Original Article:

Towards Techno-human: A Brief History of Artificial Limbs and Organs

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Abstract:

Background: The 'techno-human', which is the result of combining the human body with a machine or device which we have been made familiar with through science fiction movies, is frequently perceived as a distant and futuristic concept. However, when we examine history, we realize that the techno-human is not a phenomenon unique to the future or the present, but rather has a long and significant history dating all the way back to antiquity. ***Objective:*** This study aims to detail the progression of techno-humans from antiquity to the present, by focusing on the historical development of artificial limbs and organs. ***Methods:*** In this study, a literature review ranging from the earliest examples of the human body meeting technology to today's complex and functional artificial limb and organ technologies was conducted, and the information gathered through retrospective review of primary and secondary sources was evaluated. ***Results and Discussion:*** It is seen that people who lost their limbs as a result of amputation or disease have been using prostheses, albeit primitive, since ancient times. Today, advances in technology such as CAD/CAM and 3D printer technologies enable the production of prostheses from lighter materials and at a faster rate. Contrary to the long history of artificial limbs dating to antiquity, the development of artificial organs only began recently, during the 20th century. Artificial limbs and organs, with the use of more advanced technology, have the potential to be utilized for human enhancement in the future. ***Conclusion:***While prostheses, implants, and complexly built artificial organs make the human body more technological and less biological, a new stage in the biography of the techno-human in which 'enhancement' rather than 'treatment' is at the forefront pushes the limits.

Keywords: Amputation, artificial limb, prosthesis, artificial organ, techno-human, medical history.

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Introduction

The 'techno-human', which is the result of combining the human body with a machine or device which we have been made familiar with through science fiction movies, is frequently perceived as a distant and futuristic concept. However, when we examine history, we realize that the techno-human is not a phenomenon unique to the future or the present, but rather has a long and significant history dating all the way back to antiquity. The technology that people used in ancient times to make their environment suitable for them was occasionally utilized to help people who had lost their limbs for various reasons adapt themselves to nature. Today, in addition to limbs, artificial versions of some organs are also designed for people whose organs cannot function as a result of certain diseases or accidents. Mechanical or bioelectronic devices replace parts of the human body, and these technologies blur the boundaries between organic and non-organic. While prostheses, implants, and complexly built artificial organs make the human body more technological and less biological, a new chapter in the biography of the techno-human is beginning. Because, while these technologies were initially intended for medical purposes, it may be possible to design and develop limbs and organs that are more functional than normal in the future. The journey of the techno-human, which began with wooden prostheses in antiquity and continues today with prostheses and artificial organs, including complex and more functional electronic systems, is examined in this study.

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Methods

In this study, a literature review ranging from the earliest examples of the human body meeting technology to today's complex and functional artificial limb and organ technologies was conducted. Using databases such as *Pubmed*, *Google Scholar* and *Science-Direct*, the keywords *amputation*, *artificial limb*, *prosthesis*, *prosthetics*, *artificial organ*, *history,* and *medical history* were searched separately and in various combinations. And the information gathered through retrospective review of primary and secondary sources was evaluated. The history of neuroprosthetics is the subject of a separate study and is beyond the scope of this one.

Results and Discussion

Techno-human in Antiquity: From Amputation to Artificial Limbs

Some people were born congenitally limbless, while others lost their limbs through amputation due to illness, accident, infection, wild animal attack, or war. In ancient societies, amputation was not only a medical procedure to keep individuals alive, but also a method of punishment for crimes such as theft and adultery, or a method with a social dimension, performed as a ritual.The famous Indian epic Mahabharata, for example, mentions a young man named Ekalavya who sacrificed his right thumb at the request of his teacher, who taught him archery techniques.[1] A study examining pathological examples from early Egypt shows that a forearm may have been deliberately amputated around 2000 BC.[2] Again, a study conducted by Dupras *et al.*[3] also shows that amputation was used as a medical treatment method in Ancient Egypt around the same period.

