Historical Development of Lower-Extremity Prostheses †

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In studying the history of the construction of artificial limbs to substitute for lost legs, which has been transmitted to us by written words, objects of art and handicraft, objects found in excavations, and so forth, and learning of the development of the artificial leg through the centuries, one gains knowledge of the foundation on which modern prosthetics is based. Such an historical review, furthermore, permits one to appreciate what modern scientific prosthetics and rehabilitation have accomplished to date for the limbless.

The loss of the means of locomotion is a tragic disaster for the animal. Such a loss deprives it from hunting, from protecting itself against the vicissitudes of weather and climate, and exposes it to the likelihood of a miserable death. Man, with his inventive brain, found ways and means to help himself and to escape the fate of the animal. It has been stated that, ". . . the history of artificial limbs is probably as old as humanity, as it is supposed that a maimed fellow would try to find a remedy for his imperfections."[1] A branch of a tree, used as a stick or a crude crutch, substituted for a lost leg and helped man to regain his power of locomotion. These crude primitive aids were, of course, a far cry from the conception of an artificial limb.

The Era of Antiquity

It is not known when and where the first prosthesis was produced. The earliest mention of an artificial leg seems, according to Major, to be in Indian literature.[2] He states that in the *Rig-Veda*, the oldest book of the *Vedas* (Veda period of India, about 1500 to 800 B.C.), the use of artificial eyes and artificial teeth, as well as artificial legs, was recorded. One wonders that no other records from the ancient Orient, referring to artificial limbs, have been found, although it must be assumed that war injuries, the cruel punishment of errant citizens, and the inhuman maiming of war prisoners which were practiced in that era, as well as the endemic diseases which caused the loss of parts of extremities, must have propagated the idea of the production of artificial limbs.

Our research on this subject, as far as ancient Chinese history is concerned, was fruitless. Correspondence with the China Institute in America

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and with Professor Joseph Needham of Cambridge reported that they had not come across any evidence in this branch of traditional Chinese medicine on the use of artificial limbs after amputation; it was further reported that their studies had not yet been all-exhaustive and they would not be at all surprised if they ultimately did find some evidence or reference to this type of practice. Correspondence with scholars and teachers of the Old Testament failed to produce any information on this subject other than the fact that chopping of toes and thumbs as a cruelty practiced on captured Jewish prisoners of war is mentioned.

Following this era the earliest historical record of a prosthesis seems to be that from Herodotus (485-425 B.C.).[3] In Book IX of his great historical work, he tells the story of the Seer Hegesistratos of Elis who was imprisoned by the Spartans and held with one foot immobilized in the stocks.

After obtaining a knife, he amputated his foot through—"apetame ton tarson" (original Greek text)— what we believe to be the Chopart joint—thus enabling him to put weight on the heel after his escape from prison. The story further tells that he ultimately supplied himself with a wooden foot.

Although the Greco-Roman physicians from Hippocrates to Celsus and Galen described amputations, they made no mention of any prosthetic devices. There is no doubt that peg legs were known and used in this era as evidenced by several historical discoveries. Beaufort[4] described a vase from the Louvre which displays the figure of a man supporting himself with a long stick attached to a peg leg at the knee; the foot of the other extremity is substituted by a wooden capsule. This vase was found in southern Italy and it is said to be the product of the fourth century, B.C. In 1862, the fragment of an Ionian vase was found (fig. 1)[5] decorated with the figure of a naked man, sitting in a chair and holding in his left hand a lyre; the

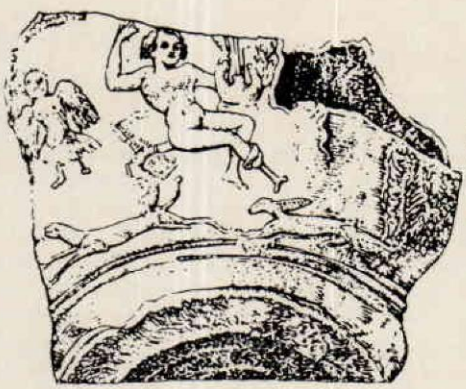

Fig. 1—Pen drawing of a fragment of antique vase unearthed near Paris in 1862 which shows a figure whose missing limb is replaced by a pylon with a forked end. Permission has been obtained from the American Academy of Orthopaedic Surgeons to reproduce this figure from the Orthopaedic Appliances Atlas.[5]

