Chapter

Impact of Medical Advancement: Prostheses

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Abstract

This chapter shall provide a brief introduction to the prostheses and their development in the current advance technological era. The prosthesis design, control, and architecture completely changed with the change in the amputation level. The transradial amputee stump design, electronics, battery, and circuit placement change significantly with the change of the residual arm of the amputee. This leads to designing the prostheses with the focus of the amputation level and ease of customization. Recent development in the 3D printing and open source prosthetic design leads the user to choose, modify, and print the prostheses with the required sets of functionalities. In this chapter, a brief introduction of the prostheses has been given, starting with the types of prostheses according to the level of amputation and functionality. Then, the state-of-the-art prostheses available commercially and under research will be introduced. Afterward, the 3D printed prostheses are discussed. This chapter will end with the comparison of the medical advancement over the average life of people in general and comparison of the same for countries with low and high per capita income.

Keywords: prostheses, upper limb, lower limb, amputation, myoelectric, 3D printing, state-of-the-art, per capita income

1. Introduction

According to the estimation of the World Health Organization (WHO), 650 million individuals suffer from a disability worldwide. About 80% out of 650 million individuals reside in developing countries [1]. Among 650 million, approximately 3 million suffer from the upper limb amputation and 2.4 million of which live in the developing countries [2]. According to the study conducted in 2016, the population of upper limb amputation is suffering from 16% transhumeral, 12% transradial, 2% forequarter, 3% shoulder disarticulation, 1% elbow disarticulation, 2% wrist disarticulation, 61% transcarpal, and 3% bilateral limb loss [3]. The rehabilitation services to overcome the disability by using prostheses are so uncommon and expensive that only 3% of the amputees in the developing countries have access to them [1].

The prostheses are the artificial devices that improve the quality of life of a disabled person by replacing the missing or lost limb due to congenital disease or trauma or injury [4]. The prostheses may replace the lost or missing limb in terms of appearance, functionality, or both. The prostheses may be classified by the level of amputation and by their functionality (as shown in **Figure 1**) [3, 5–7].

This section will begin with the brief introduction of the types of prostheses due to amputation and functionality. Then, the commercially available prostheses

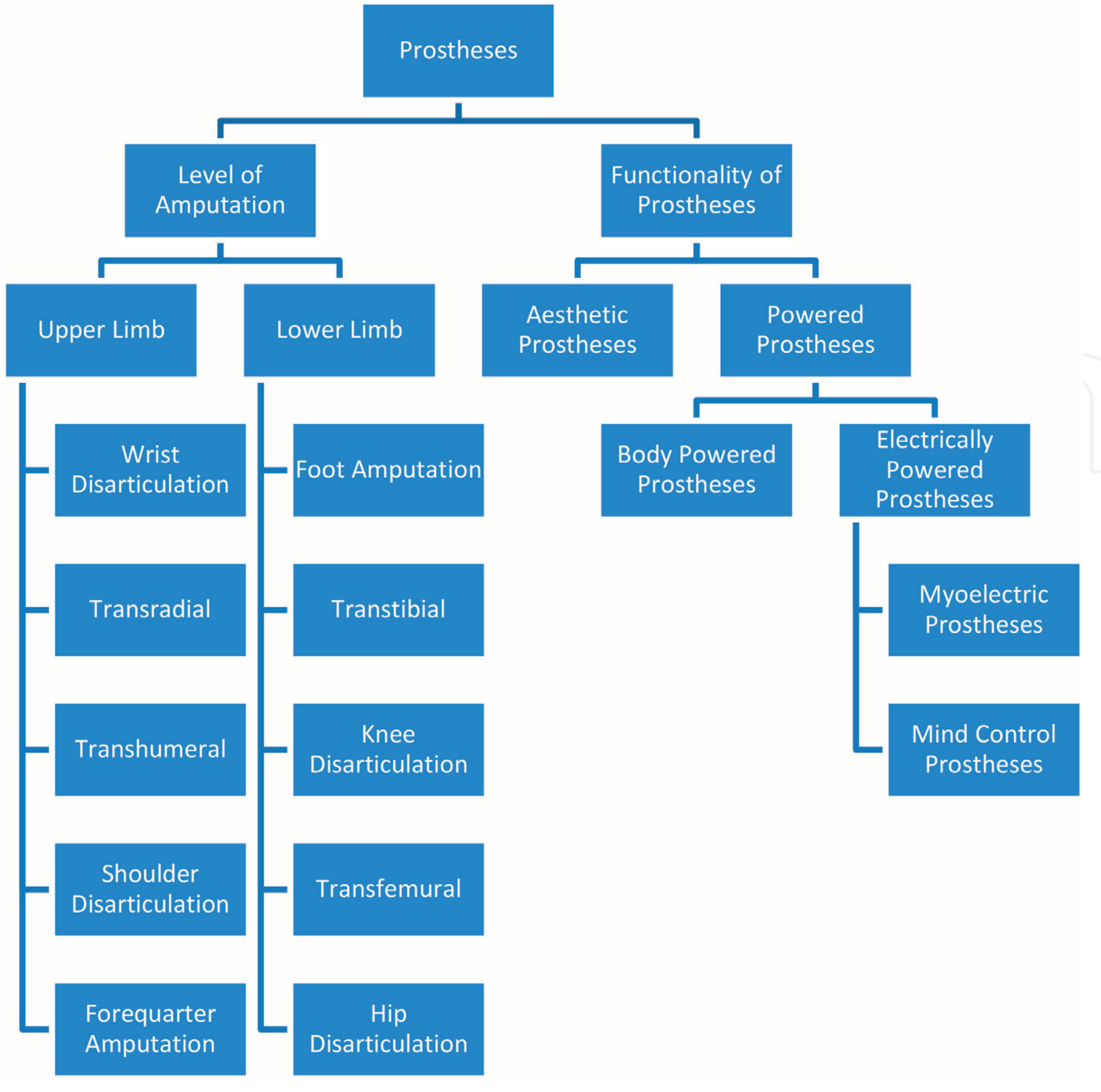

Figure 1.
Classification of prostheses.

are discussed, followed by the state-of-the-art prostheses under development. At the end of this section, 3D printed prostheses are discussed. Finally, the section is concluded with a tabular comparison of all these prostheses highlighting the affordability of the prostheses.

