UPPER EXTREMITY PROSTHETICS

CURRENT STATUS & EVALUATION
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DICK H. PLETtenburg

VSSD
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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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PREFACE to this edition

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PROSTHESSES IN HISTORICAL PERSPECTIVE
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.
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 b₀.
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.
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.
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.