Fig. 2—Mosaic from the Cathedral of Lescar, France, depicts an amputee supported at the knee by a wooden pylon. Some authorities place this in the Gallo-Roman era. From Putti, V., Historical Limbs.[1] Permission has been obtained from the American Academy of Orthopaedic Surgeons to reproduce this figure from the Orthopaedic Appliances Atlas.[5]

distal half or two thirds of the right leg is apparently missing and substituted by a peg leg. The archeologist, De Longperier, described a mosaic from the Cathedral of Lescar, France, dating back to the Gallo-Roman era which shows a figure with a peg leg attached at the knee (fig. 2).[6]

Of particular interest, as far as the history of American prosthetics is concerned, was the discovery of an old Peruvian pottery mentioned by Gillis in his *Monograph on Amputations* (1954);[7] it depicts the figure of a man with a leg amputated at the tibiotarsal junction and holding in his right hand a pointed cap to be adjusted to the stump of his leg.

Preuss, in 1911,[8] reported the existence of several chapters in the *Talmud* in which artificial limbs are mentioned. In the tractate *Shabbath*[9] Rabbi Meir and Rabbi Jose discussed the problem of whether or not the Sabbath law, which forbids the carrying of objects, was applicable to the wooden leg of a man who had lost his limb. This prosthesis was described as a log of wood, hollowed out to receive the stump, which had a receptacle for pads upon which the stump could rest. This part of the *Talmud*, called the *Mischna*, was completed in the second century, A.D. It is not clear whether the above discussion refers to a prosthesis for an above-knee stump or a long below-knee stump or, according to the interpretation of Preuss, to a forefoot amputation.

In an article published in 1939,[10] Popp stated that "wooden artificial legs were often mentioned in the sagas of the Nordic mythology." According to the *Gettir-Saga*, Oemund Ufeigsson lost a leg below the knee in battle; he later walked on a wooden leg from which he derived the name Trefote (the wooden foot).

The oldest artificial leg ever unearthed was found in 1858 in a tomb of Capua and was sent to the Museum of the Royal College of Physicians and Surgeons in London. Unfortunately, it was lost in 1941 during an air raid. It was supposed to date back to 300 B.C., the time of the Samnite wars. Photographs and descriptions are preserved. The leg is described in the following manner:

"Roman artificial leg; the artificial limb accurately represents the form of the leg; it is made with pieces of thin bronze, fastened by bronze nails to a wooden core. Two iron bars, having holes at their free ends, are attached to the upper extremity of the bronze; a quadrilateral piece of iron, found near the position of the foot, is thought to have given strength to it. There is no trace of the foot and the wooden core has been entirely crushed away. The skeleton has its waist surrounded by a belt of sheet bronze edged with small rivets, probably used to fasten a leather lining."[11]

Summarizing our knowledge of artificial limbs in the era of antiquity, we have found evidence that wooden legs in the form of peg legs were built and used from earliest recorded times. The wooden leg was designed mostly for loss of limb below the knee. The survival rate for those with above-knee amputations probably was small, if amputations ever were attempted in this region. The knowledge that we have of primitive surgery and inadequate wound treatment makes this hypothesis rather sound. It seems quite logical to assume that only a small minority of the maimed obtained artificial limbs and that this minority probably represented the privileged classes or those who were mechanically inclined and fabricated their own prostheses. A few carpenters and armorers tried their hands in producing artificial limbs. The physicians and surgeons, as such, seem to have had no interest in the care of the patient after amputation or they did not feel the necessity of being concerned with the problem of the prosthetic device.

The Era of the Middle Ages

Very little progress in the development of artificial legs is recorded in this era. Those who could afford it, probably provided themselves with wooden peg legs. The peg leg is the simplest, cheapest substitute for a lost leg; it lacks delicate metal parts which might be more subject to wear and tear. The peg leg, as mentioned previously, has been in use from the earliest centuries of history right up to the present date. It is considered the artificial limb of the poor. But, in the Middle Ages, the poorest were unable to obtain even this peg leg; they hopped around on crude crutches or propelled themselves on movable benches or discs. The privileged classes of this era, represented mostly by the knights, were inclined to conceal their battle disabilities rather than to wear wooden legs. Putti[1] shows the photograph of and describes an iron lower limb (fig. 3), the knee of which is in flexion and the ankle in plantar flexion, both joints without any freedom of motion; it was built in the fashion of an armor of that period and imitated the position of a leg of a knight on horseback. It should be remembered that during the same era when no progress was made in the construction of lower extremity prostheses, artificial iron arms were constructed with ingenious finger motions which enabled the knight to hold his lance or sword.