2. Level of amputation

The prosthesis design may change with the change in the amputation level. For example, if a person lost the little finger of the right hand, he/she would only need an esthetic prosthesis. However, if the level of amputation is wrist, then the prosthesis required must have the functionality of all fingers and thumb to grip or hold an object. In this section, the level of amputation for upper and lower limbs is discussed.

2.1 Upper limb prostheses

The upper limb prosthesis design and functionality varies with the level of amputation. There are five main amputation levels for upper limb [3], as shown in **Figure 2**, and each of them is briefly discussed below.

2.1.1 Wrist disarticulation

In wrist disarticulation, the limb is amputated at the level of the wrist without affecting the bones and muscles of the forearm. The amputee is able to perform all the movements of the arm and forearm. Also, the amputee can contract the residual muscles responsible for wrist and finger movements.

2.1.2 Transradial (below elbow)

In transradial amputation, the amputee loses limb anywhere between wrist and elbow. Since the amputee has a portion of forearm, he/she can perform the forearm rotation and also contract the residual muscles responsible for most of the wrist and finger movements.

2.1.3 Transhumeral (above elbow)

In transhumeral amputation, the amputation is between shoulder and elbow. In this type of amputation, the amputee loses all the functionality and muscles of forearm, wrist, and hand. The prosthesis used to assist this amputation must have the elbow, wrist, and hand function in order to enable the amputee to perform activities of daily living (ADL).

2.1.4 Shoulder disarticulation

In shoulder disarticulation, the amputee loses the complete arm with muscles and bones. For this type of amputation, the prosthesis required must have the functionality of complete arm.

2.1.5 Forequarter

In forequarter amputation, the amputee also loses the shoulder blade and collarbone. For this type of amputation, the prosthesis design must have shoulder movements too.

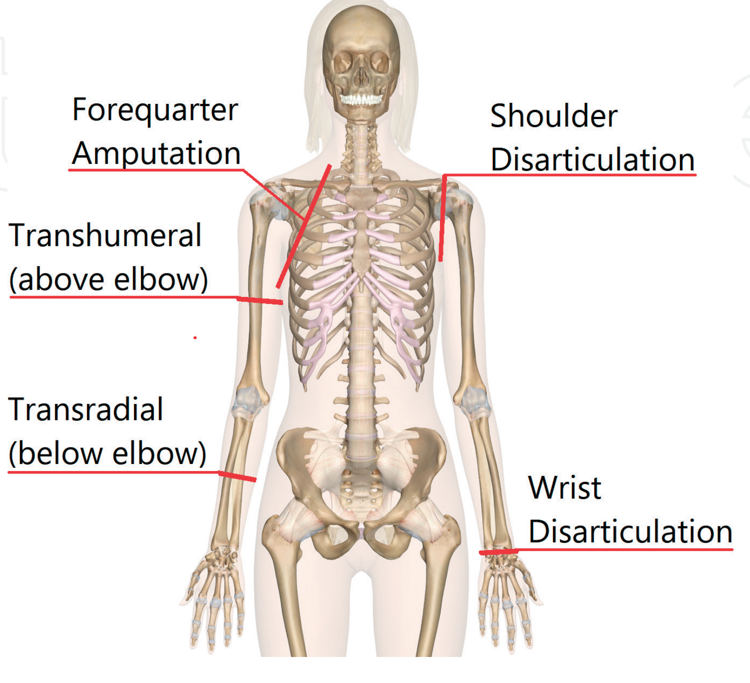

Figure 2.
Level of amputation for upper limb.

2.2 Lower limb prostheses

Similar to the upper limb, lower limb prosthesis design changes with the change in the level of amputation. There are five major levels of amputation at lower limb [8], as shown in **Figure 3**, discussed briefly in this section.

2.2.1 Foot amputation

The foot amputation may occur below the ankle at any part of the foot. In this type of amputation, the amputee only needs a robust esthetic prosthesis to help in walking.

2.2.2 Transtibial (below knee)

In transtibial amputation, the amputee loses limb between the ankle and knee. Most of the time, the residual muscle and bones may be used to drive the prosthesis being used to increase the quality of amputee.

2.2.3 Knee disarticulation

In knee disarticulation, the amputation occurs at the knee joint. In this type of amputation, the amputee loses muscles and bones below knee; however, the muscles responsible for the movements of the leg are intact.

2.2.4 Transfemoral (above knee)

Transfemoral amputation occurs between knee and hip. In this type of amputation, the amputee loses most of the leg muscles and bone. The prosthesis designed for this amputation must include the movements of the knee and ankle.

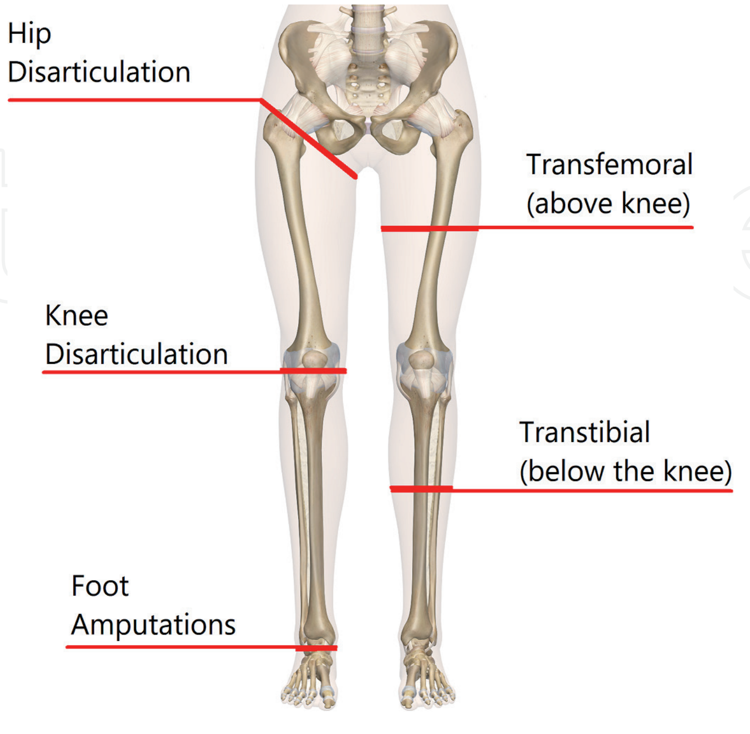

Figure 3.
Level of amputation for lower limb.

