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BIONIC PROSTHESIS HAND: A REVIEW AND FUTURE PERSPECTIVES

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Abstract. *The evolution of conventional upper limb prostheses has been, for years, incorporating numerous technologies, mainly in the areas of robotics, signal processing, and additive manufacturing (AM), using new materials and construction methods, currently having a large focus on prostheses bionics, which work using sensors on the skin or connected to the muscle, capturing the electrical pulses produced by muscle contraction and transforming them into signals for moving the prosthesis, through complex circuits and electronics embedded in its operating system, which makes this process viable. Despite the development, many are still not able to satisfactorily and organically reproduce the movements of a human hand, not fulfilling its essential function to improve/restore user's motor skills, requiring more and more improvement in these types of equipment. Thus, this article aims to present a literature review on bionic prostheses from 2001, providing the main constructive characteristics for development, analyzing the material, signal processing, and the results achieved in this context, in addition to innovative points and evolutionary over the years, providing a basis for deepening the theme. The results show state-of-the-art literature articles on bionic prostheses, taking into account the search markers used ("Bionic prosthesis", "Hand" and "Three-dimensional printing") and the consulted platforms (Scopus, PubMed, and Web of Science). It was concluded, among other points, that the development of bionic prostheses needs extreme deepening and discussion, with several fields for potential exploration and development of future research in the area of materials, applied robotics, printing by additive manufacturing, and signal processing, especially when analyzed on the aspects of myoelectric signals (EMG), having great relevance in the social context, as it helps in the development of more accurate prostheses, capable of providing better adaptability, functionality and more complete movement resumption for the user, which enables the performance of various daily and work activities, contributing to the integration of the individual in society.*

Keywords: *Bionic Prosthesis, Hand, Additive Manufacturing, Review, Future Perspectives.*

1. INTRODUCTION

The amputation of a limb has a great impact on people's lives and can be extremely traumatic and will, in addition to losing motor functions and causing physical and psychological damage (Saradjian *et al.*, 2008). Total or partial hand amputation is one of the most common procedures in trauma involving acquired disabilities (Imbinto *et al.*, 2016). Thus, there is a commitment of occupational status, leisure activities, and social interaction, especially for people with amputations in the upper limbs, because it makes it difficult to perform daily activities in an incisive way (Whyte and Carroll,

2002), and may present clinical conditions of depression, anxiety, and anger after amputation (Frierson and Lippmann, 1987).

In recent decades, several types of technologies are being employed in the development of hand prostheses, making the use of three-dimensional printing and robotic devices, combined with complex circuits, sensors, electrodes, neural networks, surface electromyography, and artificial intelligence (Fajardo *et al.*, 2015; Pambudi *et al.*, 2016; Tabakov *et al.*, 2018), which in several cases perform a brain-muscular interconnection, being possible communication with the user's nervous system (Inmann and Haugland, 2004). These new types of prosthetic devices are called bionic prostheses and are revolutionizing man's way of interacting with the machine and its interface (AlZubaidi and Al-Bayaty, 2017).

Among the considerations for the development of bionic hand prostheses, numerous characteristics must be taken into account during the manufacturing and development process, as they directly interfere in the functioning, acceptability, and price of the product for the user. In this sense, demands such as the most appropriate signal processing, involving sensory feedback, the selection of materials that are in biological conformity, and the most appropriate manufacturing process, are important characteristics for construction (Hahne *et al.*, 2018; Miclaus *et al.*, 2017). However, to address all important aspects the cost becomes high, making the prosthesis not accessible to most people (Chappell, 2016).

Analyzing manufacturing processes, three-dimensional printing, using fused deposition modeling (FDM) and stereolithography, has become widely used for the development of prostheses, and with the popularization of three-dimensional printers, the use of additive manufacturing has been a simpler and cheaper form of construction, besides allowing greater flexibility of customization and better anatomical adaptability, significantly reducing costs (Leite *et al.*, 2019; Miclaus *et al.*, 2017; Silveira Romero *et al.*, 2020).

