ARPN Journal of Engineering and Applied Sciences

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DEVELOPMENT OF TENODESIS GRIP ENHANCE ORTHOSIS (T-GEO) USING 3D PRINTING TECHNOLOGY

Shafiq Shukor[1], Natiara Mohamad Hashim[2], Nor Ayuni Che Zakaria[1] and Abdul Halim Abdullah[1]
[1]School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia
[2]Faculty of Medicine, Universiti Teknologi MARA (UiTM), Sungai Buloh Campus, Sungai Buloh, Selangor, Malaysia
E-Mail: halim471@uitm.edu.my

ABSTRACT

The spinal cord is a disease that can cause disabilities and affects the patients to carry out daily tasks. In this case study, the patient could not pinch the fingers but could flexion and extension of the wrist. The objectives of this study are to design and develop a customized adaptive device to help the respective patient. The model was developed based on the engineering design process to select the best design. The model was named Tenodesis Grip Enchance Orthosis (T-GEO) and further analyses using computational analysis to predict the product's performance. Then, the model was fabricated using 3D printing technology. Three different concepts were introduced, and the best design was selected using the pugh method. The findings suggested the product functioned well and capable of helping the patient regain the ability to pitch.

Keywords: spinal cord injury, assistive device, orthosis, 3D print, PLA.

INTRODUCTION

Spinal cord injury refers to damage to any part of the spinal cord or nerves at the end of the spinal canal. Spinal cord injury often causes permanent changes in strength, sensation, and other body functions below the injury site [1]. According to World Health Organization [2], about 25,000 to 50,000 people worldwide suffer from the spinal cord injury annually. Most of them were caused by preventable causes such as road traffics crashes, falls, or violence. People who suffer from spinal cord injury are most likely to die prematurely than people who do not. Therefore, assistive devices are essential to spinal cord injury patients. Assistive devices are products, a set of equipment, or even a system to improve the working, learning, and daily activities of people with disabilities [3]. However, in the low-income and mid-income country, not every people have access to assistive devices. Only 5% to 15% of people who need assistive devices have access to them. The device's production was limited due to higher costs and little trained people and expertise [4].

In this study, orthosis for spinal cord patients was designed and developed. The patient had lost the ability to grip the fingers but still could extend and flex their hands. Therefore, the designed orthosis will help the patient grip properly by the extension and flexion of the hands. The assistive device was named Tenodesis Grip Enhance Orthosis or T-GEO. This project aims to design and analyze the customized orthosis T-GEO model using commercial Computer-Aided Design (CAD) software. The best design was selected and fabricated using 3D printing technology.

MATERIALS AND METHOD

This project involved several design processes, including the definition of a problem, development of concepts, selection method, computational analysis, and fabrication.

Problem Definition

The development of the product was initiated by interviewing the patients conducted by the medical team from the therapist clinic in Universiti Teknologi MARA (UiTM) Hospital. Patients will share their problems in carrying out daily tasks or suggest some improvements from the existing aid devices provided. The recorded data will benefit most to the team to identify the suitable features in customizing the products. In this study, the patient experienced the loss of pinching ability in both hands. However, he still manages to flex and extend his hands. Few data were identified and measured to create the customized product, as listed in Table-1.

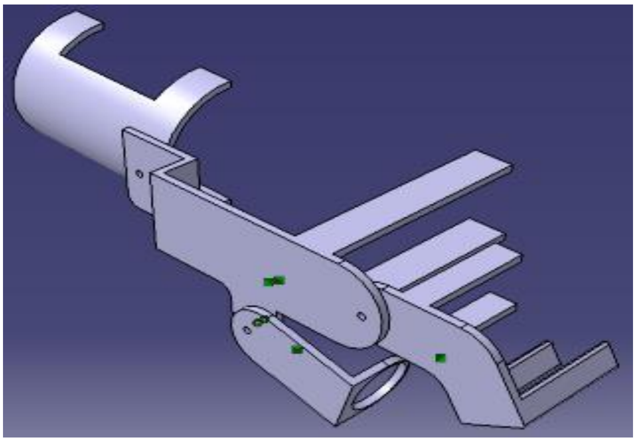
Table-1. The size of the patient's index finger and middle finger.

Finger	Length	Wide	Thickness
Index	0.09 m	0.02 m	0.02 m
Middle	0.1 m	0.02 m	0.02 m

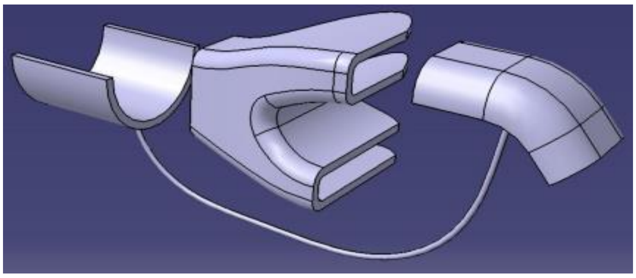
Development of Product

Three conceptual designs of the intended products were developed, as illustrated in Figure-1.