2.2.5 Hip disarticulation

In hip disarticulation, the complete leg has been amputated. The amputee may not be able to perform hip movements and may need a fully functional biomimetic leg prosthesis to recover from his/her disability.

3. Esthetic prostheses

Esthetic prostheses aid the disabled person by masking the attention of the public, so that the person may roam around in public without notice. This type of prostheses increases the quality of the subject's personal life by giving them confidence, which is essential for a person to perform the activities of daily living (ADL).

These types of prostheses are passive and have no active component. The main consideration in the design of the cosmetic prostheses is to match the exact skin tone texture, nails, and size of the subject. **Figure 4(a)** shows the finger amputation with a cosmetic prosthesis; after wearing the cosmetic prosthesis, it is quite difficult to notice the amputation of the subject as shown in **Figure 4(b)** [9].

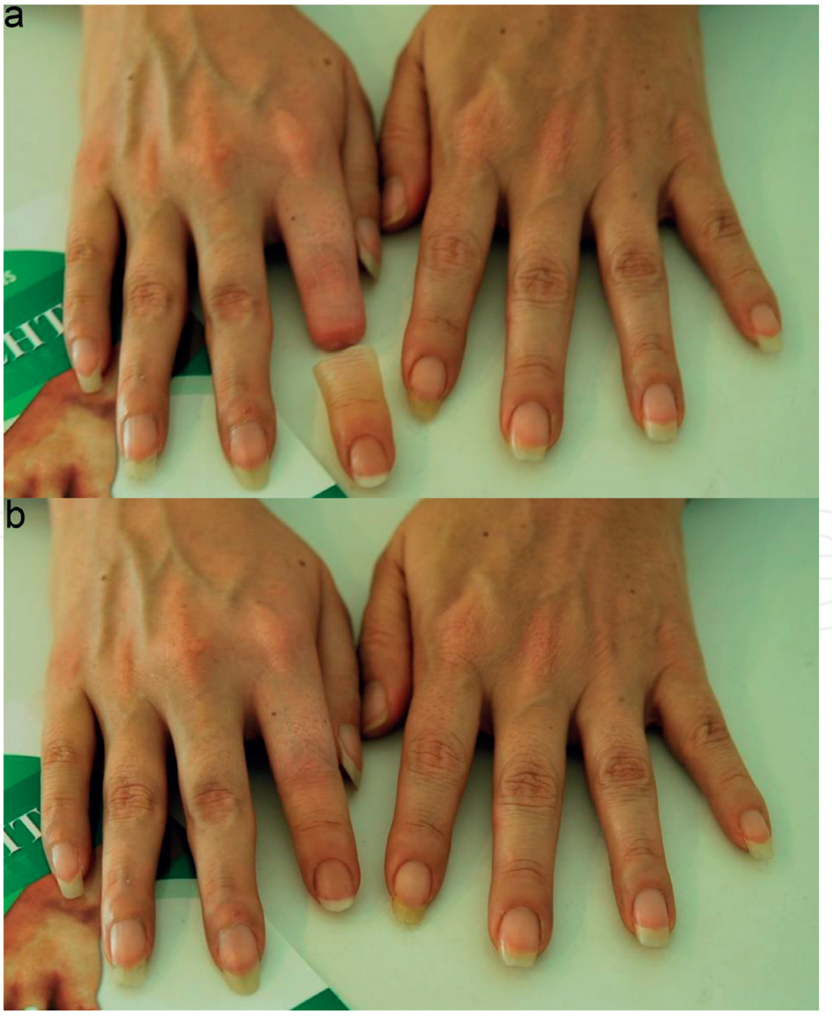

Figure 4.
(a) Amputated finger is shown with the esthetic prosthesis before putting it on and (b) after putting on the esthetic prosthesis.

4. Powered prostheses

The powered prostheses are further divided into the following:

1. Body-powered prostheses

2. Electrically powered prostheses

4.1 Body-powered prostheses

The body-powered prostheses aid the disable person in achieving the functionality lost due to the loss of the limb. The body-powered prostheses also increase the quality of the subject's life by allowing them to perform the activities of daily living (ADL) without the assistance of another human being.

These types of prostheses consist of a tendon or a cable that is attached with the person's body and by pulling that cable, the body-powered prosthesis performs the desired operation [10]. A typical body-powered upper limb prosthesis consists of socket, wrist, control cable, harness, and terminal device as shown in **Figure 5** [11]. The socket is worn on the residual limb, while the harness is worn on the opposite shoulder. To open or close the terminal device, the subject moves his/her shoulder, which results in the movement of harness, which in turn pulls the control cable. Most of the terminal devices in the body-powered prostheses are metal hooks due to the fact that it can withstand high loading and easy to control with a single cable-spring mechanism [12].

4.2 Electrically powered prostheses

Unlike the body-powered prostheses, electrically powered prostheses have actuators to perform the opening and closing of the terminal device. The electrically

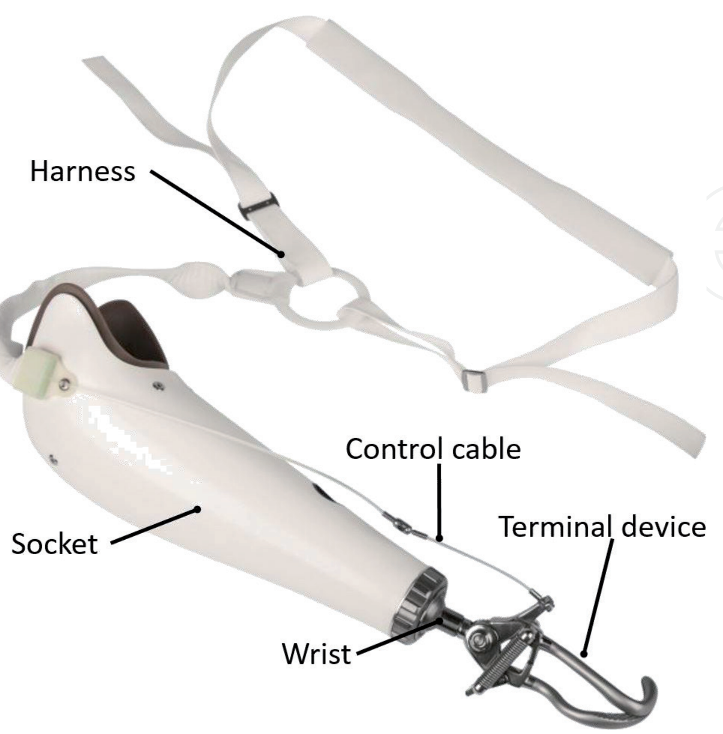

Figure 5.
A typical body-powered upper limb prosthesis.

powered prostheses are more delicate and versatile that enhance or mimic the functionality and appearance of the missing limb of the body.