Thus, despite the evolutions present in bionic prostheses using 3D printing, there are still gaps in the methodologies of manufacturing and elaboration of the project, in addition to the application of concepts of material resistance, movement analysis, types of signals employed, materials, and the interface between the patient and the prosthesis (Lopes and Tomás, 2018.). The review of (Ten Kate *et al.*, 2017) provides a quantitative overview of some 3D printed upper limb prostheses, identifying the advantages and disadvantages, as well as the revision of (Vujaklija and Farina, 2018), however, they are not focused on hand prostheses, but rather on the upper limbs, in general, they do not present an analysis focused on bionic prostheses, which allows a wide opening for comparison and detailing of these technologies.

Therefore, this article aims to perform an overview that involves bionic hand prostheses using additive manufacturing in the last twenty years, addressing the differences present in their constructions and development.

2. METHODOLOGY

The articles were selected through the following databases: PUBMED (U.S. National Library of Medicine), Scopus, and Web of Science. The descriptors were combined between the terms related to "Bionic Prostheses", "hand" and "three-dimensional printing", with a mandatory controlled descriptor of the DeCS (Descriptors in Health Sciences) and its correspondents in the English language MeSH (Medical Subject Headings). The research was expanded through a manual search in the reference lists of the selected studies.

Included in this review were studies published in the last 20 years, that is, between 2001 and 2021, involving the use of automation in hand movement, that made use of 3D printing directly in manufacturing and had the full and available text. Review articles, theses, dissertations, and case analyses were excluded.

The selected articles were analyzed according to the characteristics of the manufacture of bionic hand prostheses through additive manufacturing, which was summarized in a standardized way, based on the following topics: 3D printing technology, the material used in printing, sensor/actuator, type of signal employed, main results described (Table 1);

3. RESULTS

In the review, a total of 6,128,242 articles were identified, of which 420 were pre-selected for the content of the title and abstract. Of these, 393 were excluded after applying the exclusion criteria (Review articles, theses, dissertations, and case analyses), leaving 27 for analysis of the full text. After a complete reading of the articles, 12 were excluded, 6 for not having full texts available for analysis, and 6 for not fully addressing the development of bionic prostheses. Thus, for this study, 15 articles were selected, as described in Figure 1.

Given the analysis of the studies, it can be seen that these articles were published between the years 2016 and 2020, all of which are published in English. Regarding the use of Additive Manufacturing (AM) technology, 7 articles used Fused Deposition Modeling (FDM) technology (Abdul Wahit *et al.*, 2020; Curline-Wandl and Azam Ali 2016; Gretsche *et al.*, 2016; Jones *et al.*, 2017; Prakash and Sharma, 2020; Tian *et al.*, 2017) and 8 do not provide the method employed.

Regarding the material used for printing, 6 studies used Acrylonitrile Butadiene Styrene (ABS) (Abdul Wahit *et al.*, 2020; Ccorimanya *et al.*, 2019; Curline-Wandl and Azam Ali, 2016; Gretsche *et al.*, 2016; Hota *et al.*, 2016; Jones *et al.*, 2017), 3 studies used polystyrene filament and polylactic acid (PLA) (Prakash *et al.*, 2020; Prakash and Sharma, 2020; Said *et al.*, 2020), 2 studies used Thermoplastic Polyurethane (TPU) (Mohammadi *et al.*, 2020; Said *et al.*, 2020) and 1 study made use of Carbon Fiber to Print (Tian *et al.*, 2017). In addition, the study by Said *et al.* (2020) and Krausz *et al.*

