A Review On Current Technological Advancements In Prosthetic Arms

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***Abstract*— Many people now-a-days are facing amputation in their early 20's or 30's, mainly because of lack of awareness regarding quality measures to be used while mining process in coal mines or in various industries. Different types of amputees has to tackle different day-to-day problems. Majority of amputees lies under people who have lost their arms or legs or sometimes both during military conflicts. There are various types of prosthesis available in market across globe for physically challenged people who have lost their arm or legs, to give them a support system for uplifting their spirit.**

Keywords— Prosthesis, artificial technology, amputation.

I. INTRODUCTION

Prosthetic arm is an artificial technology to give back a sense of completeness to amputees who have lost their hope of being able to work 'normal' again. A lost upper or lower limb may cause physical, mental and emotional breakdown. To overcome or reduce such consequences, many innovators have recently developed technologies like prosthesis by which amputees can regain their lost spirit. Different amputations require different prosthesis. For example, upper limb prosthesis will include the prosthetic arm. Prosthetic arms or legs help amputees in carrying out their day-to-day life activities or manage their work accordingly. Different technologies like mechanical switches, various sensors, automations, etc. are majorly used in manufacturing prosthetic limbs.

II. TYPES OF PROSTHETIC ARMS

1. Inali Prosthetic Hand:

Inali foundation is an organization well-known for their prosthetic arms. Key concept behind their arms is Mechatronics. The word Mechatronics is a fusion of mechanical and electronics technology. They provide switch based prosthetic arms, usually powered by rechargeable batteries, along with an adapter. The average cost of their hand goes around Rs.13,000 to Rs.50,000 only. The material used for manufacturing the outer portion of the prosthetic arm is made up of fabricated material (easy to adapt by amputees).The gloves are made up of Silicon. All the hands are customized according to the patient's medical requirement and all the casting measurements are taken. The main functioning of their hand includes opening and closing of the prosthetic arm, ultimately helping patients or amputees in carrying out their daily life activities [2], [3] .

Fig.1. Inali Prosthetic Hand (Image courtesy: inalifoundation.com)

2. Body Powered Prosthetic Hand:

Body-powered prosthetic arms offer an effective solution for individuals with shoulder disarticulation. This prosthesis typically connects to the user's body via straps or cables, enabling them to move their upper arm, shoulder, and chest to extend and retract the hand or hook [1]. The materials used to create these devices can vary, with 3D printed plastic, aluminum, steel, and titanium all being suitable for construction. Rubber lining is also often employed, as it provides a better grip. These advanced prosthetics rely on harnesses that are connected to the body and transfer movement to the cable system, allowing for the opening and closing of a hook or hand. Additionally, they are relatively lightweight when compared to other types of prostheses. Furthermore, these prostheses are relatively

affordable when compared to other types of robotic prostheses.

Overall, body-powered prosthetic arms offer a great solution for those with shoulder disarticulation. They provide users with an impressive range of motion and reliable performance for many years. The components of the body-powered prosthesis are:

- A strap and a cable
- A wrist unit
- A terminal device i.e., a hook or a hand
- A socket
- Shoulder disarticulation prosthesis that contain an elbow and a shoulder [1]

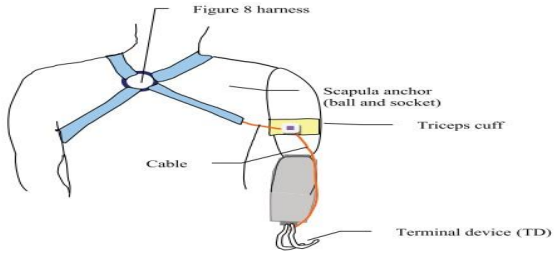


Fig.2. Body Powered Upper limb Prosthesis Simulator. Source: Adapted from [1]

The body-powered arms typically use a Bowden strap system to convert the shoulder joint's flexion and abduction movements into mechanical signals for the prosthesis [1]. This enables the user to control and operate a mechanical terminal device, such as a mechanical gripper, with ease. To be able to use a body-powered prosthesis comfortably, the user must wear a harness attached to the Bowden cable with a spring or hinge at the shoulder joint. The mechanical gripper is then connected to the Bowden cable and reinforced with an adjustable cable tensioner that ensures reliable operation [1]. The cost of a body-powered upper limb prosthesis ranges from Rs.5 lakh to Rs.7 lakh, depending on the mode of control. Overall, the combination of body- powered prostheses and mechanical grippers provides users with an efficient and effective way to perform daily activities. The harness also helps to ensure that no force is lost or wasted during body motion and maximizes the performance of the mechanical gripper [1].