These types of prostheses usually consist of motors (as an actuator), which is used to drive a mechanism to achieve the movements of the terminal device. These motors receive control signals from the main controller which, after the analysis of the input signal, instructs the motor to achieve desired movements. The electrically powered prostheses are further divided into two types on the bases of the sensing or input signals [6].

4.2.1 Mind-controlled prostheses

The mind-controlled prostheses (also called brain-controlled prostheses) sense the signal from brain, i.e., electroencephalogram (EEG) [13]. The controller extracts the information from the EEG signals after amplification and filtration in the form of features. These features are then used by the pretrained classifier to classify the desired movement of the prostheses.

4.2.2 Myoelectric prostheses

The myoelectric prostheses use the same mechanism as of mind-controlled prostheses. The only difference is the sensing or input signal. In myoelectric prostheses, the signal is sensed from the muscle level instead of the brain. These signals are named as electromyogram (EMG). The EMG signal is usually sensed at the residual muscle of the amputated limb. Therefore, the EMG signals are easy to predict the intentions of the user as compared with the EEG signals. On the other hand, EMG signals are likely to be dissimilar if the position of the sensor is slightly changed or the contraction of the muscle changes [14].

The myoelectric prostheses are the most commonly used prostheses due to onsite EMG signal acquisition and relatively simpler control scheme. The state-of-the-art prostheses [15] for the upper limb will be discussed in this section with the open source 3D printing counter prostheses [16].

4.2.2.1 i-Limb by Touch Bionics, UK

Touch Bionics is one of the top companies in producing prostheses for transradial, wrist disarticulation, and finger amputees. A finger of i-Limb consists of four-bar mechanism driven by a DC motor via worm gears. The latest model i-Limb Quantum weighs 470 g for the ultrasmall model and 630 g for the large model. The four sizes of i-Limb Quantum are shown in **Figure 6** [17].

The new i-Limb Quantum has four different modes of control:

1. Trigger muscle control: this is the default control scheme based on a finite state machine (FSM). The user contracts his/her muscle to control the prosthesis by switching between the states of the FSM.

2. Quick grip app control: the Touch Bionics has introduced a mobile app that can communicate with the i-Limb quantum. This app can be used to control the prostheses and perform the desired operation without sensing the EMG signals from the user's muscle.

3. Intelligent motion gesture control (i-mo): i-mo makes use of the internal sensors to detect the movement of the prostheses and activate a pre-programmed grip on the i-Limb quantum.

4. Grip chips proximity control: this is the unique programmable feature introduced in i-Limb quantum; whenever the user moves his/her hand near the grip chip, the pre-programmed grip will be enabled, allowing the user to quickly use that specific grip.

Although the Touch Bionics has developed a state-of-the-art prosthesis, there is always a room for improvement. Lack of sensory feedback to control the grip limits the performance of the i-Limb. Also, the user must select from the defined grips available with the model and preprogram them. Another factor that limits the amputee to get the i-Limb prostheses is the high price tag [18].

4.2.2.2 Bebionics by Ottobock, Germany

The Ottobock company has a wide variety of prostheses, including both upper limb and lower limb solutions. For consistency, the upper limb hand myoelectric prosthesis of Ottobock, i.e., Bebionics, is discussed in this section.

The Bebionic is available in three sizes and weighs between 390 and 600 g, as shown in **Figure 7** [19]. Each finger of Bebionics is driven by a custom linear actuator through four-bar mechanism. Similar to i-Limb quantum, the Bebionic has an FSM-based control scheme to select among the 14 different grip patterns and hand positions [20].

The structure of the Bebionic is developed using aerospace industry grade aluminum, which gives it a robust structure and is lightweight. The Bebionic suffer from the same constraints as of i-Limb due to unavailability of the sensory feedback, pre-programmed grip pattern, and high cost.

4.2.2.3 Vincent Hand by Vincent Systems GmbH, Germany

The Vincent Systems GmbH is specialized in producing the myoelectric prosthesis hand. Currently, Vincent Evolution 3 has been released with four different sizes, i.e., extra small, small, medium, and large. The extra-small size of Vincent Evolution 3 is the lightest myoelectric prosthesis hand, which weighs only 386 g with the transcarpal wrist [21] (**Figure 8**).

Each finger of Vincent Evolution 3 comprises of a DC motor that drives the four-bar mechanism with the help of worm gear to achieve the flexion-extension of the finger. The control scheme of Vincent Hand is a specialized type of FSM, which senses two EMG signals and can attain five different grip groups directly from the central hand position. Another advantage of the Vincent FSM is that you can jump to the central hand position from any grip by a long "open" signal. The "open," "close," and "trigger" are customizable and the user may choose any other unique signal instead of co-contraction [22].

Similar to Bebionics and i-Limb, Vincent Evolution 3 lacks the sensory feedback essential to control the grip force. Therefore, Vincent Evolution 3 has preprogrammed grips and fingers are coupled with open/close function.

4.2.2.4 Modular prosthetic limb by John Hopkins Applied physics Lab, USA

The modular prosthetic limb (MPL) is the most advanced prosthesis hand developed by the John Hopkins Applied Physics Lab, USA, under the umbrella of Revolutionizing Prosthetics 2009 (RP 2009) [23]. Unlike the commercially available prostheses, MPL contains motor at each joint of the finger. The MPL has 26 degrees of freedom (DOF) including wrist, elbow, and shoulder movements.

Figure 6.
i-Limb Quantum by Touch Bionics, from left to right: extra small, small, medium, and large.

Figure 7.
The Bebionics V3 by Ottobock, from left to right: small, medium, and large.

The MPL is customizable and can be used for all major upper limb amputation. The overall weight of the MPL is 3.5 kg, and the hand with wrist weighs around 1.32 kg as shown in **Figure 9**.