However, when several important Egyptian medical papyri were examined, no information about amputation or prosthetics could be obtained.[4] Despite not being preserved in full text over time, the Edwin Smith Papyrus, a papyrus that provides surgical information, is crucial in that it is one of the first written medical artifacts that has been found and evidences that Egyptians had a scientific approach to surgery and operation. Although body wounds head to toe were systematically described in the papyrus, abdominal and lower extremities and the amputation of limbs were not addressed.[5-6] The Ebers Papyrus, on the other hand, focused only on minor surgeries, such as 'What to do when an alligator bites?' as well as the preparation of drugs to be wrapped around wounds, the treatment of burn wounds, and so on.[7]

When it comes to Greek medicine, amputation procedures are found in the text *On the Joints* in the *Corpus Hippocraticum*, which is thought to have been written by students following Hippocratic tradition.[8] Although it is known that Hippocrates is far from scalpels and knives, and that Hippocratic medicine was not particularly fond of surgery, we also see that the limbs were amputated when necessary in Greek medicine.

When looking at these texts, considering it was written in the 4th and 5th centuries BC, it is seen that it was safe to completely cut fingers or toes from their joints, and normal treatment was sufficient. It was also stated that if the amputation does not occur in the joint but in the bone, these cases are not dangerous and heal easier than the former.[8]

"Cases of complete amputation of fingers or toes at the joints are usually without danger –unless a patient suffers from collapse at the time of injury– and ordinary treatment will suffice for such wounds. Again, where the amputation is not at a joint, but somewhere in the line of the bones, these cases also are not dangerous, and heal even more readily than the former; and if the projection of fractured ringer-bones is not at a joint, reduction is without danger in these cases also..."

In another part of the same text, it is stated that sometimes people collapse from pain during amputation and such collapse brings sudden death to many people.[8] Given that anesthetic and antiseptic methods will be developed thousands of years later, it is not difficult to come up with the speculation that early amputations resulted in the death of a significant number of people.

"... For if the patient suffers pain during the amputation, and the limb happens to be not yet dead at the place where it is cut away, there is great risk of collapse from pain; and collapses of this kind have brought sudden death to many."

In the comprehensive encyclopedia *De Medicina*, written by the famous Roman encyclopedia writer Celcus in the 1st century BC, the Latin word 'serrula' was used to refer to an 'amputation saw' and amputation is described in detail as a dangerous procedure that is sometimes necessary -in cases where it is the only remedy- although patients often die from blood loss or syncope.[9]

"When gangrene has developed between the nails and in the armpits or groins, and if medicaments have failed to cure it, the limb, as I have stated elsewhere, must be amputated. But even that involves very great risk; for patients often die under the operation, either from loss of blood or syncope. It does not matter, however, whether the remedy is safe enough, since it is the only one. Therefore, between the sound and the diseased part, the flesh is to be cut through with a scalpel down to the bone, but this must not be done actually over a joint, and it is better that some of the sound part should be cut away than that any of the diseased part should be left behind…"

Again, in volume VIII of *De Medicina*, it is stated that amputation is usually required when bones such as the thigh or upper arm are fractured and the fragments are separated from another, as they are prone to severe infection and greater gangrene, as well as wounds.[9]

"The case is rather more grave, when there is a flesh wound as well as a fracture, and especially when muscles of the thigh and upper arm are involved: for they are liable to more severe inflammations and also have a greater tendency to gangrene. And in the case of the thigh-bone, if the fragments have separated from one another, amputation is generally necessary…"

As can be understood from Celcus's statements, it is conceivable to say that amputation was used as a medical treatment method in Roman medicine, just like in Ancient Egyptian and Ancient Greek medicine.