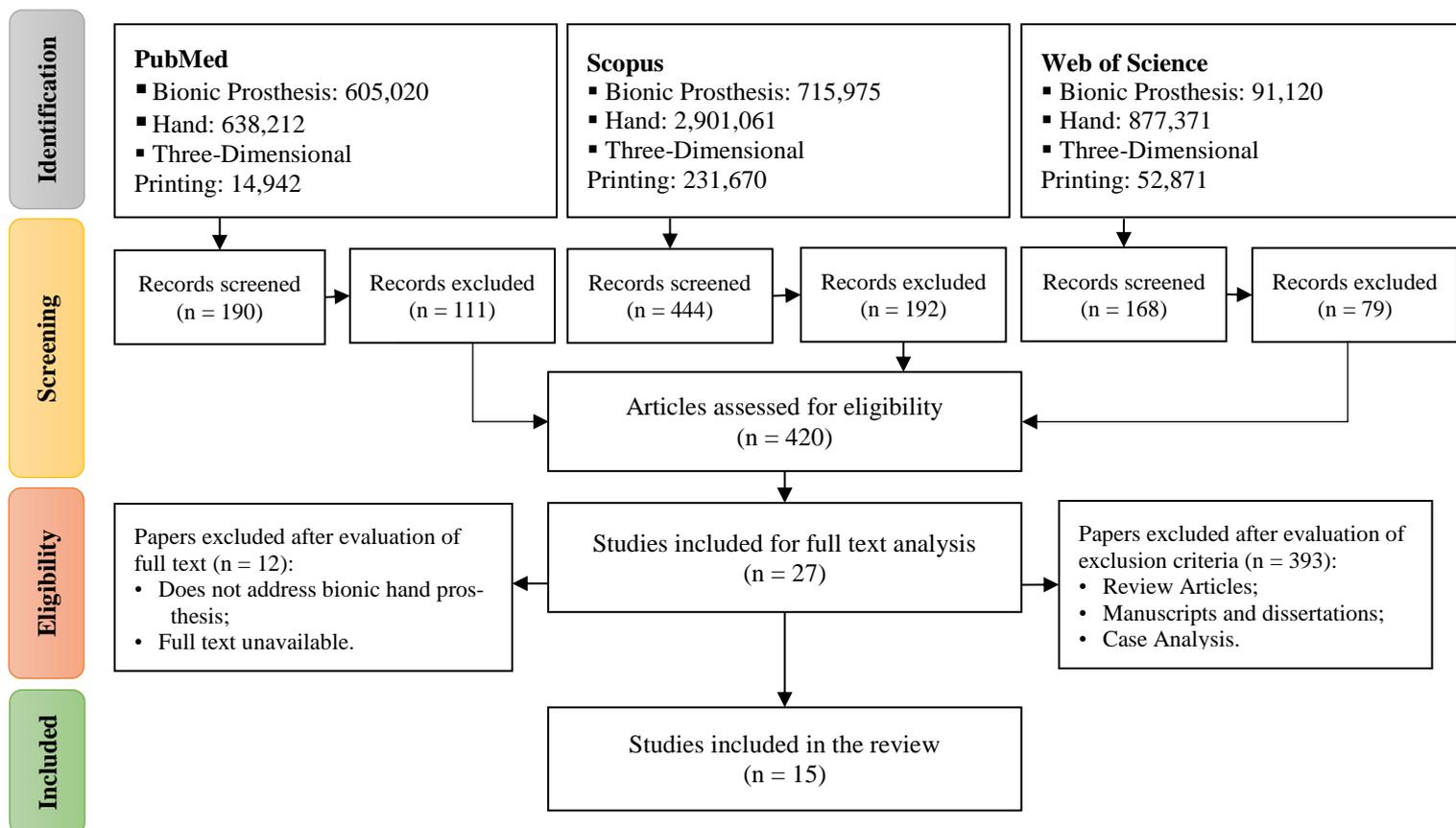


Figure 1. Flowchart of searches and results in the databases used.

(2016) used two materials for the manufacture of the device (PLA and TPU) and (Stratasys Tango Black Plus and Stratasys VeroClear), respectively. Three studies did not provide information about the material used.