Fig.3. Body Powered Prosthetic Arm (Image courtesy: onesmileonearm.wordpress.com)

3. Myoelectric Prosthetic Hand:

Myoelectric based mechanism prosthetic hands are basically based on the signals generated by our surface muscles. EMG based prosthesis is a wide innovation in the field of prosthetic arms. The myoelectric signals are basically electrical impulse generated from the relaxation and contractions of surface muscles [4]. These signals are basically captured using electrodes that are placed on the muscles of the amputee. Strong signals can generate high controlled motion of the prosthetic hand. Myoelectric hands typically cost between Rs.70,000 to Rs.3.5 lakhs. With gradual training, the amputees can use this myoelectric based prosthetic arm with ease [4].

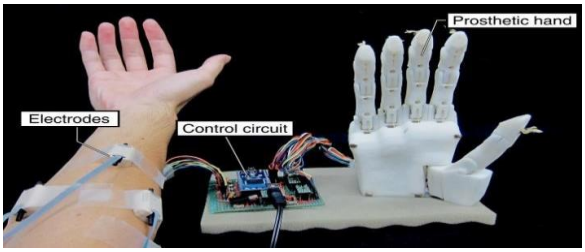


Fig.4. Myoelectric Prosthetic Hand (Image courtesy:https://www.science.org/doi/10.1126/scirobotics.aaw6339)

4. Be-Bionic Prosthetic hand (RSL Steeper,Inc.):

The Be-bionic hand is designed by RSL Steeper that provides multi-articulated hand functionality to amputee. It has fourteen selectable grip patterns and distinctive features that give it unrivaled adaptability, functionality and performance [5], [6]. Each finger of the hand is powered by separate motors, which gives the user a natural coordinated grip and movement that is controlled by dynamic microprocessors. The Be-bionic hand is designed to be comfortable and easy to use, with its motors positioned to enhance weight distribution. This makes it feel much lighter than other prosthetic hands, allowing for improved dexterity and ease of control. The motors also keep track of the position of each finger, providing precise and accurate control over movements. The hand will cost between Rs. 18 lakh and Rs.26 lakh. It has been designed so that users can have an easy-to-use and comfortable experience with this innovative device.

Furthermore, the Be-bionic hand can be customized easily with various interchangeable parts, allowing users to tailor the device to their own unique needs. All these features make the RSL Steeper Smart Hand a unique tool that enables people with disabilities to regain their independence [5], [6].

Fig.5. Be-bionic (RSL Steeper) hand structure (Image courtesy: Ottobock)

5. i-Limb Hand from Touch Bionics:

The i-Limb is a bionic arm for amputees that offers a revolutionary new level of control and comfort. It is a revolutionary device that uses sensors to provide people the ability to control their prosthetic hand through muscle impulses. The user can have full control of their robotic hand and can grasp balls and other objects with great accuracy. This state-of-the-art prosthesis also offers a very

life-like high resolution silicone cosmetic option that allows amputees to have a more natural look and feel. The i-Limb access provides many benefits compared to traditional myoelectric hands. It was designed with comfort in mind and comes with a custom painted glove. The Prices for the Access model of the i-Limb start at around Rs. 32 lakh and go up to more than Rs. 40 lakh for the Quantum variant. The glove provides additional comfort, as it takes into account the user's unique needs and requirements, ensuring a comfortable and secure fit.

The i-Limb also has multiple grip patterns, allowing it to be used in a wide range of settings. With its many features and benefits, the i-Limb is revolutionizing the way prosthetics are used by giving arm amputees greater freedom and independence [7].

Fig.6. i-Limb Hand (Image courtesy: Touch bionics)

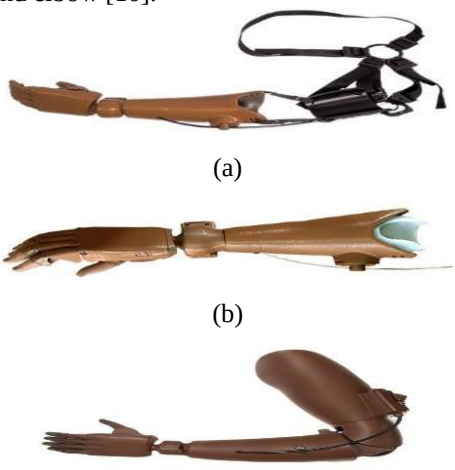
6. Partial hand prosthesis:

Partial hand mechanism involves patients having some of their fingers injured or sometimes lost in accidents. The partial hand involves intricate and small parts, attached to patient's wrist which helps them in grasping or holding different objects. For amputees or patients with no-remaining fingers, a commercial product, trans-carpal hand is adapted and used worldwide. For those who have lost their trans-metacarpal limbs, Biden created an EMG based prosthetic arm, who have their remaining fingers in functioning mode and other unlinked fingers adjacent to the MP joints[8],[9].Various PAP (Pick and Place) experiments are carried out in order to test the partial hand's functioning. Usually, the PAP experiments involves grasping and holding objects from a distance of 150 (mm^2) square area and to move that hand apart and to release that same object which the hand is holding on to a distance of 500 (mm) apart [8],[9].

Fig.7. Body powered Partial hand
(Image courtesy:https://www.armdynamics.com/ourcare/finger-and-partial-hand-prosthetic-options)

7. Victoria Artificial Hand:

The Victoria Artificial Hand is a body-powered prosthetic hand that comprises of a hand, a wrist, an upper extremity socket, a triceps collar, and a strap. It fits each amputee comfortably and offers good functionality and a natural appearance. The hand has the ability to modify its hold, allowing the fingers and thumb to detect the contours of diverse objects and form a firm grip. Additionally, the thumb and fingers have rubber tips to aid in grasping smaller objects. The prosthesis ball-and-socket wrist can be adjusted to fit different hand positions. The wrist allows the amputee to accomplish a variety of jobs because it is simple and instinctive to use. This prosthetic Victoria hand made out of silicone and steel (bolt and nut). There are three types of sockets, Trans-radial, Trans-radial suspension, Trans-humeral. Company manufactures affordable prosthetic hands for amputees using 3D printing technology. The Trans-radial socket is originally designed for individuals with amputations below the elbow. The Trans-radial suspension prosthesis is designed for amputees with shorter limbs which is close to the elbow. The Trans-humeral socket is for individuals with amputations between the shoulder and elbow [10].



(a)

(b)

(c)

Fig.8. Victoria Artificial Hand (a) Trans-Radial (b) Trans-Radial Suspension(c) Trans-Humeral(Image courtesy: Victoria Hand Project)

8. Cyber Prosthetic Hand:

The main aim of the cybernetic prosthetic hand is to connect to the peripheral nervous system and attempt to mimic the sensory-motor functions of the human hand as closely as feasible [11]. Several elements, including a bio-mechatronic component, a transducer, a sensing mechanism, a control mechanism, and batteries, make up a prosthetic hand. The three-finger RTR2 ("Rehabilitation Technology Research") hand was reconstructed to enhance the hand grasp functionality[11]. There are four dc motors used, which control the three finger movements, and the thumb's adduction and abduction operations are performed by the final one [11]. There are 10 degrees of freedom in total, and the predicted weight is 400 grams. Each finger is under-actuated, and the RTR2's mechanism is used. The proximal phalanges are 16 mm wide [11].

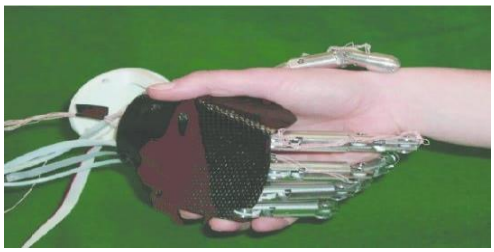


Fig.9. Cyber Prosthetic Hand
(Image courtesy: Future and Emerging Technologies)

9. Myo Plus Pattern Recognition Hand:

A ground-breaking initiative to reimagine the control of myoelectric prostheses led to the development of the Myo Plus pattern recognition technology. It allows direct control of the prosthesis by merging artificial intelligence with the user's natural EMG impulses [12]. To ensure a seamless experience for both users and prosthetists, the Myo Plus app allows for easy calibration and fine-tuning of the system [12]. The entirety of the process is designed to be intuitive and straightforward, giving users the freedom to adjust their personal settings and make the most out of their prosthesis. With its innovative approach to myoelectric technology, Myo Plus is ushering in a new era in prosthesis control. It is reliable, efficient, and provides users with more control than ever before [12].