The replacement of amputated limbs with their technological versions, otherwise known as prostheses, also dates back to ancient times. Prostheses are artificial parts that are used to restore the functionality of a lost limb in people who have had their limbs amputated due to a disease or who have lost limbs in accidents, wars, or punishment. Although it is primarily intended for functional purposes, the importance people place on their appearance as well as the need to feel 'complete' psychologically and spiritually have also led to the use of prostheses.[10]

One of the oldest scriptures of the Indian tradition, the *Rig Veda*, mentions a queen who lost a leg during a battle in the 7000s BC and was able to return to war thanks to an iron prosthetic limb.[11] Some drawings and ceramics from antiquity also indicate that prostheses may have been used in early times. The Greek historian Heredotus also stated that the oldest prosthesis (484 BC) belonged to an Iranian soldier named Hegesistratus. According to him, in order to escape the captivity of his enemies, this soldier cut off his foot and replaced it with a wooden version.[12-13] Similarly, some documented sources claim that Roman General Marcus Sergius was wounded during the war around the 3rd century BC, and after his hand was amputated, he replaced it with a prosthesis and returned to the battlefield with an 'iron hand.'[10] However, such information is likely to be fiction, and their scientific reliability is controversial.

Looking at the scientific studies on prosthetics, it is claimed that the oldest known intravital limb prosthesis is a wooden female thumb found in Ancient Egypt.This work, published in the *Lancet* in 2000, shows that the right big toe of a woman, who is estimated to have lived in the 11th-8th centuries BC, was amputated while the woman was alive, and that a carefully designed wooden prosthesis replaced the amputated finger.[14] Although other examples of wooden prostheses from the Ancient Egyptian period have been found in research, studies suggest that these prostheses were implanted during mummification, or at the very least after death, to prepare people for the afterlife by ensuring the integrity of their physical body.[15]

An archaeological excavation in 1884 found a bronze-encrusted wooden lower leg prosthesis belonging to a Roman person, dated circa 300 BC. There is no information about the functional or esthetic purpose of this prosthesis.[16,17]According to the results of an archaeological-palaeopathological study conducted in China, published in 2013, a wooden leg prosthesis belonging to a man in the age range of 50-65 years was found. It is stated that this prosthesis, which is estimated to date back to the 3rd-2nd centuries BC, is the oldest leg prosthesis that has been functionally used while the person was alive, as in the example of the big toe prosthesis in Egypt.[18]

Although it is known that amputation was widely performed in antiquity, studies of prostheses from later periods which is supported by archaeological or historical evidence are quite limited. The artificial foot, found in Switzerland, made of wood with iron nails belonging to a man estimated to have lived between the 5th and 7th centuries AD, the 6th century prosthetic foot found in a tomb in

Southern Austria, or the adult male foot prosthesis from the 7th-8th centuries found in Germany, can all be given as an example to these studies.[16]

Techno-human from Middle Ages to Modern Times

Although it is known that ligatures were used to stop bleeding and heal wounds in the period of Galen, these practices were abandoned in the West throughout the Middle Ages, and surgeons resorted to unbearably painful methods such as using hot oil to stop bleeding. During this period, also dubbed the dark age of the West, just as in other branches of science, not much development in the field of surgery and prosthesis was made. Many of the prostheses were used to conceal missing limbs as a result of war or to look esthetically pleasing. Although it is known that knights sometimes used prosthetic hands to hold their shields in battles, there was no focus on the functionality of prostheses during these periods. With the exception of those who lost limbs in war, only the rich could use hook-shaped hand prostheses or wooden legs.[19]

During the 10th and 11th centuries, important works in the field of medicine were produced in the Islamic civilization which was in its golden age, and suggestions on how to stop bleeding and wound treatment were put forward based on the surgical topics that were discussed in the works of Abū Bakr al-Rāzī's *"Al-Havifi't Tıbb"* or Ibn Sina's *"The Canon of Medicine"*. [20] In the last volumes of *Al-Tasrif* written by Al-Zahrawi, also known as the 'prince of surgeons', surgical methods and instruments were included, and it was recommended to amputate extremities that had become gangrenous in order to save the patient.[1]

"Sometimes the extremities become gangrenous. you must cut off that limb as far as the disease has spread, so that the patient may escape death or greater affliction, greater than the loss of the limb."