Regarding the types of sensor/actuator used, 9 articles made the use of electromyography sensors (EMG or sEMG) (Abdul Wahit *et al.*, 2020; Curline-Wandl and Azam Ali, 2016; Fajardo *et al.*, 2015; Germany *et al.*, 2016; Mohammadi *et al.*, 2020; Prakash *et al.*, 2020; Prakash and Sharma, 2020; Said *et al.*, 2020; Sánchez-Velasco *et al.*, 2020), 2 of which were using MYO Armband (Said *et al.*, 2020; Sánchez-Velasco *et al.*, 2020) and 9 studies described the servomotor used, (Ccorimanya *et al.*, 2019; Gretsche *et al.*, 2016; Hota *et al.*, 2016; Krausz *et al.*, 2016; Mohammadi *et al.*, 2020; Prakash *et al.*, 2020; Prakash and Sharma, 2020; Sánchez-Velasco *et al.*, 2020; Tian *et al.*, 2017), responsible for the movement of the fingers.

Regarding the type of signal employed, 10 studies applied Electromyography Signal (EMG signal) (Abdul Wahit *et al.*, 2020; Ccorimanya *et al.*, 2019; Curline-Wandl and Azam Ali, 2016; Fajardo *et al.*, 2015; Germany *et al.*, 2016; Jones *et al.*, 2017; Mohammadi *et al.*, 2020; Prakash and Sharma, 2020; Said *et al.*, 2020; Sánchez-Velasco *et al.*, 2020), 1 study applied Force Myography (FMG) together with Pulse Width Modulation (PWM) (Prakash *et al.*, 2020) and 1 study used Transistor-Transistor Logic (TTL) (Hota *et al.*, 2016). Three articles did not describe the sign employed.

For the main results found in the articles, it can be observed that 10 studies made the development of hand prostheses using a new designer (Abdul Wahit *et al.*, 2020; Ccorimanya *et al.*, 2019; Fajardo *et al.*, 2020; Gretsche *et al.*, 2016; Hota *et al.*, 2016; Jones *et al.*, 2017; Krausz *et al.*, 2016; Said *et al.*, 2020; Sánchez-Velasco *et al.*, 2020; Tian *et al.*, 2017), employing biomechanical analyses that favored the optimization of movements. In addition, 4 studies focused on the development of control systems (Curline-Wandl and Azam Ali, 2016; Germany *et al.*, 2016; Prakash *et al.*, 2020; Sánchez-Velasco *et al.*, 2020), and can be applied in various types of open-source prosthetic devices. The results found for each article, as well as the descriptions of each analysis returned about the main topics addressed, are in Table 1.

4. DISCUSSIONS

This review aims to analyze the technologies present in the development of hand prostheses involving additive manufacturing as a means of manufacture. Regarding cad design and hand-applied biomechanics studies, the studies by Abdul Wahit *et al.* (2020); Fajardo *et al.* (2015); Jones *et al.* (2017); Krausz *et al.* (2016); Sánchez-Velasco *et al.* (2020) and Tian *et al.* (2017) provide a deeper look at the elaboration of CAD drawings and the mechanisms of connection between palm and fingers, in addition to specifying the software employed (SolidWorks, Autodesk Inventor). The studies of Germany *et al.* (2016); Prakash *et al.* (2020); Prakash and Sharma (2020) and Sánchez-Velasco *et al.* (2020) used prostheses

Table 1. Separation of data presents in articles.