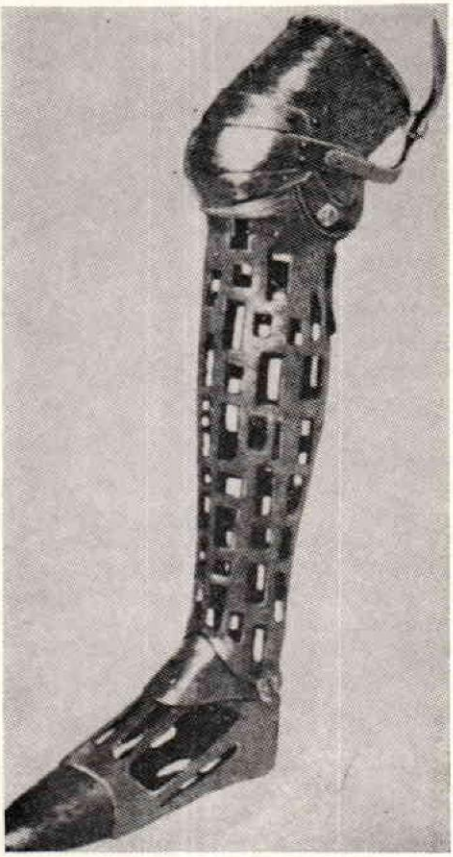

Fig. 3—Sixteenth-century lower limb designed for aesthetic purposes. It was apparently intended to conceal the mutilation of a mounted knight. Redrawn from Putti, V., Historic Artificial Limbs.[1] Permission has been obtained from the American Academy of Orthopaedic Surgeons to reproduce this figure from the Orthopaedic Appliances Atlas.[5]

Summarizing the status of the artificial leg in the Middle Ages, we have observed that there was little or no progress in the development of the lower extremity prosthesis. The peg leg was the "leg of the day." The poorest people did not receive any help from society; they used makeshift substitutes for their lost limbs and lived outside the realm of society usually as beggars or peddlers. Such conditions remained unchanged up to the first centuries of modern times (fig. 4).

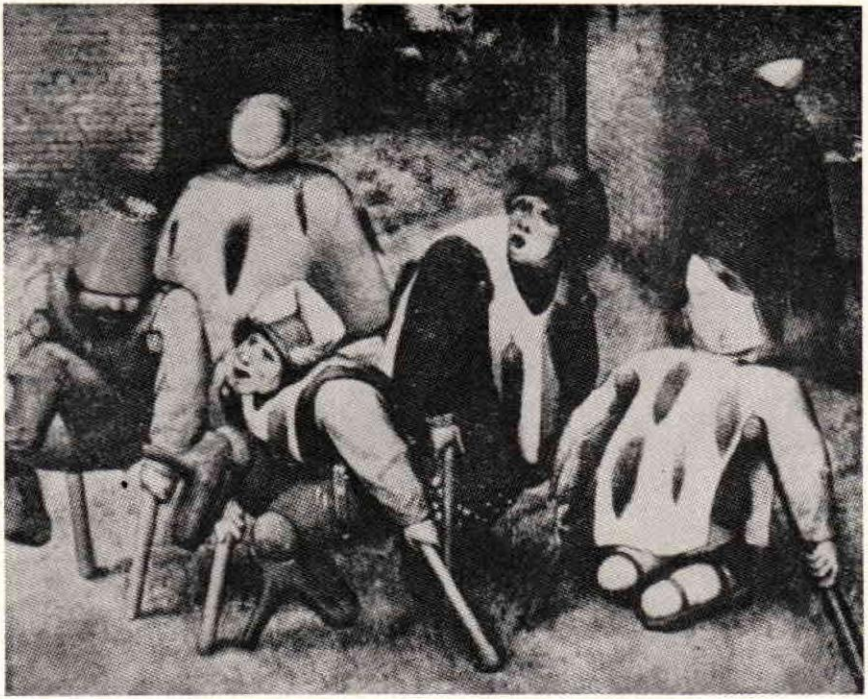

Fig. 4—This sixteenth-century painting by the famous artist, Pieter Breughel, hangs in the Louvre and is known as "The Cripples." It portrays with stark realism a street scene which probably was not an unusual sight in the time the artist lived.