Fig.10. Myo Plus Pattern Recognition Hand
(Image courtesy: bionicsforeveryone.com)

10. Adam's Hand (Bionic Hand):

Adam's hand is being developed by BIONIT LABS. Adam's Hand is a myoelectric prosthetic hand that employs one motor to move all of the fingers and adapt the size and appearance of things that are grabbed [13],[14]. The novelty is that they simply work effectively to open or shut the hand that will automatically adjust to the object being grabbed. The electromyography (EMG) data, which come from the electrical impulses of muscle fibers, are what the myoelectric prostheses rely on to function. Muscles contract as a result of their intention. The electrodes for upper-limb prostheses are positioned within the prosthetic socket and in close proximity to the arm or forearm muscles [13], [14]. The price of a hand goes from 25 lakh to 35 lakh. The Adam's Hand technology is based on the idea of under actuation, that is a scenario of a high-power density DC motor that can result in the actuation of multiple degrees of freedom (DOF) [13],[14].

Fig.11. ADAM'S HAND
(Image courtesy: Bionics for everyone)

11. Activity Based Prosthesis:

The prosthetic hands which are generally manufactured are not useful for sports driven activities. Various sports requires strong prosthesis mechanism. For example, swimming, running, boxing, etc. There are three categories in activity based prosthesis:

a. Ankle and foot based: Micro-controller based ankle/foot movements are designed to adjust automatically, depending upon the walking speed of the amputee and on the environmental conditions. A hand can cost between Rs. 20 lakh and Rs. 50 lakh. Axial or horizontal rotation lost has been replaced by endoskeletal torsion unit; especially used in scenarios where the limb must be forced to rotate while bearing weight. Say, while playing a game of golf [15].
b. Knee based: Body powered prosthesis is used. Usually required while running [15].
c. Ankle and foot and knee based prosthesis [15].

Fig.12. Activity Based Prosthesis for Boxing (Image courtesy: https://www.armdynamics.com/ourcare/occupational-therapy)

12. Michelangelo Hand Trans-carpal Prosthesis:

Otto Bock designed the Michelangelo Hand, a ground-breaking device that electronically moves the thumb into various positions so it may perform like a human hand. This hand included several gripping options that enable users to carry out daily activities like opening and closing operations, gripping a key or ball, holding a credit card, etc. When gripping a pen, plate, or bowl with the Michelangelo Hand's thumb, the flexible-positional wrist joint provides a more natural shape that can perform basic movements of hand[16]. This versatile hand can be used as an assistive device for physically challenged persons who have limited mobility in their fingers and hands, allowing them to perform basic activities with ease. It is also beneficial for people with amputated limbs as it helps them to lead a more independent life. The net cost of the Michelangelo Hand ranges from Rs. 40 lakh to Rs. 60 lakh. The Michelangelo Hand is truly a remarkable invention that has been designed

to maximize the convenience and comfort of its users. Thus, the Michelangelo Hand from Otto Bock is an incredible piece of technology that enables users to function more like a human hand and perform everyday tasks with ease [16].

Fig.13.Michelangelo Trans-carpal Hand
(Image courtesy: Ottobock)

13. Myo-electric hand prosthesis handii from exiii, Japan:

Myo-electric prostheses do not require the use of muscular force or physical leverage because they are controlled by an external source of power. Thus, a biochemical process that can produce electric impulses with a micro voltage can be implemented with the aid of this modern approach of prosthesis.

The handiii COYOTE is a prosthetic hand that is operated by EMG. The tool is a myo-electric arm with a low price and excellent functionality. A hand costs between Rs. 8 lakh to Rs. 32 lakh. The handiii uses a wireless connection link to send data from the arm's EMG sensor to a mobile phone [17]. By pressing a little button on the elbow portion, the handiii's user can switch between a variety of grips, including a pinch, grip, five-finger hold, etc [17]. The following design principles were used to develop the handiii:

a) Algorithms for sensor integration and monitoring using a typical smartphone technique.
b) Brings the required number of motors down to one for each finger.
c) Reduces production costs and customization labour by using 3D printing .