Author / Article	3D Printing Technology	Materials	Sensor / Actuator	Signal	Main Results
GRETSCH, KENDALL F.; et al. "Development of Novel 3D-Printed Robotic Prosthetic for Transradial Amputees". <i>Prosthetics & Orthotics International</i> 40, no 3; June 2016; Page 400–403.	Fused Deposition Modeling (FDM)	Acrylonitrile Butadiene Styrene (ABS)	Microservo motor (MG90); Inertial Measurement Unit (IMU)	-	Development of a hand prosthesis (Robohand) using additive manufacturing for patients with transradial amputation. The movement of the prosthesis is limited to the total opening of the five fingers of the hand and total closure, being controlled by the position of the user's shoulder.
KRAUSZ, NILI E.; et al. "Design and Fabrication of a Six Degree-of-Freedom Open Source Hand". <i>IEEE Transactions on Neural Systems and Rehabilitation Engineering</i> 24, no 5; May 2016; Page 562–72.	-	The finger and thumb pads were printed in a compliant material (Stratasys Tango Black Plus); The remainder was printed in a hard plastic (Stratasys VeroClear)	MM 1724-T-006-SR Faulhaber motor; 1516-T-006-SR Faulhaber motor	-	Development of a test hand that allows the implementation of various prosthesis control strategies in a physical hand. The hand has one degree of freedom for each finger, with coupled metacarpophalangeal and proximal interphalangeal joints, and two degrees of freedom for the thumb: one for flexion/extension and one for rotation.
CURLINE-WANDL, SCOTT A., E M. AZAM ALI. "Single Channel Myoelectric Control of a 3D Printed Transradial Prosthesis". <i>Organizado por Wei Meng. Cogent Engineering</i> 3, no 1; December 31, 2016.	Fused Deposition Modeling (FDM)	Acrylonitrile Butadiene Styrene (ABS)	EMG Sensor; Arduino Uno	Electromyography Signal (EMG signal)	Although it shows interesting development by the single-channel myoelectric controller, improvements must be made in the interaction between preprocessing and open source microcontrollers for use in printed prostheses.
TIAN, LI.; et al. "The Making of a 3D-Printed, Cable-Driven, Single-Model, Lightweight Humanoid Robotic Hand". <i>Frontiers in Robotics and AI</i> 4; December 4, 2017; 65.	Fused Deposition Modeling (FDM)	Carbon fiber to print	Servo motor HITEC HS-5070MH	-	Development and manufacture of a robotic hand using 3D printing for humanoid robots, which was able to perform most of the handgrip gestures of a human hand.

Author / Article	3D Printing Technology	Materials	Sensor / Actuator	Signal	Main Results
WAHIT, A.; et al. "3D Printed Robot Hand Structure Using Four-Bar Linkage Mechanism for Prosthetic Application". <i>Sensors</i> 20, no 15; July 27, 2020; 4174.	Fused Deposition Modeling (FDM)	Acrylonitrile Butadiene Styrene (ABS)	Myoware Electro-myography sensor; S-LFS-4-4 ways Infrared (IR) Sensor	Electromyography Signal (EMG signal)	The robot hand prototype was developed and built with 3D printing, using the four-bar connection mechanism, the same size as an average human hand, with individual motor for each finger, in addition to computer simulation analysis and real test.
MOHAMMADI, A.; et al. "A Practical 3D-Printed Soft Robotic Prosthetic Hand with Multi-Articulating Capabilities". <i>PLOS ONE</i> 15, no 5; May 14, 2020; e0232766.	Fused Deposition Modeling (FDM)	TPU (Thermoplastic Polyurethane with Shore 90 – TPU90)	Surface electromyography (sEMG); Geared DC micromotors (6V HPCB Micro Metal Gearmotor, Pololu Inc.)	Electromyography Signal (EMG signal)	Development of a soft robotic hand prosthesis (X-Limb), with design solutions that satisfy the required mechanical, morphological, kinodynamic and functional characteristics.
FAJARDO, J; et al. "Galileo Hand: An Anthropomorphic and Affordable Upper-Limb Prosthesis". <i>IEEE Access</i> 8 (2020): 81365–77.	-	-	Surface electromyography (sEMG); Microcontroller unit (MCU) based on the ARM Cortex-M4 architecture on a custom control board.	Electromyography Signal (EMG signal)	Development of an upper limb prosthesis with a modular design using 3D printing, using an sEMG controller that presented a remarkable speed of movement response (low latency), with the hand posture pre-established by the user. The NASA Task Load Index (TXL) test was also performed to verify the effectiveness of the interface, obtaining a satisfactory result.
JONES, G. K.; et al. "Prosthetic Design Directives: Low-Cost Hands within Reach". <i>IEEE ... International Conference on Rehabilitation Robotics: Proceedings 2017</i> (July 2017): 1524–30.	Fused Deposition Modeling (FDM)	Acrylonitrile Butadiene Styrene (ABS)	Main circuit board (MCB) -Microcontroller (MCU); Teensy 3.1 convenient USB serial interface; High speed MCU (MK20DX256)	Electromyography Signal (EMG signal)	The Touch Hand II was built without using sensor techniques, centralizing the electronics in an MCB. Three speed settings and three torques were created to customize the preset settings for each grip and provide the user with precise control, being able to replicate ten grip positions used on common everyday objects, with just on-off commands.

