CHANGES IN TECHNOLOGIES AND MEANINGS OF UPPER LIMB PROSTHETICS: PART I - FROM ANCIENT EGYPT TO EARLY MODERN EUROPE

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ABSTRACT

This paper is the first-of-a-three-part series that examines changes in technologies and meanings of upper limb prosthetics from ancient Egypt to the present. Contemporary design of powered upper-limbs shares a number of continuities with older methods of limb making. Both cosmetic and functional prostheses have been in production for at least the last 3,000 years. Wars have long been a spur to technological innovation in artificial limbs. Prostheses making has sought to return soldier-amputees to combat, whether on horseback or in tanks. Technological innovation in other fields has provided materials for improvement in artificial limbs, such as the replacement of wood by iron, iron by steel, or plastic by composites. Since the early modern period, the development of new artificial limbs has been mistaken as a specialty of medical doctors. The making of artificial limbs has since at least Ancient Egypt been as much about technological innovation as the creation of new meanings of prostheses, whether the design of arms for the underworld of the Duat or hands as industrial tools.

INTRODUCTION

The management scholar Roberto Verganti has both combined and expanded our definitions of *innovation* and *design* through the concept of design-driven innovation. In his definition of *design*, it not only includes design as a form of product, e.g. bringing visions of beauty to products, or design as creative problem solving, e.g. human centered-design anchored in user discovery, but a third meaning of design as "making sense of things [1]." In this third meaning, design contributes new meanings, whether combined with radical or incremental technological innovation. In this paper we examine how multiple meanings of powered upper prostheses have emerged in the design of these limbs, including "prosthesis as afterlife limb", "prothesis as battle tool" and "prothesis as natural limb".

ANCIENT UPPER LIMB PROSTHESES

Recent studies are revising accounts of ancient Greece and Rome as the source of the first prostheses, and medieval Europe as a dark age of heavy, crude prostheses for battle and hiding amputations [2]. There is evidence from ancient Egypt that artificial body parts were used to reinstate the physical body for its reanimation and continued existence in the next life. As well, functional prostheses were designed and used for mobility [3]. Artificial big toes found with Egyptian mummies and dated to the 11th to 7th centuries BCE show both a realistic appearance and functional performance in contemporary walking tests with replicas [4]. The inference is that a "nascent prosthetic science may have been emerging in the Nile Valley as early as 950 to 710 BC", perhaps demonstrating ancient Egyptian knowledge of human anatomy [5]. Upper-limb prostheses, in contrast, were rarely used in ancient Egypt, and then only by the rich. The oldest Egyptian cosmetic hand found on a mummy dates to 2000 BCE [6]. Another cosmetic hand has been dated to 200 BCE [7].

Beyond Egypt, there is evidence of prostheses in ancient Greece, Rome, Peru and China. In Greek mythology, the god Hephaestus, sometimes shown with shriveled foot, is skilled in the technical arts and making of prostheses [8] Other written records include Herodotus' description of the wooden foot and an iron arm prosthesis of the 3rd century BCE Roman general, Marcus Sergius Silus [9].

Although archaeological evidence for amputations before 1000 is uncommon, there are reports of artificial limbs during the first millennium. Artificial feet have been found in burials in Bonaduz, Switzerland from the 5th to 7th century and Griesheim, France, dated to the 7th to 8th century. A male from Longobard, Italy during the 6th to 8th century was found with a forelimb amputation and prosthetic device [10]. The historian Reed Benhamou in a *Technology and Culture* article on the history of the artificial limb in preindustrial France wrote that "Artificial hands capable of at least the palmar pinch required to hold a pen may have been made as early as the 10th century [11]."

EARLY MODERN LIMB PROSTHESES

As with amputations before the year 1000, there is little historical, archaeological or iconographic evidence of artificial limbs before the 16th century [12]. Most amputations may have been lethal, as techniques to stop extensive bleeding only became widely known in the 17th century. As well, there was a lack of knowledge of how to avoid infection. In the sixteenth century, doctors cauterized gunshot wounds with boiling oil. It was only after the French army barber-surgeon Ambroise Paré (1510–90) ran out of oil in a battle that he began using ointments and dressing as an alternative. Seeing improvement in his patients, Paré discovered that ligation of blood vessels controlled bleeding during amputation [13]. However, even in those rare cases in which severe upper limb trauma did not result in deadly hemorrhage and infection, only the wealthy could afford customized prosthetic upper limbs.