However, there is no evidence in the literature that these works contain information about prosthesis or artificial limbs.

With the reintroduction of ligature in surgery to the West by Ambroise Paré, a sixteenth-century French army surgeon, it can be said that a new era in amputation surgery and prosthetics had begun. In addition to introducing modern amputation surgical procedures to the medical world, Paré designed complex prostheses for amputees without lower and upper extremities. His prosthetic studies, in which he sometimes used adjustable joints, have provided the first accurate understanding of functionality in prostheses.[12,19] In addition to Paré's modern surgical methods, surgeons became more confident in performing amputations with the discovery of Morel's bandage in 1674, which resulted in the amputation of limbs becoming the most common surgical practice.[12] As a natural result of these processes, interest in artificial limbs has also increased.

One of the most important factors in the development of both the history of medicine and the history of prosthetics is wars. Prostheses that emphasize functionality have begun to be designed to give soldiers and later civilian amputees a greater chance of living a better life after gunshot wounds sustained in war.[21] For example, the prosthesis designed by John Hanger in the late 1800s was designed after the American Civil War, which left many soldiers as amputees, and elevated the prosthetic design to a modern level.[22] With the use of ether and chloroform as general anesthetics in 1846-47 and the development of antiseptic procedures by Joseph Lister in 1867, surgical operations have become more comfortable and can be performed for longer periods, and thus successful amputations have been achieved. In addition to such important medical inventions, as the American civil War did, the First and Second World Wars resulted in many amputees, leading to the design of more functional prostheses by accelerating prosthesis technology.

Prosthetics technology, which gained momentum after the World Wars, has continued its development with the introduction of computer-aided design and manufacturing systems (CAD/CAM) in this field since the 1970s and it is now possible to make prostheses using lighter and more flexible materials. Moreover, microprocessors, software, and sensors have enabled the adaptation of prostheses to intelligent robotic systems,[23] and the spread of 3D printer technology has also paved the way for the production of personalized, faster, and cost-effective prostheses. 3D printers can meet the ongoing need for new protheses created especially by the ongoing development of amputee children, which affects the psychosocial development of the children.[22] Where with the current state of prosthetic technology, artificial

limbs give amputees the ability of mobility once again, and sometimes, as in the example of South African paralympic athlete Oscar Pistorius, enable them to gain features that can exceed normal human abilities.[24] This issue not only sparks discussions in the context of disability and human enhancement, but it also raises the possibility that healthy people may give up their own limbs in favor of mechanical bodies in the future given that artificial limbs can be designed to be far more flexible or functional.

Techno-human with Artificial Organs

Despite the history of artificial limbs from antiquity to the present day, artificial organ technologies are the subject of a much more recent era. Since the development and clinical application of these technological devices, which are placed directly inside the body, require a very complex process, we were able to witness successful artificial organs and implants for the first time in the 20th century. Due to the aging population, insufficient organ donations, and the huge number of patients on organ waiting lists, the number of natural organs that can be transplanted is quite limited. As a result, there is a greater interest in artificial organs and the development of artificial organ technology. However, today, most artificial organs are not able to fully perform the functions of natural organs that have been lost, most often they serve as an important tool to keep the patient alive until the transplantation.