Modern Times (1600 to 1900)

In the sixteenth century, a break-through occurred in the surgical management of the amputee and the fabrication of prostheses. This was achieved mainly because of the brilliant mind and surgical skill of Ambroise Paré. He improved the surgical technic for amputations and re-introduced the ligation of vessels to obtain adequate hemostasis (Celsus, several centuries earlier, had suggested this procedure). Paré recommended preferred sites for amputations, improved the treatment of wounds, and designed prostheses for his patients. He was the first surgeon to work in close collaboration with the tradesman who was the forerunner of the modern-day prosthetist. The first known artisan was an individual known by the name of "le petite Lorrain," an apparently skilled locksmith. Paré's prosthesis (fig. 5) with the movable knee and tarsal section of the foot, knee lock, and other controls, was fabricated in the fashion of armor. It was crude and heavy but "contained many of the essential principles of present day prostheses."[12] Many of his drawings and descriptions are not unlike some of those of prostheses in common usage today. For this reason he is rightly called the founder of "modern principles of amputations."[5]

After Paré and until the end of the eighteenth century, there apparently was no other attempt made to construct an improved above-knee artificial limb. It seems that no great demand for such a limb existed since above-knee amputations were rarely performed, although, with the introduction of Morel's tourniquet (1684), amputations in general were performed more frequently in Europe with a wide scale of indications for them.

In 1696 the Dutch surgeon, Verduin,[13] constructed a below-knee prosthesis with a wooden foot and a copper socket; two lateral steel bars, hinged at the knee joint, reached up to above the middle of the leather thigh-cuff (fig. 6). It took several decades until Verduin's leg received general recognition. With some modifications, it became the most widely used below-knee prosthesis.

Following Verduin other below-knee prostheses were designed by Ravaton (1755), Charles White (1776), Bruenninghausen (1796), Ruehl and others.

The mechanic, Gavin Wilson of Edinburgh, at the end of the eighteenth century, was the first after Paré to attempt to solve the problem of the above-knee prosthesis.[14] His prosthesis was fabricated of hardened leather with a knee joint which could be flexed in sitting but was designed with a stiff knee joint in ambulation. Furthermore, this prosthesis was the first one constructed with what is known today as an "ischial seat."

The author of the book, *"One Leg, the Life and Letters of Henry William Paget, First Marquess of Angelesey* (1768-1854),[15] wrote:

"He wore what was known as a 'clapper leg,' so called because locomotion was accompanied by a clapping sound. In due course, a limbmaker

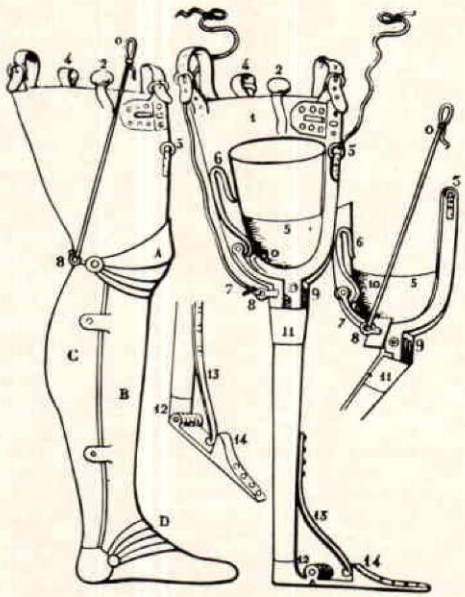

Fig. 5—Artificial leg described by Ambroise Paré in 1561. The sheet metal plates which give the appearance of armor, disguises a peg leg for a thigh amputation. It is fitted with a joint at the knee to permit the wearer to sit on his horse, and a knee lock to make it rigid for walking. Retouched from the Orthopaedic Appliances Atlas.[5] Permission has been obtained from the American Academy of Orthopaedic Surgeons.