The growing affluence in the early modern period is evidenced by the holdings of artificial upper limbs in the London Science Museum. It has five upper, artificial limbs dating from the 16th to 18th centuries [14]. The lack of lower limbs in the collection, despite being more numerous than upper limbs both then and now, is likely attributable to the use of wood and leather in artificial legs (excepting for knights on horseback), versus iron or steel for upper limbs. Among the most famous prosthesis of the early modern period is the iron hand of German knight Götz von Berlichingen (1480-1562). An artisan made the prosthesis battle armour for him after he lost his hand during the Siege of Landshut (circa 1505) in Bavaria. It featured five digits that were capable of a fingertip pinch, could be flexed and locked so he could to hold reins, grasp and swing his sword and return to battle with disability concealed. The iron upper limb of a Turkish pirate, Horuk Barbarossa, was discovered in an Alsatian tomb dated to 1564. He lost his hand in the Battle of Bugia (circa 1517) against Spain, and, like Götz von Berlichingen, received an iron replacement so he could fight again in battle. The Barbarossa upper limb also featured a movable wrist joint, elbow joint and fingers. Following a similar theme, Duke Christian of Brunswick lost his left hand in the Battle of Fleury (circa 1622) and received an iron hand from a Dutch craftsman. The only account of a non-combative hand prosthesis from the period comes from outside of Europe. It is attributed to the Italian surgeon Giovanni Tommaso Minadoi, who in 1512 “while travelling in Asia recorded observations of an upper limb amputee who was able to remove his hat, open his purse, and sign his name [15].”

According to numerous accounts, the first prosthetic device “that demonstrated a sound understanding of basic biomechanical functions” was designed by Paré [16]. It was a mechanical hand operated by catches and springs. It sought to copy with metal the motion and appearance of the missing hand, as well as offer beauty and ornament to wealthy patrons. In some reports, the hand met with limited success. In others, it was heavy but “successfully restored a knight’s ability to hold a shield or weapon in battle” and “were carefully crafted with the shape and appearance of human hands, rather than simply inanimate tools to hold objects [17].” It was not, however, designed by Paré, but obtained from a locksmith living in Paris, known as “le petit Lorrain.” [18] According to Heidi Hausse, it provides evidence of “ongoing practices of creating prosthetic technology in this period” within the domain of locksmiths, gunsmiths, clockmakers, and armorers in the early modern period. Neither Paré nor the surgeons who read his *Oeuvres* could fabricate the prosthesis or understand design, as opposed to the master craftsmen, who were capable of both. Rather it was the surgeons of wealthy patients who could afford these luxury items containing expensive materials and new technology.

A similar division between surgeons and master craftsmen is seen during the English Civil War (1642–51). “The Hospital of the Savoy in London treated amputee soldiers whose prosthetic requirements survive in credit bills submitted by William Bradley, hospital carpenter, indicating he supplied wooden legs and their attachments, made repairs, and provided crutches of various lengths [19].” This also presents evidence of the beginning of the institutionalization of prosthetic device design and manufacturing within hospitals.

EIGHTEENTH CENTURY LIMB PROSTHESES

The eighteenth century saw the refinement of early modern upper limbs, the expansion of craft businesses into advertising, the beginning rehabilitation programs in hospitals and new ideas of politeness that led to expressions of uneasiness with visible disability. The refinements included body powered upper limbs. In 1732, the Académie Royale des Sciences reviewed a below elbow artificial arm designed by a clockmaker named Kreigseissen. It was made from sheets of copper and had joints at the wrist and at the first and second knuckles. These joints also offered lateral movement of the thumb to accomplish a palmar pinch were accomplished with pulleys activated by bending the elbow. There was also reduction in the weight of upper limbs. The Götz von Berlichingen artificial hand weighed about 1.5 kilograms, a little less than the average male hand and forearm. By 1792, an artificial arm made in Switzerland had less than a third of the weight due to the use of steel instead of iron for the springs, barrel casings, cables, and triggers, papier-mâché and parchment for the forearm, and cork for the wrist and hand rather than metal or wood. As evidence

of the continuing role of master craftsman in the design of prostheses, Reed Benhamou wrote that "It is no coincidence that these are the same materials used in 18th-century automatons, for several of the clockmakers, locksmiths, and *mécaniciens* who used the lightweight materials and miniaturization techniques required by these devices also produced artificial limbs. Indeed, some 18th-century prostheses may be called spin-offs of technology [20]."