The MPL is tested on human subjects who underwent targeted muscle reinnervation (TMR) surgery [24]. The TMR surgery is the process of connecting the residual motor nerves of lost muscle into the nearest large muscle, so that, the intentions of moving the lost muscle can be detected. This technique is quite useful for a person who lost a major portion of his/her limb.

The recent development in targeted sensory reinnervation (TSR) technique [25] allows the MPL to send the sensory feedback directly to the nerves of the lost limbs. This is the major limitation of the commercial prostheses that MPL has overcome [26]. In TSR surgery, the residual sensory nerves are connected or reinnervate at the nearest large muscle, so that, the sensory feedback of the prostheses can be sensed via the electrode. The MPL is the most advanced prostheses, and it is not commercially available yet.

4.2.2.5 Vanderbilt hand by Vanderbilt University, USA

The researchers at the Center for Intelligent Mechatronics Lab at Vanderbilt University, USA, have developed a 9 DOF prosthesis hand with 4 degrees of control (DOC). The Vanderbilt hand uses four motors with a tendon-spring mechanism to achieve essential grips to perform ADL. Instead of using a single motor for each finger, Vanderbilt hand uses one motor for the index finger, two motors for thumb, and one motor for remaining three fingers (i.e., middle, ring, and pinky). The adult human hand-sized Vanderbilt hand weighs around 546 g as shown in **Figure 10** [27].

Figure 8.
Vincent evolution 3 by Vincent Systems GmbH.

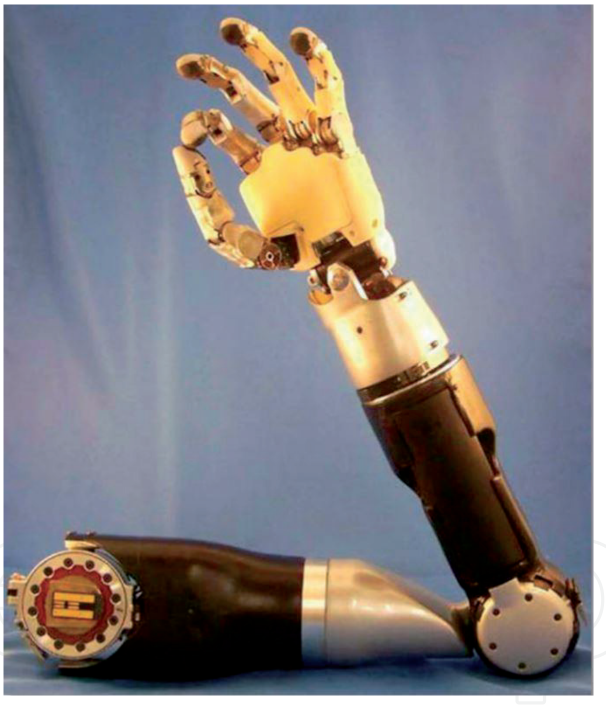

Figure 9.
The modular prosthetic limb by John Hopkins Applied Physics Laboratory, USA.

The FSM of Vanderbilt hands is shown in **Figure 11** [28]. The Vanderbilt hand uses two onsite EMG signals for switching between the states of the machine. The co-contraction will be used for thumb reposition and opposition states. The contraction of the forearm flexor is associated with the upward movement, and contraction of the forearm extensor is associated with the downward movement as shown in the state diagram of the Vanderbilt hand.

The Vanderbilt hand has a unique mechanism and control scheme, but it lacks the functionality and features offered by the MPL. However, the price estimation of the Vanderbilt hand is much lower as compared to the MPL.

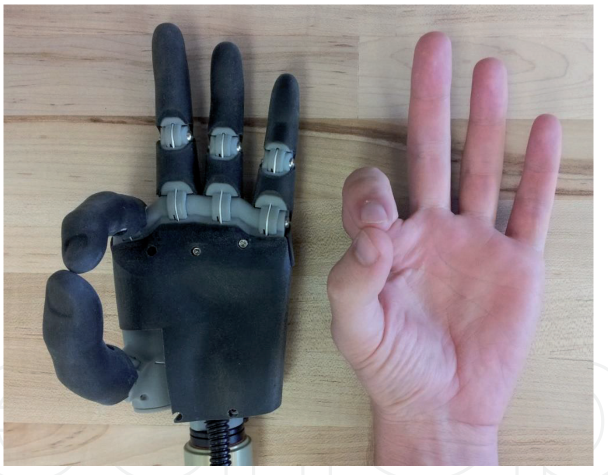

Figure 10.
Third-generation Vanderbilt hand by the Center for Intelligent Mechatronics.

4.2.2.6 Hero Arm by Open Bionics, UK

The Open Bionics has released multiple open source 3D printed prostheses including, Dextrus Hand, Ada Hand, Brunel hand, and Hero Arm. The latest and most advance among all, i.e., the Hero Arm is shown in **Figure 12**. The Hero Arm is designed for a person with transradial amputation. There are two versions of the Hero Arm, one with four-motor-drive mechanism and other with three-motor-drive mechanism. The only difference is that the index and middle fingers are actuated with a single motor in a three-motor version.

The Hero Arm has tendon-flexure-based mechanism for flexion extension of the finger. The control scheme of the Hero Arm consists of FSM that utilizes the contraction of wrist flexion and extension muscles. The trigger signal for switching the grip is open signal, pause, and then holds the open signal for 1 s. Further details of the Hero Arm can be found at [29].

The main advantages of the 3D printed prostheses are low cost, easy modification, and customization. On the other hand, 3D printed prostheses mostly lack the performance and robustness offered by the commercial prostheses [16].

4.2.2.7 Tact Hand by University of Illinois, USA

The Tact Hand is another open source prosthesis hand developed by the researchers at the University of Illinois. Each finger of the Tact Hand is driven by a DC motor through the string. The string is attached with the underactuated four-bar mechanism of the finger. As the motor rotates clockwise, it winds up the string on the spool, creating tension in the string, which in turn flexes the finger. The rubber band attached at the back of the finger assists in the extension of the finger when the motor rotates anticlockwise, releasing the tension in the spring as shown in **Figure 13** [30].

Tact Hand is the cheapest 3D printed prostheses as claimed by the author [30]. However, it lacks the esthetic look, robustness, and durability, offered by most of the commercial prostheses.