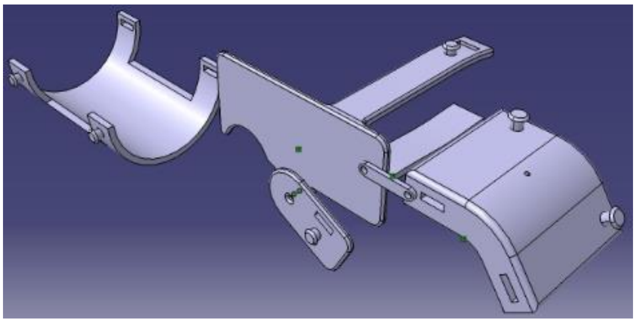
VOL. 16, NO. 24, DECEMBER 2021 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences



(a) Concept 1



(b) Concept 2



(c) Concept 3

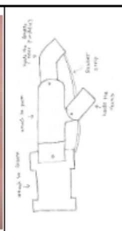
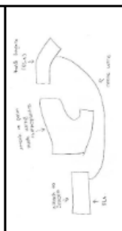
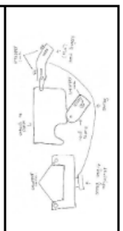
Figure-1. Conceptual designs in developing the T-GEO.

Selection of Solution

In evaluating for the best design, the Pugh chart was used, as shown in Table-2. The Pugh chart is a tool used to compare the method against criteria in the early stage of the design process. The design that has the highest total score will be selected to be modelled [5]. Several criteria were identified: aesthetics, comfort, numbers of parts, simplicity, weight, cost, and materials, and compared with the datum selection. The datum was a device that had the same function but different mechanisms and materials.

Based on the table, Design 1 was chosen due to the number of scores. Design 1 has the most uncomplicated design, and the mechanism is low-cost and lightweight. The materials used are PLA which is less expensive and shared in the 3D printing industry. Design 2 has better aesthetic value; however, the materials that plan to be used are thermoplastic because it is more comfortable than PLA, but thermoplastic is way more expensive than PLA. The mechanism also used steel cable, which is not recommended for AAD. The third design also used PLA material, but the mechanism is a bit complex and may be difficult to print and have many parts.

Table-2. The Pugh charts.

Criteria	Weight	 Datum	 Design 1	 Design 2	 Design 3
Aesthetics	2	0	-	+	-
Comfort	2	0	-	+	+
Number of parts	1	0	++	++	-
Simplicity	1	0	++	0	0
Weight	1	0	++	++	+
Cost	2	0	++	--	++
Materials	1	0	+	+	+
+		0	11	9	8
0		7	0	1	1
-		0	4	4	3
Total		0	7	5	5

Modelling

The selected design was modelled using computer-aided design (CAD) software. The model consists of four parts: parts 1, 2, 3, and 4. The overall thickness of the model is 3 mm, as shown in Figure-2.

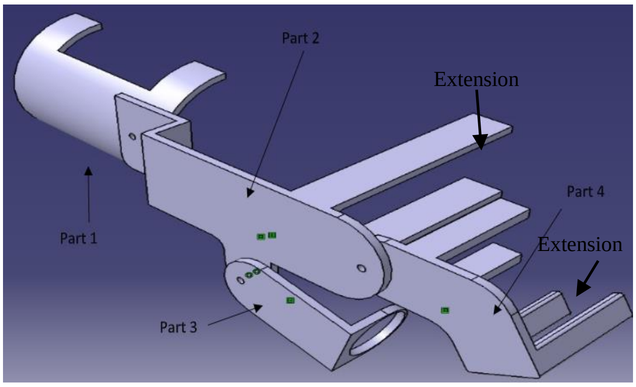


Figure-2. 3D model of the selected design concept

Computational Analysis

As the 3D model of the products was developed, the analysis of the products will be made. The analyses that will be made are the bending analysis to study the deformation of the products when force is applied and the Von Mises analysis to examine the strength of the products and the distribution of stress when pressure is applied. The study was also made by using the Catia software for modelling and analysis, and simulation purposes.

The material that has been used to make the device is polylactic acid (PLA). PLA is considered eco-friendly and biodegradable material. The price is also low, thus making this material commonly used in 3D printing. PLA was made using renewable sources like sugar in

VOL. 16, NO. 24, DECEMBER 2021 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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maize and sugarcane. PLA also has better toughness compared to other plastics.

RESULTS AND DISCUSSIONS

Stress Analysis in T-GEO Model

The strength of the model was analyzed and discussed on the resulting stress distribution. Different loading magnitudes were applied on each part to represent the mass of each component, as shown in Table-3. Meanwhile, Table 4 shows the force acting at the fingers. The volume of the fingers obtained from the interview session was converted into mass and loading force.

Table-3. The masses of all parts.

Parts	Mass (kg)
1	0.019
2	0.028
3	0.005
4	0.012

Table-4. The force of each finger.