Shaping the response to wartime limb loss were Enlightenment values and a new culture of politeness. In early the early eighteenth century visible "'deformity' made others uneasy and threatened the virtuous social interaction or 'conversation' that lay at the core of notions of politeness [21]." Moreover, in Britain, many "condemned the use of prosthetic technologies as deceitful, prideful and impious [22]." By the late eighteenth century, prostheses came to be associated with Enlightenment visions of scientific discovery of the mechanics of the human body and technological progress in replicating nature. In this cultural shift the association of prosthesis with the sin of pride and Puritan ideals of unadorned purity was reformulated as artificial improvement. Prosthesis use came to be seen as restoring wholeness and normalcy and practicing polite behaviour in putting others at social ease. In this way prostheses users were meeting their moral duties of a sociable society. With this context the advertisement of prostheses as devices of scientific improvement further influenced the growth of this idea of politeness, with as much emphasis on agreeableness, decorum and taste, as it did with the medical marketplace. Toward the end of the 18th century, the French Revolutionary Wars (1792-1802) led to new opportunities for sales of protheses. In addition to tailoring prostheses for individual amputees, "craftsmen solicited endorsements, advertised their products in the popular press, and, in general, attempted to sell prostheses as they might any other commodity [23]."

These themes are present in the eighteenth-century invention of rehabilitation. The rehabilitation physicians Reuben Eldar, and Miroslav Jelić write that the "true spirit of rehabilitation…started in Europe in the 18th century [24]." One of the sources for the new medical discipline of rehabilitation was orthopaedics. The French physician, Nicolas Andry (1658-1742) in setting out the principles of the new field wrote in his *Orthopédie*, translated into English in 1743, that "We are born for one another, and ought to shun having any thing about us that is shocking [25]." As such, orthopaedics was in its origins "defined primarily in terms of aesthetic improvement rather than restoration of functional ability [26]." These ideas found incorporation in new institutes and clinics, including the first orthopaedic institute, founded in Orbe Switzerland in 1780, followed by the orthopaedic hospitals in Wurzburg, Germany in 1812, Paris in 1826 and London in 1837. It would be another hundred years before the "scientific and technological transformation of orthopaedics" occurred during the twentieth century interwar period with the rise in interest in research and development [27].

The concept of physical normalcy gained further momentum in the nineteenth century with the emergence of bodily statistics [28]. It was accompanied by increasing public awareness of prosthetic devices in marketplaces. The forces behind this growth in social consciousness of artificial parts as aesthetic improvement included the use of advertising by the prosthesis industry [29]. With the rise in social awareness there were also increases in demand for functional devices, especially for industrial workers who sought to return to work after limb loss [30]. This meant the emergence of a new market for industrial workers and new meanings for their devices, versus middle class and aristocratic amputees who wished to maintain social distinction through limbs which were presentable in polite society [31]. One of the new technologies that allowed for maintenance of social distinction was a body-powered upper limb prosthesis designed by German dental surgeon Peter Baliff in 1818 [32]. It used leather straps connected to the trunk and shoulder girdle to flex fingers and extend the forearm prostheses. It offered to amputees for the first time a means to operate prosthesis with fluid body motions. It also provided the basis for subsequent improvement and adaptation throughout the nineteenth century. It was applied to above-elbow prostheses by a Dutch sculptor, Von Peterssen, in 1844. In 1867 the Comte de Beaufort redesigned it for lower cost production for use by the poor and amputee veterans of the Crimean War (1853-56). There followed numerous redesigns, including a double spring hook for holding objects, similar to that of the well-known split hook of today

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