Table 1 summarizes the characteristics of the commercial and 3D printed hand prostheses discussed in this section. All the prostheses use an underactuated mechanism to reduce the complexity of the hand design. Underactuated mechanism not only reduces the requirement of the actuators at each joint, but also simplifies the control scheme of the hand, which in turn reduces the weight of the prosthetic

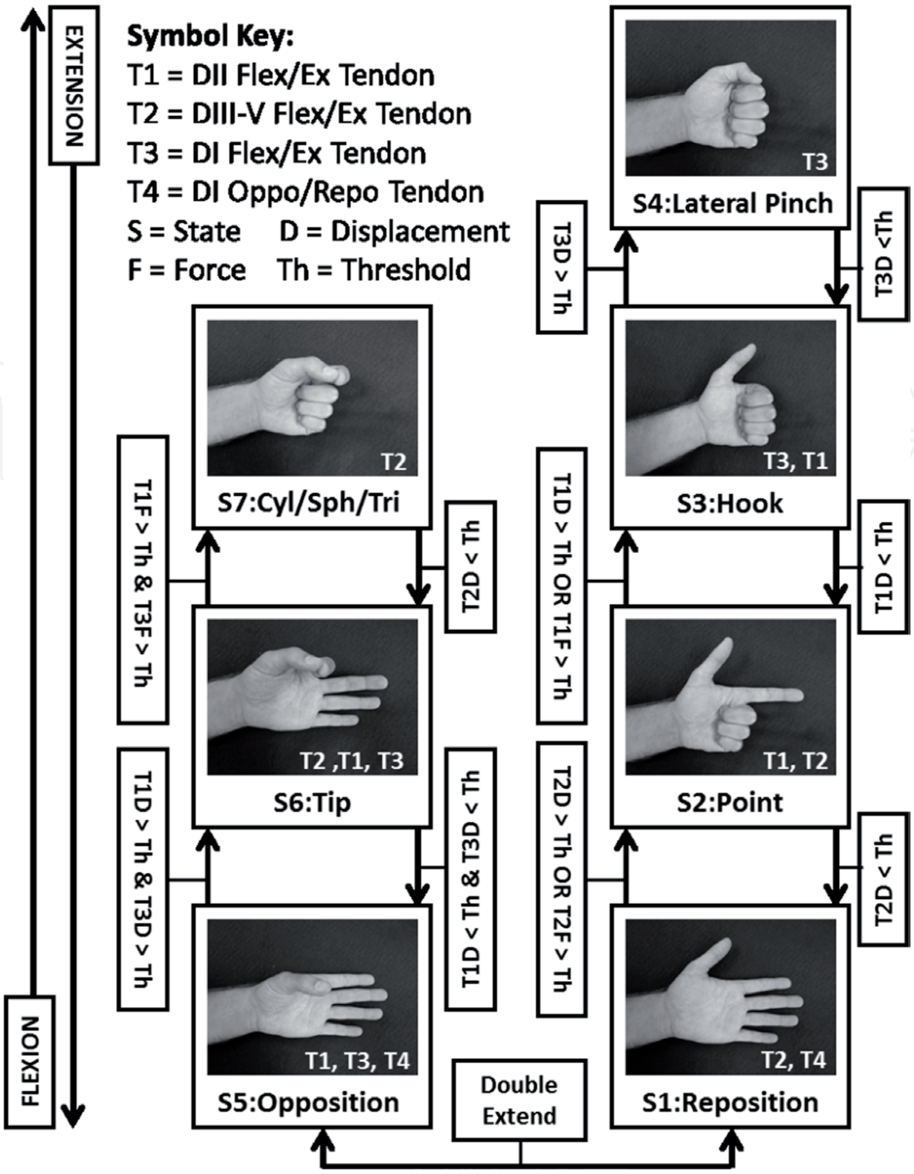

Figure 11.
The finite state machine of the Vanderbilt hands.

Figure 12.
The Hero Arm from Open Bionics.

hand. The Hero Arm is the lightest among the studied prostheses with weight as low as 280 g. The actuator used by the commercial and 3D printing prostheses is DC motor. The most common configuration is to use DC motor with worm gear, lead screw or spool, and tendon to translate the motor rotation into the finger flexion

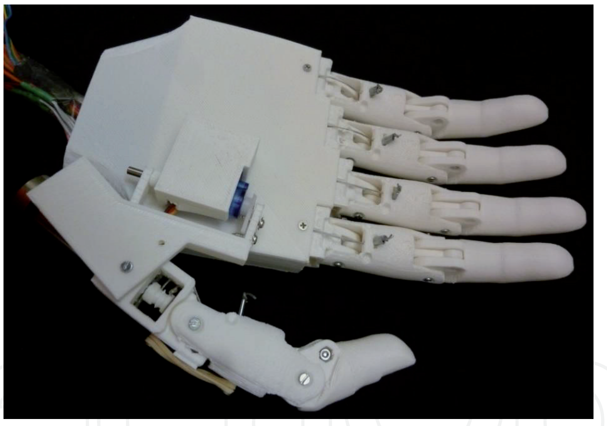

Figure 13.
Tact: an open source hand prosthesis.

Hand/ developer	Mass (g)	Size (L × W × H) (mm)	Joints/ DOF	No. of actuators	Actuation method	Joint coupling	Cost (USD)
Tact/ University of Illinois [30]	350	200 × 98 × 27	11/6	6	DC motor-tendons	Linkage spanning MCP to PIP	250*
Ada V1.1/ Open Bionics [31]	380	215 × 178 × 58	10/5	5	Linear actuator tendons	Tendon linking to MCP to the fingertip	1200
Hero Arm/ Open Bionics [29]	280–346	—	10/3–4	3–4	DC motor tendons	Tendon linking to MCP to the fingertip	—
i-Limb/ Touch Bionics [17]	450–615	180–182 × 75–80 × 35–41	11/6	6	DC motor-worm gear	Tendon linking to MCP to PIP	40,000
Bebionic V2/ RSL Steeper [32]	495–539	190–200 × 84–92 × 50	11/6	5	DC motor-lead screw	Linkage spanning MCP to PIP	35,000
Vincent Hand/ Vincent System [21]	—	—	11/6	6	DC motor-worm gear	Linkage spanning MCP to PIP	—

**Exclusive of motors and circuit cost.*

Table 1.
Characteristic comparison of the prosthesis hand.

extension through the four-bar mechanism. This mechanism is housed inside each finger/thumb with the dimension as close as the dimension of a normal healthy adult for large size prosthesis and relatively smaller for medium and small versions to fit younger subjects.