Author / Article	3D Printing Technology	Materials	Sensor / Actuator	Signal	Main Results
HOTA, R. K. et al. “Design and Control of Tendon Driven Robotic Hand for Prosthesis Applications”. D.K. Mandal and C.S. Syan (eds.), CAD/CAM, Robotics and Factorie-sof the Future, Lecture Notes in Mechanical Engineering; Page 535 – 542. 2016.	-	Acrylonitrile Butadiene Styrene (ABS)	Brushed DC motors from Dynamixel-AX 12 ^a servos	Transistor-Transistor Logic (TTL)	The hand designer was performed in SolidWorks and manufactured in 3D printer using ABS material. The MATLAB GUI interface and the SynGrasp tool allowed the analysis of different hand pension measures, which in the future can be adapted to the myoelectric signal.
CCORIMANYA, L.; et al. “Design of a Myoelectric 3D-Printed Prosthesis for a Child with Upper Limb Congenital Amputation”. Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference. Volume 2019; Pages 5394 – 5398; July 2019.	-	Acrylonitrile Butadiene Styrene (ABS)	Servomotor (GWS Pico STD); Miorcontroller (BLE Nano v1.5); Printed circuit board (PCB)	Electromyography Signal (EMG signal)	Construction of a myoelectric hand prosthesis for children with congenital amputation, manufactured by 3D printing using ABS material, applying sound biofeedback and a soft socket with in-liner electrodes. The performance of the control applied in the tests performed was satisfactory, but presented involuntary opening and closing movements of the hand and a delay in fully completing the movement of the prosthesis as the main points for future improvement of the project.
PRAKASH A.; et al. “ Force Myography Controlled Multifunctional Hand Prosthesis for Upper-Limb Amputees”. Biomedical Signal Processing and Control; Volume 62; September 2020; Article number 102122.	-	Polylactic Acid (PLA)	Digital servomotor (DS-3225); EMG Sensor	Force Myography (FMG); Pulse Width Modutation (PWM)	Development of a solution for 3D printed hand prostheses using low-cost FMG. During the article, it was used in two different prostheses (prototype 1 and 2), with prototype 2 being the one with the best performance in the grip tests performed.
PRAKASH A.; SHARMA S. “ A low-cost system to control prehension force of a custom-made myoeletric hand prosthesis”. Research on Biomedical Engineering; Volume 36; Issue 3; Pages 237 – 247; 1 September 2020.	Fused Deposition Modeling (FDM)	Polylactic Acid (PLA)	Servomotor (MG-996R); Surface electromyography (sEMG); Force-sensitive resistor (FSR).	Electromyography Signal (EMG signal)	Development of a low-cost system for the control and measurement of grip strength in a myoelectric hand prosthesis manufactured in 3D printing. The developed system showed satisfactory response time, being tested on five people with transradial amputation for basic gripping movements. A real-time measurement of grip strength was performed on the EMG signal during the tests.