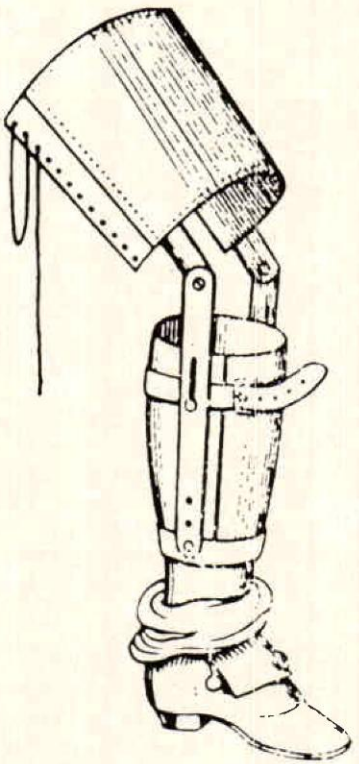

Fig. 6—A Dutch surgeon, Verduin, in 1696, constructed this leg, which somewhat resembles the modern type of below-knee prosthesis. Permission has been obtained from the American Academy of Orthopaedic Surgeons to reproduce this figure from the Orthopaedic Appliances Atlas.[5]

named James Potts of Chelsea, who had invented an artificial leg articulated at the knee, ankle and toe joints, provided him with one of these limbs."

This limb, made in 1816, became known as the "Anglesea leg." It consisted of a wooden socket and shank, a steel knee joint, and a wooden foot with articulation in the metatarsophalangeal joints which permitted dorsiflexion of the distal portion of the foot; artificial tendons ran from the femoral condyles to the heel and from the lower leg to the metatarsophalangeal joints of the foot, facilitating the push off of the foot (fig. 7). A similar limb with an articulated knee joint was designed by Potts for above-knee amputees. The Anglesea leg with some modifications was used in England until the first World War.

At about this period the artificial limb became romanticized in the literature. Thomas Hood (1759-1845) in his *Miss Kilmansegg and Her Precious Leg*, published in 1840 in the New Monthly magazine, [11, 16] concludes his delightful poem about Miss Kilmansegg and the loss of her precious leg with the following selection:

But when it came to fitting the stump
With a proxy limb—then flatly and plump
She spoke in the spirit olden;
She couldn't—she shouldn't— she wouldn't have wood
Nor a leg of cork, if she never stood,
And she swore an oath, or something as good,
The proxy limb should be golden.

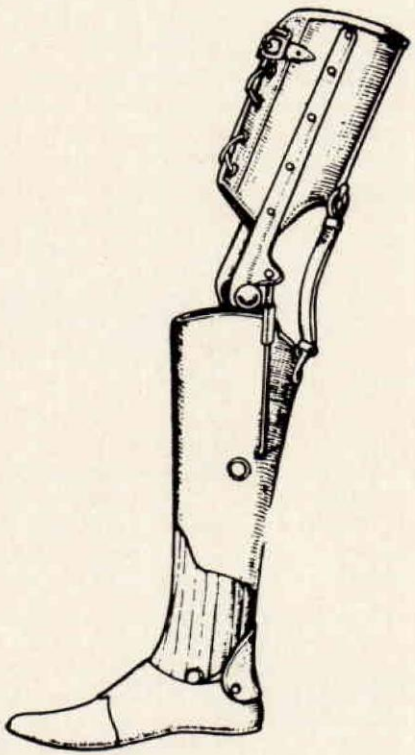

Fig. 7—Later model of the Anglesea leg, originally made in 1816. Permission has been obtained from the American Academy of Orthopaedic Surgeons to reproduce this figure from the Orthopaedic Appliances Atlas.[5]

At the World's Fair in London in 1851 the only artificial limb which received honorable citation was that of Dr. Palmer of Philadelphia. It is said that its construction was a modification of the limb designed by William Selpho of New York which, in turn, represented an improvement of the Anglesea leg. The Palmer leg, made of wood, had movable knee and ankle joints, the coordinated action of which was controlled by artificial tendons; the toe joint depended on spring action. This prothesis, after numerous modifications, became widely used in America, England, and France up to the time of World War I and was known as the "American Leg." The introduction by Marks of the use of rawhide for covering the outer surface of the wooden parts improved the strength and durability of the limb.