5. Impact of advancement in prostheses and medical devices

Owing to the technological boom in the twenty-first century, the healthcare industry has also advanced considerably. This progress is evident in all subfields of the healthcare systems. Surgical procedures have moved on from bone drillings to innovations like robotic surgeries, MARVEL (multiangle rear-viewing endoscopic tool), and surgical glasses. The field of biomedical imaging has advanced from x-ray imaging to molecular imaging. Likewise, rehabilitation engineering has moved on from wooden dentures and minimalist crutches to cyborg body prostheses. Pharmaceutics has now headed toward immunotherapy, pharmacogenetic testing, and RNA therapeutics.

It is now a common notion that such rapid advancement in biomedical innovation and research is the leading cause of improvement in the quality of human life and longevity [33]. A number of studies credit this increase in longevity to the pharmaceutical innovations, which has appeared to be the most research-intensive subfield of the healthcare industry. Lichtenberg has proved time and again that pharmaceutical innovations have a profound effect on health and longevity [34–41]. By his research, he cemented the notion that drug innovations decrease mortality rate, hospitalization rate, and improve the general well-being of the society.

Through similar studies, authors have linked the advancement in biomedical innovations to increase the longevity and general betterment of health. For example, Cutler et al. concluded that the ultimate determinant of health is scientific advancement and progress, which in turn is influenced by economic and academic growth [42]. Another study considering the USA population found that the improved health of genial Americans is owing to the advancement in medical technologies [43]. Fuchs also asserts that the primary cause of increased longevity is the fruit of biomedical innovations after the Second World War [44]. Furthermore, the National Institutes of Health (NIH) claims that their research has enabled average Americans to live 30 years more (in 2012) than they did in 1900 [45]. The variables, inspected the most in such studies, are the medical services and procedures prevalent in the population and the availability of drugs and healthcare artifacts for the people. Lichtenberg studied medical care and behavioral risk factors in increasing or decreasing longevity [46].

While the outcome variable that is usually inspected in these studies is longevity, defined as "a long duration of individual life" or "the length of life" by Merriam-Webster Dictionary [47], another important outcome measure is the performance of activities of daily living (ADLs) under the influence of medical interventions.

The effects of biomedical innovations other than pharmaceutical innovations on health and longevity are comparatively more difficult to gauge as there are fewer researches on this topic. As evident from the fact that more than 50% of the research on biomedical innovations is provided by pharmaceutical companies, other researches take a back seat [48].

In most of the cases, the biomedical technological advancements are not easy to gauge. An extensive amount of data is required to measure the availability of healthcare facilities, and even more difficult is to quantify the qualitative nature of the healthcare facilities. In order to solve this problem, a surrogate measure is taken for the biomedical advancement that is the per capita income of the population in consideration. The reliability of gross domestic product (GDP) as an indicator of biomedical advancement is asserted by the World Health Organization (WHO) when it continuously lauds France for its excellent biomedical system, with a GDP per capita of USD 46732 in 2019. Furthermore, the Organization for Economic Co-operation and Development (OECD), in its official magazine, the OECD Observer, reports that a 10% increase in life expectancy makes up an annual 0.3–0.4% growth in the economy, proving that the relationship is bidirectional [49]. On the other hand, the countries with lower GDP have been reported to have a life expectancy rate by a study that analyzed the 213 years' worth of data [50]. One obvious reason for this relationship is the fact that people with less economic stability tend to avoid getting treatment for "minor" health issues such as malaria, flu, and infections. This leads to worsening of the symptoms and eventually casualties that would otherwise have been easily avoided. Also, if there is an endemic in the country like Ebola, tourism and foreign visits tend to dry up, setting back the economy further.

Taking this into consideration, we attempted to find a relationship between the GDP of the countries of the world with the expected life in years for the year 2018. The methodology and results are stated in the following sections.

6. Data acquisition

In order to analyze the annual per capita income of the countries, the World Economic Outlook database of the International Monetary Fund (IMF) was accessed, as provided freely by the Gapminder Foundation [51]. The data from 183 countries for 10 years (2009–2018) were filtered to match the available data of the life expectancy rate of different countries. The estimated lifespans of the countries were retrieved from Geobase [52].

7. Regression analysis

For statistical analysis of the data, we performed regression analysis via IBM SPSS Statistics. The regression analyses are performed taking GDP as the independent variable and life expectancy as the dependent variable. We used the natural logarithm to GDP values. The resultant R^2 values are plotted in **Figure 14**.

It is evident from the graph that over the decade, the GDP alone explains 47–69% of the cross-country variation in life expectancy. This strengthens the notion that GDP per capita income is an important contributor in prolonging the life of the individuals.

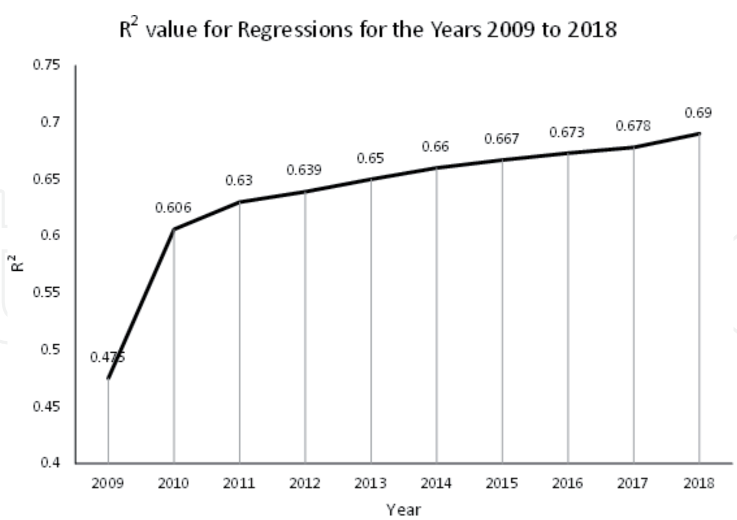

Figure 14.
R^2 values for cross-sectional regressions by years.