Fig.14. Myo-electric hand prosthesis handiii from exiii
(Image courtesy: https://www.medicalexpo.com/prod/exiii-104325. html)

III. UPPER LIMB PROSTHETIC MARKET

The prosthetic hand market has seen rapid growth in recent years due to the efforts of leading players like Ottobock SE & Co.KGaA. Aetna Inc. (Japan), Touch Bionics Inc. (Japan), Coapt, LLC (Switzerland), Steeper Inc. (USA), Human Technology Inc. (USA), Ambionics Pvt Ltd (UK), and OpenBionics (Australia)[18]. These companies are driving innovation in the Prosthetic hand market and have enabled it to reach a total market size of 61,06,42,97,500.00 INR ($745 million) in 2021 [18]. 3D printing technologies are being used to create cost-effective myoelectric prosthetics which are becoming increasingly popular in this field. This growth is expected to continue well into the forecast period and companies are looking to capitalize on this opportunity by providing more products tailored to the needs of those with prosthetic hands. Moreover, advancements in technology are making it easier for people to obtain access to better quality and more cost-effective prosthetic devices. Additionally, key players in the market are investing in research and development activities related to myoelectric prosthetics in order to bring innovative products to the market which can help improve patient outcomes.

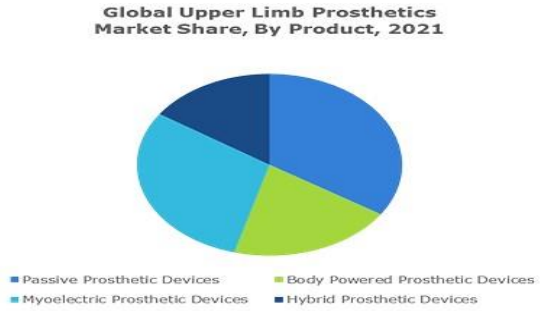


Fig.15.Global upper limb prosthetic market
Share, by product, 2021 (Image Courtesy: www.gminsights.com)

The Upper limb prosthetic market is broadly divided into four types of prosthetics: Myoelectric, Passive, Body-powered and Hybrid [18]. Of these, myoelectric hand prosthetics are the fastest-growing industry. Myoelectric are the most dynamic and advanced type of prosthetics available on the market today, and their life-changing capabilities for amputees have been widely reported. Other types of upper limb prosthetics include passive, body-powered, and hybrid devices. Passive prosthetics are the simplest form of upper limb prosthetics and provide minimal support and movement. However, these devices can still be effective in many cases and are a great option for those looking for a low-cost solution. Body-powered prosthetics utilize a cable system that is operated by the user to control their movements. Finally, hybrid prosthetics combine elements of both passive and myoelectric prostheses, allowing for greater functionality while still being relatively affordable.

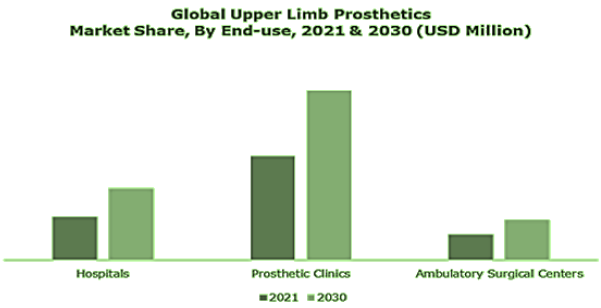


Fig .16. Global upper limb prosthetics market share, by end use, 2021 & 2030(USD million) Image Courtesy: www.gminsights.com

Prosthetic clinics have been dominant in the upper limb prosthetics market, with a share of around 60% in 2021[18]. This share is projected to increase through 2030 due to advancements in prosthetic devices and technical improvements that can be tailored to each customer's deformity [18]. Hospitals and ambulatory surgical centers are also expected to experience growth in product uptake during this period. Prosthetic clinics offer unique advantages such as greater accessibility, providing a wide range of options for prosthetic devices, and specialized staff trained to assist patients with upper limb amputations. With all these developments in the industry, it is evident that the demand for upper limb prosthetics is on the rise, a trend which is expected to continue through 2030 [18]. Prosthetic clinics, hospitals, and ambulatory surgical centers are all playing an important role in making upper limb prosthetics more accessible and affordable to users across the globe.

IV. CONCLUSION

While technologically advanced solutions enable patients to regain significant levels of motor and sensory mechanisms, it is now time to consider alternatives that are not only functionally acceptable but also accurately estimate the encounter of a natural hand. In this paper, we have studied different types of prosthetic hands that are available worldwide. Upper limb prosthetics have made significant progress in terms of functionality, particularly for high-end products such as the BeBionic and i-Limb hands on the market. Unfortunately, the rising price of such devices precludes the majority of amputees from purchasing them.

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REFERENCES

[1] Ayub R, Villarreal D, Gregg RD, Gao F. Evaluation of transradial body-powered prostheses using a robotic simulator. Prosthet Orthot Int. 2017 Apr;41(2):194-200.doi: 10.1177/0309364616650077. Epub 2016 Jul 28. PMID: 27469105.