The more widely accepted use of general anesthesia, in about the middle of the nineteenth century, together with the experiences gained during the

Civil War in the United States and the increased use of Lister's procedures exerted tremendous influences on surgery. With the marked improvement in the technic of amputation, more frequent usage was accepted when indicated, whereas, previously, some of these procedures for amputation had been taboo, more or less. Thus, the demand for prostheses increased, augmented by the growing number of civilian industrial accidents. The limbmaker was no longer an especially skilled carpenter or blacksmith; he became a trained prosthetist who worked in shops specializing in the fabrication of artificial limbs. The firm of Marks and Hanger became widely known for its contributions in the improvement of the manufacture of artificial limbs. While others tried to design ankle and foot joints which imitated the natural motion, Marks constructed the rubber foot and Hanger the cordless ankle, using rubber bumpers for control of motion. Neither type allowed lateral motion but they increased the safety and stability of the wearer.

There were physicians in this era other than Palmer and Bly who were interested in prosthetics. Beaufort in France,[4] called by a German author "the undefatigable inventor of inexpensive and practical artificial limbs for the poor," constructed among other limbs a foot with a rocking sole, a modification of which became known as the "Dollinger foot." It was widely used for amputees during World War I. There was Heather Bigg of London who, in 1885, published a textbook entitled *Amputations and Artificial Limbs* which included anatomical studies on alignment of the parts of the prosthesis. There was Hermann of Prague who, in 1868, wrote a treatise, *Mechanism of Gait With an Artificial Leg and a New Construction of an AK and BK Prosthesis;* he also introduced aluminum to replace the steel parts of the prostheses.

The majority of surgeons, however, were quite uninterested in their amputee patients after healing was completed. The limbmaker alone had to assume the responsibility and treat the amputee at his own discretion. There was no rapport between surgeon and limbmaker, the latter often lacking fundamental knowledge of basic anatomy. In 1881 the then well-known German professor, Max Schede,[4] appealed to the medical profession with the following:

"Did our learned forefathers consider it unworthy to descend from the proud loftiness of science into the workshop of the mechanic to give him that aid which can come but from a conscientious physician? We only note the conspicuous fact that in a time when nearly every surgeon considers himself obligated to add new and unnecessary and useless instruments to the armamentarium chirurgicum, only a few consider it worthwhile to devote some afterthoughts to the further fate of the amputee."

The Era of the Twentieth Century

It was not until World War I that Schede's words took fruitful root. In Europe and in the United States special amputee centers were established where surgical and prosthetic care was given the wounded. In these centers the surgeon and limbmaker met at the "bedside" of the patient to discuss optimum sites prior to amputation and the management of the patient immediately after surgery; their joint concern was to select and fabricate the best artificial limb possible to suit his particular needs.

As stated previously, World War I produced the American leg which was improved by use of the solid rubber foot or the articulated "bumper foot," popular in Europe.

The Englishman, Marcel Desoutter, made a fundamental contribution to the suspension method of fabricating an above-knee prosthesis. Up to this period the conventional suspension was the shoulder suspension with its extending effect on the artificial knee. To overcome its disadvantages (discomfort and the unsightly shrugging motion of the shoulder to prevent slipping of the stump from the posthesis), he introduced the concept of pelvic suspension. This ultimately led to today's pelvic band with the single-axis metal hip joint which affords improved stability, although it is somewhat at the expense of freedom of motion of the hip joint. This new type of suspension in turn stimulated improvements of the artificial knee which became freed from the control of the shoulder suspension. The knee joint then became equipped with braking and friction devices. The same Marcel Desoutter introduced in 1912 the first all aluminum lightweight prosthesis. Subsequently, aluminum became the favorite material in England for use in prostheses.

In Germany the Schede-Haberman leg[4] with its "physiological" knee joint promised improved stability and a "soft and natural gait." Professor Putti at the Institute Rizzoli in Bologna conducted scientific investigation of materials suitable for use in the construction of prostheses. Putti, deeply interested in historic artificial limbs, had old Italian tombs of known amputees opened to study the construction and mechanism of prostheses of the past.