8. Quartile mapping

For the sake of ease, we mapped the GDP per capita income and life expectancy for 2018 on the world map, see **Figures 15** and **16**. The mapping is done by first defining four quartiles of each variable. The cutoff points for each quartile are mentioned in the captions of these two figures. By keeping the color coding same for

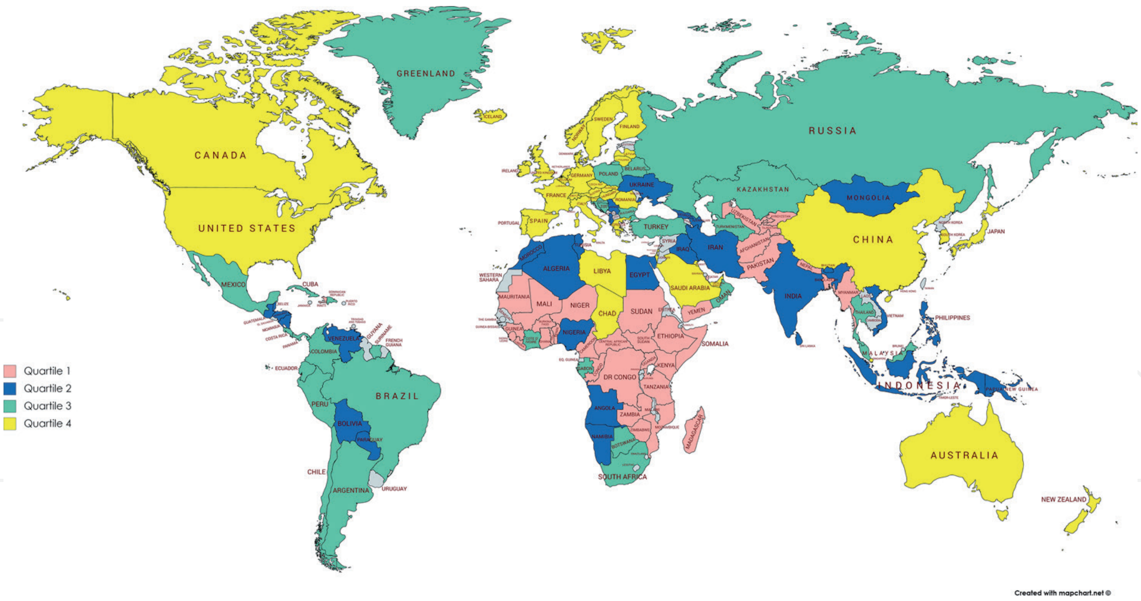

Figure 15.
Mapping of the world according to the four quartiles of the GDP per capita income of the countries. Where quartile 1 is 0 to 2297.5 USD, quartile 2 is 2297.6 to 5874 USD, quartile 3 is 5874.1 to 17617.5 USD, and quartile 4 is 17617.6 to 129,710 USD.

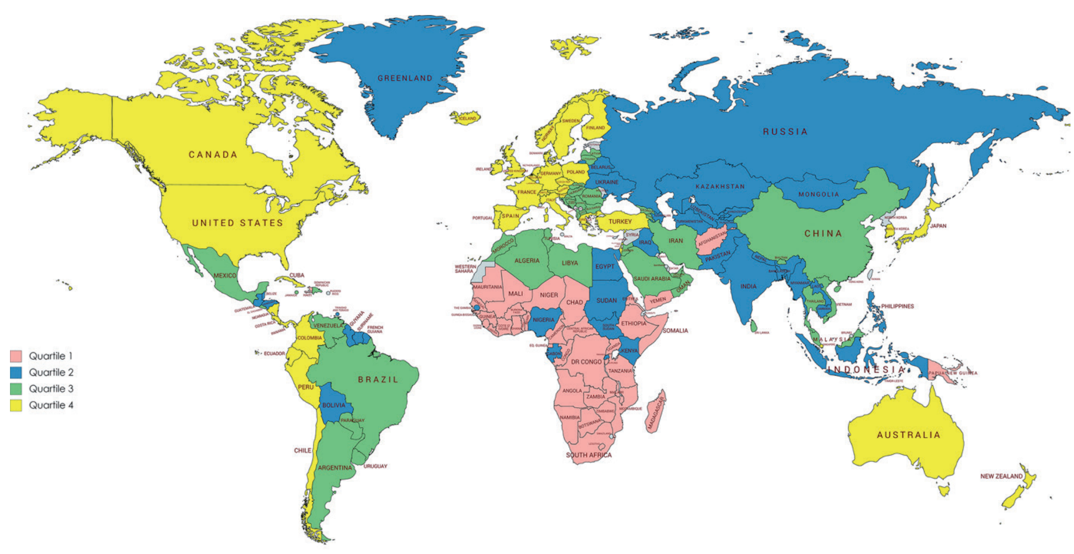

Figure 16.
Mapping of the world according to the four quartiles of the longevity of the countries. Where quartile 1 is 0 to 67.25 years, quartile 2 is 67.3 to 74.15 years, quartile 3 is 74.2 to 78.125 years, and quartile 4 is 78.2 to 84.2 years.

the quartiles of both the variables, we attempted to make the comparison of both variables making it apparent. Quartiles were calculated with the help of the buvilt-in QUARTILE function of MS excel for each of the two data groups. The mapping was performed using the online tool provided by www.mapchart.net.

9. Discussion

In this chapter, we first had an overview of the biomedical innovations of the current times. We then hypothesized that these innovations may have a profound effect on the life expectancy and general health of the population. For this, we revisited the relationship of GDP per capita income to the life expectancy, taking GDP as the surrogate measure of the health facilities provided in the country. Our analyses included data for the past 10 years (2009–2018) for 183 countries.

These analyses targeted one key question: does life expectancy increase with increasing income?

Overall, the analysis of the GDP and life expectancy data of the past 10 years suggests a considerable correlation between income level and life expectancy. It is to be noted that biomedical innovations are more likely to be bought and utilized in countries with stronger economies and higher income levels. Hence, the longevity of their citizens increases. In contrast, the countries with poorer economies are unable to possess the latest biomedical innovation and hence have shorter lifespans and worse quality of life of their citizens.

As a future direction, the research and development (R&D) of biomedical technology should weigh in the factor of affordability and mass production. For this, the researches may opt for cheaper and locally available materials while building the end product. Also, the outsourcing of R&D and production of these technologies will create more employment options in developing countries.

10. Conclusion

The results of our analyses showed that there exists a direct positive relationship between per capita income and the expected years of life across countries. These results support our hypothesis that growth in the biomedical industry and a resultant growth in the healthcare industry will have a positive impact on the economy. This positive impact will improve the longevity of the people.

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