[2] Inali Foundation. "About Inali foundation – Inali Foundation,"Inalifoundation, https://inalifoundation .com/about-inali-foundation/(accessed Jan. 1, 1970).

[3] "Patient Corner – Inali Foundation," Inalifoundation, https://inalifoundation.com/patientcorner/(accessed Jan. 1, 1970).

[4] R. Ahmed, R. Halder, M. Uddin, P. C. Mondal and A. K. Karmaker, "Prosthetic Arm Control Using Electromyography (EMG) Signal," 2018 International Conference on Advancement in Electrical and Electronic Engineering (ICAEEE), Gazipur, Bangladesh, 2018, pp. 1-4, doi: 10.1109/ICAEEE.2018.8642968.

[5] C. Medynski and B. Rattray."Bebionic Prosthetic Design." Dukespace.https://dukespace.lib.duke.edu/dspace/handle/10161/4733/(accessed Jan. 01, 2011).

[6] Wayne.williams. "Ottobock Bebionic Hand". https://bionicsforeveryone.com/ottobock-bebionic-hand/(accessed March 26, 2022).

[7] i-Limb Quantum, Aug. 2020, [online] Available: https://www.ossur.com/en-gb/prosthetics/arms/ilimb-quantum.

[8] R. Weir, E. C. Grahn, and S. J. Duff, "A new externally powered, myoelectrically controlled prosthesis for persons with partial-hand amputations at the metacarpals,"*JPO: Journal of Prosthetics and Orthotics*, *13*(2), 26-31(2001).

[9] OttoBock, Transcarpal Hand,2014. http://professionals.ottobockus.com/cps/rde/xchg/ob_us_en/hs.xsl/6909.html

[10] B. Phillips, G. Zingalis, S. Ritter and K. Mehta, "A review of current upper-limb prostheses for resource constrained settings," 2015 IEEE Global Humanitarian Technology Conference (GHTC), Seattle, WA, USA, 2015, pp. 52-58, doi: 10.1109/GHTC.2015.7343954.

[11] M. C. Carrozza, P. Dario, F. Vecchi, S. Roccella, M. Zecca and F. Sebastiani, "The Cyberhand: on the design of a cybernetic prosthetic hand intended to be interfaced to the peripheral nervous system," Proceedings 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2003) (Cat. No.03CH37453), Las Vegas, NV, USA, 2003, pp. 2642-2647 vol.3, doi: 10.1109/IROS.2003.1249269.

[12] Wayne.williams. "Ottobock Myo Plus Pattern Recognition".https://bionicsforeveryone.com/ottobock-myo-plus-pattern-recognition/(accessed February 19, 2021).

[13] Z. Xu, Y. Tian and Y. Li, "Research on prosthetic hand modeling based on ADAMS and MATLAB," 2011 International Conference on Electronics, Communications and Control (ICECC), Ningbo, China, 2011, pp. 1635-1638, doi: 10.1109/ICECC.2011.6067883.

[14] Wayne.williams."Adam's Hand from BioIT Labs."https://bionicsforeveryone.com/adams-hand-from-bionit-labs/.(accessed June 14, 2021).

[15] Jan J.. Stokosa, "Limb Prostheses Options - Special Subjects - MSD Manual Consumer Version," Msdmanuals,Sep.1,2022. https://www.msdmanuals.c om/en-in/home/special-subjects/limb prosthetics/limb-prostheses-options/(accessed Jan.1, 1970).

[16] "Michelangelo Hand | Michelangelo Hand / AxonHook | Michelangelo/Axon-Bus System | Upper Limb Prosthetics | Prosthetics | Ottobock US Shop," Mar. 11, 2015. [Online]. Available:https://shop.ottobock.us/Prosthetics/Upper-Limb-Prosthetics/Michelangelo-Axon-Bus-System/Michelangelo-Hand-AxonHook/Michelangelo-Hand/p/8E500~5R-M/

[17] Myo-electric hand prosthesis - handii. (n.d.). Exiii - Multi-articulated/Adult. https://www.medicalexpo.com/prod/exiii/pr%20oduct-104325-711140.html/(accessed Jan.12, 2023).

[18] "Upper Limb Prosthetics Market Size & Share Forecasts – 2030." Global Market Insights Inc.https://www.gminsights.com/industry-analysis/upper-limb-prosthetics-market/(accessed Jan.22, 2023).