Since most organs in the human body have a rather complex structure, scientists from various disciplines and geographies around the world have made significant contributions to the successful development of these technologies. With new advancements in fields such as nanotechnology, artificial intelligence, bioinformatics, genetic engineering, tissue engineering, and stem cell studies, artificial organ technology is expected to advance to a much higher level in the coming future.[25]

Looking at the history of artificial organ studies, it can be said that the most significant development in the modern period was the initial application of dialysis as an artificial kidney for renal support in 1943 by Willem Kolff, who is considered the father of artificial organ technology.[26] Despite the fact that an artificial kidney is life-saving, people who have dysfunctional kidneys need to utilize a dialysis machine due to the unavailability of a technology that can be implanted in humans. The artificial kidney's life-saving feature has prompted the question, "Why can't we artificially produce other organs?" and with the support of IBM, John Gibbon successfully used a heart-lung machine in an open heart surgery of an 18-year-old woman for the first time in 1953.[27] Human-made organs that could be implanted in humans had not yet been developed in those years, but today's successful heart surgeries would not have been possible without the heart and lung machine designed by Dr. Gibbon.

In the years when the definition of brain death was not yet present in the literature, implanting a human-made heart would undoubtedly be a big step towards creating the 'techno-human' as one of the greatest achievements in the history of medicine. It would take a little longer in those days to implant a technical, human-made device in place of the heart, which was considered the center of the human body as an extremely crucial organ for human survival.

Many experiments were conducted on animals, and one of these experiments in 1957 resulted in a dog surviving for 1.5 hours with an implanted artificial heart.[28] In 1969, a human subject received an artificial heart implant for the first time, and the patient died 64 hours later. Twelve years later, an artificial heart implanted into a second human subject could only support the patient for 39 hours before the patient succumbed shortly after the transplant. Dr. William DeVries implanted an artificial heart into a 61-year-old patient named Barney Clark in 1982, who survived for 112 days afterwards. In an operation in 1984, a patient who had an artificial heart implanted survived for 620 days with artificial heart support, providing the longest survival success through this process.[29]

The first pacemaker was implanted into a 77-year-old male patient by Dr. William Chardack in 1960,[30] while surgeon John Charnley performed the first hip replacement surgery in 1962,[25] and the first mechanical heart valve was approved by the FDA in 1965.[31] Although a fully closed-circuit artificial pancreas system has yet to be fully developed, the MiniMed 670G hybrid closed-circuit system, also known as an "artificial pancreas", designed for patients with Type 1 diabetes, was approved by the FDA in 2016. This device has an insulin pump, a subcutaneously implanted sensor that measures blood sugar, and a computer chip that uses data to optimize insulin delivery.[32]

Until date, it has not been possible to develop an artificial liver as it is a highly complex organ with many vital functions such as plasma and protein synthesis, detoxification, glycogen storage, and hormone production. However, since the 1990s, artificial liver support devices have been developed to provide support until a liver transplantation method is developed. While it has been demonstrated that these support systems can at least fulfil the liver's detoxifying function, the complex synthesis and regulation activities of the liver pose complications with these devices.[33]

A study on the 'artificial womb' published in the *Nature* in 2017 brings to mind Aldous Huxley's classic dystopia *Brave New World*, in which people are created in incubation centers and have no notion of parents at all. In this study, an artificial womb called a 'bio bag' was designed by researchers to enable premature babies to complete their development healthily and there was a successful result obtained by testing this bio bag on premature lambs.[34] With this technology developed to keep premature babies alive for the time being, it might be possible to implant embryos obtained with *in vitro* fertilization (IVF) directly into artificial wombs in the future, and with this new reproductive revolution, the connection between techno-humans with technology will begin before they are born.

Another very promising development in artificial organs and organ transplantation and donation is three-dimensional bioprinting technology. Three-dimensional (3D) printer technology, also known as rapid prototyping, is a technology developed in the 1980s that uses three-dimensional designs and processes the raw material horizontally and vertically layer by layer to create three-dimensional geometry.Three-dimensional bioprinters working with the same mechanism were developed in the 2000s, and biological materials such as cells or stem cell mixtures are used as bio-inks. Each movement of the bioprinter leaves a bio-ink particle to create layers and living tissue is obtained at the end of the process.[35,36] According to some scientists, thanks to bioprinters, it will be possible to print out organs such as the heart and liver when needed in the future, just as we print an article, and thus the number of people waiting for organ transplants will decrease. However, given the highly complex structures of organs and the specialized functions of each, it would be overly optimistic to expect bioprinters to solve organ failure in the near future.