In France Broca and Ducroquet[17] reported their experiences gained in connection with the Federation des Mutiles where hundreds of disabled men had been examined and fitted with prostheses during World War I. They stressed two essential principles of efficient prosthetics, namely: (1) Accurate imitation of the external form of the natural limb is incompatible with good function, and (2) to give, for aesthetic reasons, every patient the same appliance, would only lead to disappointment of physician, limbmaker and amputee.

In the years after World War I numerous mechanical devices for improvement of artificial legs were invented, patented, and tried out in Europe as well as in the United States. Some proved to be of value; many were ephemeral products.

World War II exerted a tremendous stimulus to the further development of prosthetic devices.[5] Thomas and Haddan,[12] a surgeon and prosthetist, respectively, demonstrated improved end results of team co-operation. In 1945, under the auspices of the United States government, the National Academy of Sciences of the United States started a prosthetic research program on a broad basis. The Armed Forces, the Veterans Administration, The National Institutes of Health, the Vocational Rehabilitation Administration, universities, and private industry were called upon to participate in this program. Today more than 20 laboratories co-operate in this "Artificial Limb Program," with bioengineers, physicists, physicians, prosthetists, physiotherapists, and mechanics on their staffs. The Committee on Prosthetic Research and Development acts as the co-ordinating link in this great enterprise of prosthetic research, development, and teaching.

As a result of these closely knit joint ventures, new and more satisfactory prostheses have evolved, some of which will be discussed in the following paragraphs.

In 1863 the United States Patent Office granted a patent to Dubois Parmelee of New York for a new type of prosthesis which he described as follows:

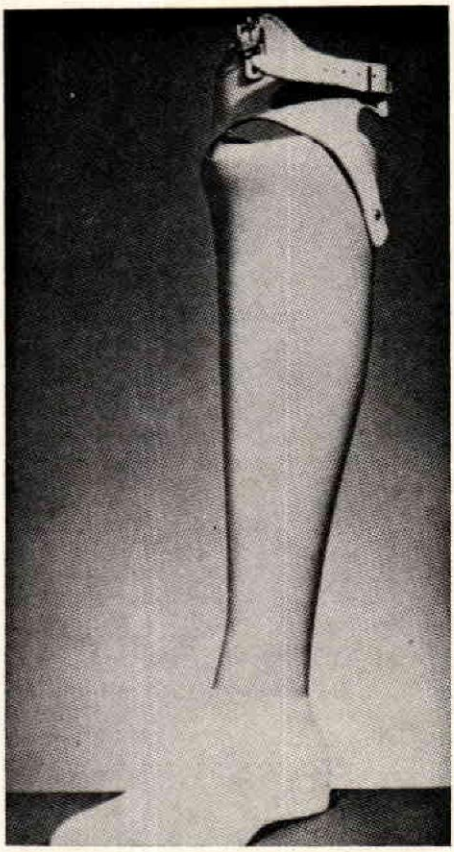

Fig. 8—Patellar tendon bearing below-knee prosthesis with SACH foot. (Reproduced with permission from Prosthetics Research Program, Veterans Administration, Washington, D.C.)

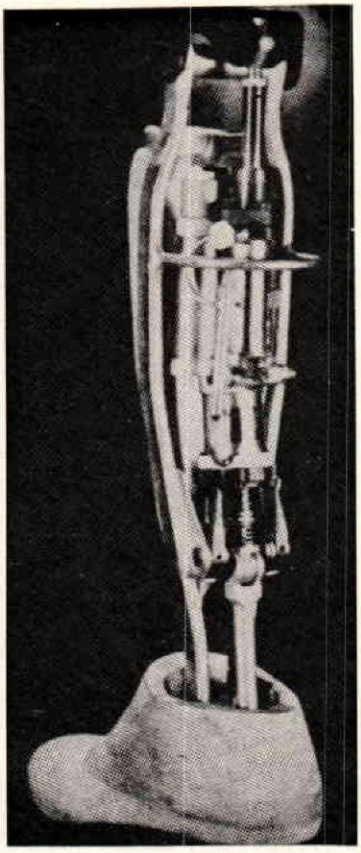

Fig. 9—The Hydra Cadence Leg without cosmetic cover. (Reproduced with permission from the Prosthetics Research Program, Veterans Administration, Washington, D.C.)