Author / Article	3D Printing Technology	Materials	Sensor / Actuator	Signal	Main Results
GERMANY, ENRIQUE I.; et al. "Myoelectric Intuitive Control and Transcutaneous Electrical Stimulation of the Forearm for Vibrotactile Sensation Feedback Applied to a 3D Printed Prosthetic Hand". Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference 2016; August 2016; 5046–50.	-	-	Surface electromyography (sEMG); Pressure sensors in the hand and palm.	Electromyography Signal (EMG signal)	The developed system was able to decode and provide predictions of the positions of the fingers of the hand printed in 3D, using muscle behavior in combination with the applied neural network. In addition, it provided intuitive control and vibratory feedback. For the stimulation parameters used, the 40 Hz frequency did not reach any sensation for a pulse duration of 5 μ s at low current intensities amplitude, whereas for a pulse duration of 10 μ s, the tickling effect grows and contraction force occurs. Frequencies from 40 Hz to 80 Hz were tested also generating contraction responses as expected, and for a 2 μ s pulse it can generate a pressure in the current range of 2 mA and 8 mA. For values above these levels, the sensation becomes painful.
SAID S.; et al. "Machine-Learning-Based Muscle Control of a 3D-Printed Bionic Arm. Sensors (Switzerland); Open Access; Volume 20, Issue 11; 1 June 2020. Article number 3144.	-	Polylactic Acid (PLA); Thermoplastic Polyurethane (TPU).	MYO Armband Acquire (Surface electromyography (sEMG))	Electromyography Signal (EMG signal)	Construction of a 3D printed bionic arm for a person with amputation of the right arm, using surface electromyography (sEMG). The data generated by the sEMG were used to test three classifiers (Artificial neural networks (ANN), linear discriminant analysis (LDA), and support vector machine (SVM) and to evaluate which would be the best option. a mean value of the training data equal to 91.21% and standard deviation of 1.92%. Furthermore, the SVM classifier provided testing accuracy equal to 89.93%, and standard deviation of 1.75%. your daily activities.
SANCHEZ-VELASCO L. E.; et al. "A Low-Cost EMG Controlled Anthropomorphic Robotic Hand for Power and Precision Grasp". Biocybernetics and Biomedical Engineering; Volume 40; Issue 1; Pages 221 – 237; January - March 2020.	-	-	MYO Armband Acquire (Surface electromyography (sEMG)); Motor Driver Dual MC33926 from Pololu1	Electromyography Signal (EMG signal)	Implementation of a low-cost EMG control system on an open source 3D printed hand prosthesis. There were modifications in the original design in order to improve some mechanical characteristics and reduce the price. According to data already present in the current literature, the kinetic functions of the prototype suggest a performance comparable with the original designer and with other commercial robotic prostheses, having observed satisfactory experimental results of gripping and gripping strength.

available on open source websites, making modifications to their designers for the application of technologies and equipment used for control. The availability of CAD drawings is extremely important for the analysis and foundation of the device, so the authors should seek to make this information feasible since in different articles this is was taken into account.

As for mechanical feasibility studies and structural analysis via numerical simulation, it is noted that the studies do not prioritize these analyses, which are fundamental for the reliability and mechanical validation of the prosthesis, besides being used in other articles on mechanical hand prostheses (Romero *et al.*, 2019). Thus, only the study of Abdul Wahit *et al.* (2020) performed static simulation analysis in the pin junction between the fingers of the hand, providing the safety factor for an incremental load of 0.1 kg, resulting from the analysis of the breakage of the structure made of ABS for loads greater than 1.4 kg.

Regarding the manufacture and construction of the prostheses, all the articles that provided the data on printing technology used the Fused Deposition Modeling (FDM) (Abdul Wahit *et al.* 2020; Curline-Wandl and Azam Ali 2016; Gretsche *et al.* 2016; Jones *et al.* 2017; Prakash and Sharma 2020; Tian *et al.* 2017), because it is a cheaper technology and present in most three-dimensional printers, besides being the most used method for printing prostheses available on open-source sites (Ferreira *et al.*, 2018; Rahim *et al.*, 2019). However, it is observed that 8 studies did not provide the printing technology used, which may compromise the construction of the device, besides not detailing the manufacturing methodology in full. For the materials used in manufacturing, it is observed the great use of ABS and PLA, used in 9 studies (Abdul Wahit *et al.* 2020; Ccorimanya *et al.* 2019; Curline-Wandl and Azam Ali 2016; Gretsche *et al.* 2016; Hota *et al.* 2016; Jones *et al.* 2017; Prakash *et al.* 2020; Prakash and Sharma 2020; Said *et al.* 2020), because they are more studied polymers for 3D printing, having several printing parameters and tests already performed with these materials, mainly for the FDM method (Di Angelo *et al.*, 2017; Mazurchevici *et al.*, 2021).

