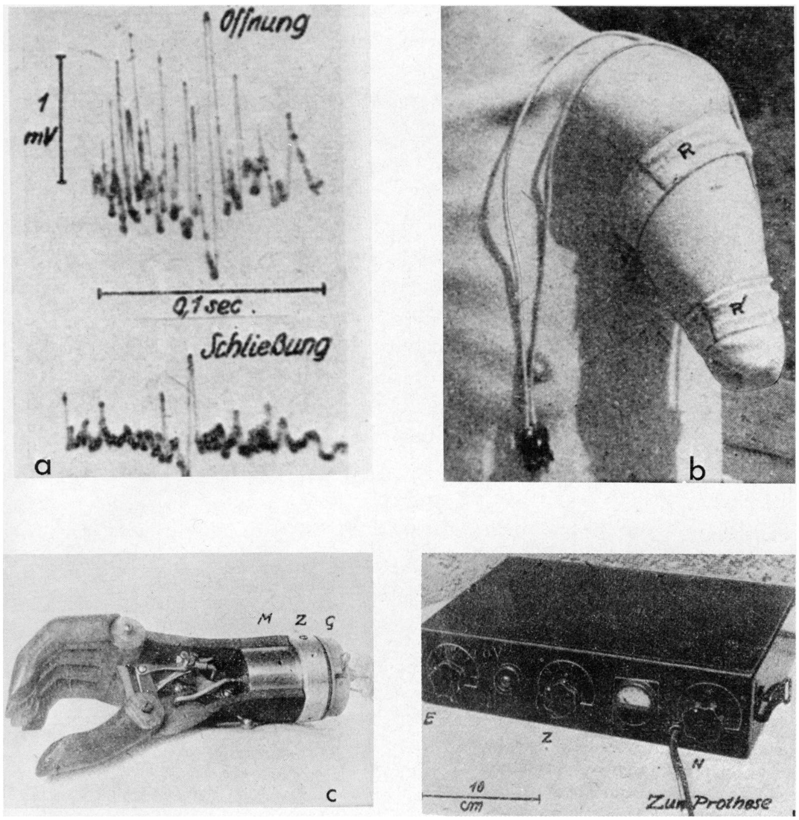

Figure 1.20 Myo-electric prosthesis by Reiter. In Figure 1.20a the myo-electric signals, as recorded by the electrodes on the arm remnants [Figure 1.20b], during opening and closing of a prosthetic hand [Figure 1.20c], are shown. An electronic controller, Figure 1.20d, processes the signals.

At the end of the sixties and early seventies, the myo-electric prostheses became general available for clinical use. Over the years they have become more refined in their mechanical engineering and in their control. Some examples of current myo-electrical prostheses are shown in Figure 1.21.

Figure 1.21 Several contemporary externally powered prostheses. Clockwise from the top left: a below elbow prosthesis from Otto Bock; a RSL-Steeper electric hand without the cosmetic cover; an Otto Bock electric hand together with the cosmetic inner hand cover; and the Motion Control ETD-Hook, an electrical powered hook prosthesis.

Today a wide variety of prostheses and prosthetic components for clinical application exists. Figure 1.14 and Figure 1.21 already show a glimpse of the wealth of available devices. The next chapter presents a more elaborate overview of the state of the art in upper extremity prosthetics.