"The first part of this invention relates to the bucket socket of artificial legs or arms intended to receive the stump; it consists of the fastening of such bucket to the stump by means of atmospheric pressure in such a manner that the straps usually employed for this purpose can be dispensed with and at the same time a perfect fit of the bucket is obtained."[5]

After some trial usage in Canada, England, and California the idea of the suction socket was given up. About seventy years later the method was reactivated in Germany and developed to such a degree of efficiency that it produced what became the standard socket for above-knee prosthesis in Germany during World War II. After the end of the war the suction socket was tested and adopted in the United States. Definite indications and contraindictions for its use were established and substantial modifications were made such as the quadrilateral shape of the socket and improved valves. When a suction socket is contraindicated now the conventional socket is used; it is designed in the same quadrilateral shape. In the last few years, after extensive laboratory and clinical testing, the "Total Contact Socket" has been adopted in American prosthetics as an improvement of the suction socket, to be used when skin irritation, ulcers, and edema develop in the area of the stump exposed to the "vacuum" part of the regular suction socket.

The old Verduin leg of 1696 has served as a mother pattern for the modern below-knee prosthesis up to the present time. The conventional below-knee artificial limb consists of a wooden socket and shank (made of aluminum or other preferred material), attached by a hinged metal bar to a leather thigh corset. This type of below-knee prosthesis has been simplified recently by the development of the PTB (patellar-tendon bearing) prosthesis (fig. 8), which omits the hinged metal side bars and the leather thigh corset. The socket, made of plastic laminate and lined with a thin layer of sponge rubber and leather, accommodates the stump up to the region below the patella where contact is made along the patella tendon and tibial condyles. A cuff or strap fastens the leg to the distal thigh above the patella.

Of further interest and improvement has been the introduction of hydraulic and pneumatic devices (fig. 9).

The old-type Syme prosthesis has been replaced by the less bulky and better fitting Canadian type or similarly constructed American type.

The introduction of the Canadian prosthesis for hip disarticulation and hemipelvectomy seems to have solved the problem of effectively fitting amputees who need this type of prosthesis (fig. 10).

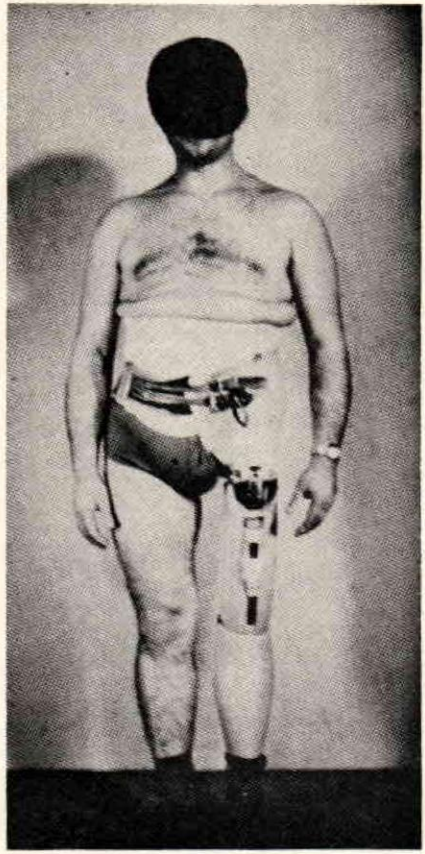

Fig. 10—Modified abdominal support and Canadian type hip disarticulation prosthesis for amputee after hemipelvectomy. (Reproduced with permission from Prosthetics Research Program, Veterans Administration, Washington, D.C.)

SUMMARY

The peg leg, the invention of the earliest times of history, has proved its usefulness through the centuries up to the present. The development of modern prosthetics was initiated by the ingenious surgeon, Ambroise Paré. The advent of general anesthesia, antisepsis, asepsis, and modern technology stimulated the further development of prosthetics. World War I and World War II as well as the increase of industrial casualties led to the creation of scientific prosthetics. Nationwide and worldwide organizations are today engaged in furthering prosthetic research and rehabilitation of the amputee. The goal of the prosthetic science is the somatic, psychic, and economic rehabilitation of the amputee. The lost limb is not the primary concern of prosthetists; rather, it is the limbless human being, to whose complete rehabilitation modern prosthetics devote their efforts.

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