Table 1. Milestones in the biography of techno-human

Amputation procedures	c2000 BC (Ancient Egypt)[1,2] c4-5th century BC, On Joints, Corpus Hippocraticum[8] c1st century BC, De Medicina[9]
Big toe prosthesis	c11-8th century BC (Ancient Egypt)[14]
Wooden leg	c300 BC[16,17]
Developments in amputation surgery and functional prosthesis	16th century - AmbroiseParé
The discovery of anesthesia, antisepsis and asepsis methods	19th century
The Hanger limb	Late 19th century – by John Hanger
Computer-aided design (CAD) / computer-aided manufacturing (CAM) era in prosthetics	1970s
Artificial kidney (dialysis)	1943 – by William Kolff[26]
Heart-lung machine	1953 – by John Gibbon[27]
Artificial Heart	1982 – by William DeVries[29]
Pacemaker	1960 – by William Chardack[30]
Artificial hip	1962 – by John Charnley[25]
Artificial uterus (experiment in premature lambs)	2017 – by Patridge et al.[34]
3D Bioprinters	21st century

The Future of Techno-human

Artificial limb and organ technology has been one of the most significant advances in healthcare throughout history, and it seems that it will continue to maintain this importance in the future. With the developments in the field of neuroprosthetics, artificial limbs will become much more functional, while artificial organ technology will provide an alternative to the problem of organ failure. Advancements in disciplines such as genetics, neuroscience, nanotechnology, robotics, artificial intelligence, and tissue engineering will shape the future of artificial limbs and organs.[25] Organs can be designed using biological materials like people's own stem cells using 3D printer technology, which will reduce the probability of encountering problems such as organ rejection. However, despite notable achievements in artificial organ technologies, there are still serious

problems that require solutions, and there is a need for multidisciplinary studies in this field.

Artificial limb technology, which has a longer history than artificial organs, currently produces lighter, more flexible, or more durable prostheses than in the past. In fact, as in the case of Oscar Pistorius, it is already possible to design prostheses that can provide functions beyond human capabilities in amputees.[24] People with disabilities are not only able to gain the ability to move again but can also gain super abilities thanks to technology. Furthermore, these prostheses can be customized to win specific sports competitions or to perform more optimally in specific jobs. These issues have been discussed in the disability and enhancement literature in recent years.

However, an ethically challenging issue is the possibility of triggering an era in which healthy people give up their own limbs for artificial ones that perform much better than regular ones, opting for mechanical rather than biological limbs. Although this situation may seem quite radical and futuristic for the moment, some individuals who identify themselves as cyborgs or transhumans state that, when safer operations become possible, they will be able to have their limbs amputated and replaced with more technologically advanced prostheses.[37]

In short, while techno-humanity until present has been compulsory for medical reasons, voluntary techno-humanity may arise in the future. However, in such a scenario, we have to seek answers to moral questions such as: Who will and will not have access to these superior technologies?, How will unfair competition affect our sense of justice?, Whether we will still be the same person when technology is implanted in our bodies?, Whether our bodies are machines that we can repair as we wish?, and Whether techno-humans who have become more technological and less biological are still considered human?.Furthermore, since current regulations focus on implantable medical devices, it is obvious that new regulations for implantable enhancing devices will be required.