The sensors/actuators used, associated with the type of signal, are also important for a proper functioning of the prosthesis, because they are responsible for making the interconnection between the user and the prosthetic device, providing the responses of the movement to be performed by the bionic hand. Thus, because it is a technology that presents wide employability and inexpensive options of devices, the studies of Abdul Wahit *et al.* (2020); Curline-Wandl and Azam Ali (2016); Fajardo *et al.* (2015); Germany *et al.* (2016); Mohammadi *et al.* (2020); Prakash *et al.* (2020); Prakash and Sharma, (2020); Said *et al.* (2020) and Sánchez-Velasco *et al.* (2020) used electromyography sensors (EMG or sEMG), which identify muscle activation patterns. However, in all articles, these sensors had some kind of limitation about EMG signal capitation, because they present involuntary movements of opening and closing of the hand, in addition to variations in the positioning of the electrodes for each user. The study by Prakash *et al.* (2020) applied Force Myography (FMG) to pulse width modulation (PWM) obtained satisfactory results, mainly in terms of signal capitation fluctuations.

Another important factor for the development of bionic hand prostheses is the tests in users. The studies of Ccorimanya *et al.* (2019); Mohammadi *et al.* (2020); Prakash *et al.* (2020) and Said *et al.* (2020) applied tests of grip and footprint of common objects in the day-to-day of the user and the studies of Abdul Wahit *et al.* (2020); Fajardo *et al.* (2020); Jones *et al.* (2017); Prakash and Sharma (2020); Sánchez-Velasco *et al.* (2020) and Tian *et al.* (2017) did bench tests, without direct application to the amputated user. These tests help to validate the designer and the sizing parameters of the device, since it submits the prosthesis to real situations, from the results obtained, determines whether the movement developed is indeed satisfactory for performing the daily tasks.

The results and observations reported providing a broad view of the development of bionic hand prostheses, serving as a basis for comparative futures and analyses. Despite providing various information, some articles, as shown in Table 1, no longer detail relevant requirements, such as the type of printing technology and the type of signal/control employed, which limits the complete analysis of the project developed. In addition, despite representing a significant advance, sEMG and EMG sensors still have limitations on signal processing (Curline-Wandl and Azam Ali, 2016), performing, in some cases, involuntary movements in situations of use.

Future perspectives for hand bionic prostheses involve the improvement of construction technologies (materials and manufacturing processes) and evolution in signal capture and processing. In this sense, neuroprostheses are already being studied, to restore touch and proprioception (ability to recognize the special location of the body), providing tactile control capacity through brain interface technologies (Adewole *et al.*, 2019). Evolutions in materials are also extremely linked to the development of prosthetic devices, with studies involving soft materials with a robotic interface (Mohammadi *et al.*, 2020), as well as materials that aim at better biological compliance for the user, approaching with human tissue (Marin *et al.*, 2020; Zadpoor and Malda, 2017).

5. CONCLUSION

About the development of upper limb prostheses, especially the hand, it is a complex task that becomes a big challenge imposed on engineers, doctors, occupational therapists, physiotherapists, among other professionals. Since, the hand is responsible for several functions that involve dexterity, the precision of movements, and positionings. Thus, the development and improvement of 3D printing technologies, such as the FDM type, and the application of polymeric printing materials, allow high degrees of customizations with high potential to meet all levels of hand amputations in which the conventional process of prioritization today has great constructive limitations regarding the production of prostheses. In

addition, the development of different programming languages and controllers, embedded systems applied to the motorization of bionic hand prostheses, allow to achieve and reproduce different and varied types of hand movements, which provides the development of more accurate and functional movements of the robotic prosthetic device. Finally, the application of clinical tests in patients who have received the prioritization is of great importance, since it is possible through the feedback of users to propose and perform the functional and constructive improvement of the device.

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