Conclusion

This work details the journey of techno-humans from antiquity to the present, by focusing on the historical development of artificial limbs and organs. A literature search was conducted, beginning with the first examples of the human body meeting technology and progressing to today's complex and functional artificial limb and organ technologies, and the information obtained through a retrospective review of primary and secondary sources was evaluated. It is seen that people who lost their limbs as a result of amputation or disease have been using prostheses, albeit primitive, since ancient times. The name that made these prostheses more functional was Ambroise Paré. In addition to introducing modern amputation surgery procedures to the medical world, the prostheses that were designed by Paré provided the first correct understanding of functionality in prostheses. Today, advances in technology such as CAD/CAM and 3D printer technologies enable the production of prostheses from lighter materials and at a faster rate. Contrary to the long history of artificial limbs dating to antiquity, the development of artificial organs only began recently, during the 20th century. Although it cannot be implanted into humans, artificial organ technology that began with the development of artificial kidneys, i.e., dialysis machines, continues to advance today with technological devices such as the artificial heart, pacemaker, heart valve, and artificial womb which is tested in premature lambs. Artificial limbs and organs, with the use of more advanced technology, have the potential to be utilized for human enhancement in the future. Because in retrospect, many of the technologies that exist today were originally designed for therapeutic purposes and then used to enhance the functions of healthy people. This leads us to believe that healthy people may desire mechanical bodies and give up their own limbs. However, at this point, regulations will be needed to decide whether these technological devices that change human ontology should be used for enhancement purposes in healthy people.

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References

1. Kirkup J. A History of Limb Amputation. London: Springer, 2007, pp.36–55.
2. Brothwell DR, Moller-Christensen V. A possible case of amputation, dated to c2000 BC. Man 1963;192–4.
3. Dupras TL, Williams LJ, De Meyer M, Peeters C, Depraetere D, Vanthuyne B, Willems H. Evidence of amputation as medical treatment in ancient Egypt. Int. J. Osteoarch2010;20:405–23.
4. Nunn JF. Ancient Egyptian Medicine. London: British Museum Press, 1996.
5. The Edwin Smith Surgical Papyrus. Published in Facsimile and Hieroglyphic Transliteration with Translation and Commentary in Two Volumes by JH Breasted, The University of Chicago Oriental Institute Publications, 1930.
6. Hughes JT. The Edwin Smith Surgical Papyrus: an analysis of the first case reports of spinal cord injuries. Spinal Cord 1988;26(2):71–82.
7. The Papyrus Ebers. Translated from the German Version by Cyril P. Bryan with an Introduction by Professor G. Elliot Smith, London: Geoffrey Bles. 1930, pp.67–77.
8. Hippocrates. On Wounds in the Head, In the Surgery, On Fractures, On Joints, Instruments of Reduction. Volume III, With an English Translation by ET Withington, The Loeb Classical Library, Massachusetts: Harvard University Press, 1959, pp.361–363.
9. Celcus. De Medicina III, With an English Translation by WG Spencer, In Three Volumes, The Loeb Classical Library, London: William Heinemann Ltd., 1961, pp. 469, 549.
10. Thurston AJ. Paré and prosthetics: the early history of artificial limbs. ANZ Journal of Surgery 2007;77(12):1114–9.
11. McNamee S. History of Amputation: From the Past to the Present. In Murphy, D. P. (Ed.). Fundamentals of amputation care and prosthetics. New York: Demos Medical Publishing, 2014, p. 2.
12. Wilson AB. Limb prosthetics – 1970. Artificial Limbs 1970;14(1):1–52.
13. Wilson AB. History of amputation surgery and prosthetics. In: Bowker HK, Michael JW (Eds.), Atlas of Limb Prosthetics: Surgical, Prosthetic, and Rehabiliation Principles. American Academy of Orthopedic Surgeons, Rosemont, IL, 1992.
14. Nerlich AG, Zink A, Szeimies U, & Hagedorn HG. Ancient Egyptian prosthesis of the big toe. The Lancet 2000;356(9248):2176–9.
15. Finch J. The ancient origins of prosthetic medicine. The Lancet 2011;377(9765):548–9.
16. Binder M, Eitler J, Deutschmann J, Ladstätter S, Glaser F, & Fiedler D. Prosthetics in antiquity—An early medieval wearer of a foot prosthesis (6th century AD) from Hemmaberg/Austria. International Journal of Paleopathology 2016;12:29–40.
17. Bliquez LJ. Prosthetics in classical antiquity: Greek, Etruscan, and Roman prosthetics. De Gruyter, 2016, pp. 2640–77.
18. Li X, Wagner M, Wu X, Tarasov P, Zhang Y, Schmidt A, ... &Gresky J. Archaeological and palaeopathological study on the third/second century BC grave from Turfan, China: Individual health history and regional implications. Quaternary International 2013;290:335–43.
19. Norton KM. A Brief History of Prosthetics. InMotion 2007;17(7):11–3.
20. Atıcı T, Atıcı E, Şahin N. Geçmişten günümüze cerrahi dikiş ipliklerinin tarihsel gelişimi [The historical development of surgical suture materials from past to present]. Turkish Journal of Surgery 2010;26(4):233–42.
21. Gailey RS, Clemens SM. Sacrifice, science, and support: A history of modern prosthetics. In Full Stride New York: Springer, 2017, pp. 35–54.
22. Manero A, Smith P, Sparkman J, Dombrowski M, Courbin D, Kester A, ... & Chi A. Implementation of 3D printing technology in the field of prosthetics: Past, present, and future. International Journal of Environmental Research and Public Health 2019;16(9):1641.
23. LeMoyne R. Advances for Prosthetic Technology: From Historical Perspective to Current Status to Future Application. Tokyo, Japan: Springer, 2016.
24. Camporesi S. Oscar Pistorius, enhancement and post-humans. Journal of Medical Ethics 2008;34(9):639.
25. Malchesky PS. Artificial organs and vanishing boundaries. Artificial Organs 2001;25(2):75–88.
26. Kolff WJ. First clinical experience with the artificial kidney. Annals of Internal Medicine 1965;62(3):608–19.
27. Hill JD. John H. Gibbon, Jr. Part I. The development of the first successful heart-lung machine. The Annals of Thoracic Surgery 1982;34(3):337–41.
28. Khan S, Jehangir W. Evolution of artificial hearts: an overview and history. Cardiology Research 2014;5(5):121–5.
29. Gerosa G, Scuri S, Iop L, Torregrossa G. Present and future perspectives on total artificial hearts. Annals of Cardiothoracic Surgery 2014;3(6):595–602.

30. Beck H, Boden WE, Patibandla S, Kireyev D, Gupta V, Campagna F, ... & Marine JE. 50th Anniversary of the first successful permanent pacemaker implantation in the United States: historical review and future directions. The American Journal of Cardiology 2010;106(6):810–8.
31. Akins CW. Results with mechanical cardiac valvular prostheses. The Annals of Thoracic Surgery 1995;60(6):1836–44.
32. Saunders A, Messer LH, Forlenza GP. MiniMed 670G hybrid closed loop artificial pancreas system for the treatment of type 1 diabetes mellitus: overview of its safety and efficacy. Expert Review of Medical Devices 2019;16(10):845–53.
33. Martínez JJG, Bendjelid K. Artificial liver support systems: what is new over the last decade?. Annals of Intensive Care 2018;8(1):1–14.
34. Partridge EA, Davey MG, Hornick MA, McGovern PE, Mejaddam AY, Vrecenak JD, ... & Flake AW. An extra-uterine system to physiologically support the extreme premature lamb. Nature Communications 2017;8(1):1–16.
35. Zhang B, Luo Y, Ma L, Gao L, Li Y, Xue Q, ... & Cui Z. 3D bioprinting: an emerging technology full of opportunities and challenges. Bio-design and Manufacturing 2018;1(1):2–13.
36. Thayer P, Martinez H, Gatenholm E. History and Trends of 3D Bioprinting. In: Crook J. (eds) 3D Bioprinting. Methods in Molecular Biology, vol 2140. New York: Humana, 2020.
37. O'Connel M. Makine Olmak [To Be a Machine], tr. Karakaş Ö. İstanbul: Domingo, 2017. p.159.