Finger	Volume (m^3)	Mass	Force (N)
Index	$3.6x10^{-5}$	0.0355 kg	0.3483
Middle	$40x10^{-5}$	0.0394 kg	0.3865
Total force			0.7348

*Density of human body = 985 kg/m^3

Figure-3 shows the analysis of part 2. The loads applied to the parts are listed in Table-5. Part 2 is the central part of T-GEO. Other parts were attached to part 2. Part 2 has three assembly holes, as shown in the figure. At hole 3, the total force is the sum of part 4, and the weight of two fingers (index finger and middle finger) as part 4 will support both fingers. Therefore, the forces exerted on part 2 are the weight of all parts attached to it at the assembly holes multiplied with g = 9.81 m/s^2). The analysis shows that only the end of the upper extension exerts the maximum force (0.111 MPa) because the upper wing will support the parts from falling.

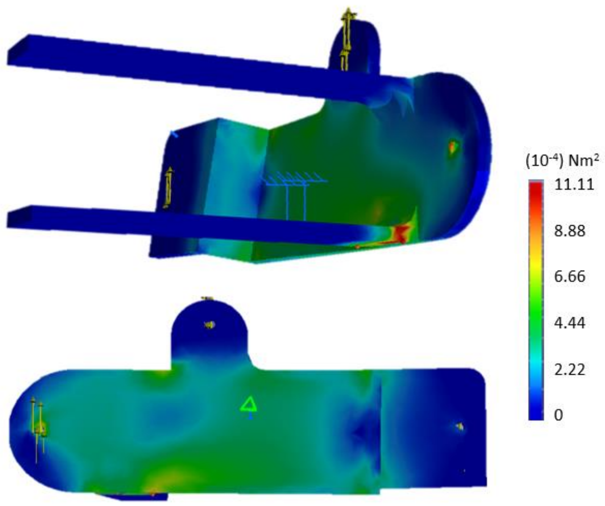

Figure-3. Stress distribution in Part 2 at different views.

Tenodesis effect is when the wrist undergoes flexion, and the fingers undergo extension and vice versa [6]. During stretching, the T-GEO will help the fingers grip as the string used in the device becomes shortened due to the wing, and during flexion, the fingers will be released as the string released. In other words, the functionality of the T-GEO is like the tenodesis effect. Tenodesis effect is a biomechanical occurrence that has been taken for granted. The human hand and fingers are just like the pulley system.

Table-5. The forces acting on the part 2.

Holes	Load Type	Mass (kg)	Force (N)
1	Part 1	0.019	0.1864
2	Part 3	0.005	0.0491
3	Part 4 and both fingers	0.0869	0.8525

The analysis of Part 4 is presented in Figure-4. The forces exerted are the total force shown in Table-3. The amount of energy exerted on extensions 1 and 2 is shown in Table-6. Extension 2 exerted 10.4 N more compared to extension 1 due to the approximate pinching force required to pinch a fork based on the literature reviews that have been done [7]. In the final product, a rubber strap will be attached to extension 2, and theoretically, the rubber strip will create the pinching force (10.4 N). The maximum stress exerted was 28.98 MPa at the assembly hole.

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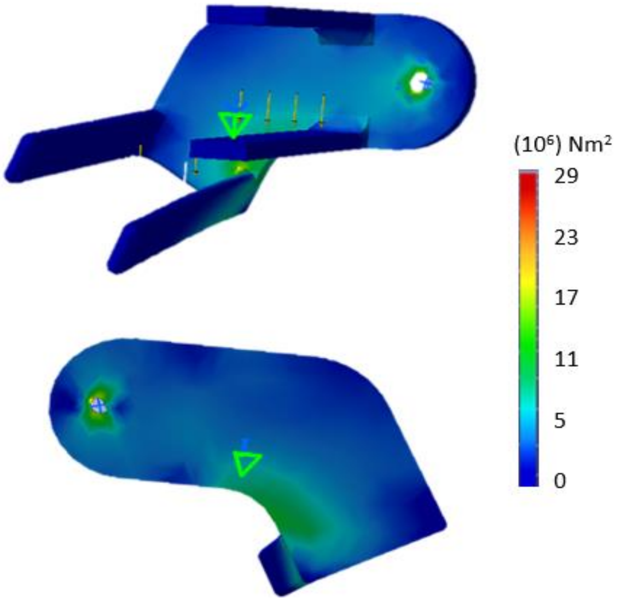

Figure-4. Stress distribution in Part 4 at different views.

Table-6. The forces exerted in Part 4.

Extension	Load Type	Force (N)
1	Both fingers	0.7348
2	Both fingers and pinch force	11.1348

3D Printing Prototype

The 3D printing method is famously used nowadays, especially in creating a 3D product from a design or model by fusing the materials in layers [8]. 3D printing was used because the research that few researchers have done shows that 3D printing was proven to yield many benefits as its ease of customization, low cost, less lead time, able to produce complex geometry, variety of materials, and stabilizability [9].

The 3D printer machine that has been used is Creality Ender 3. Before printing, the CAT part files must be converted to stl files so that slicer software can read the files. Slicer software is software that converts the 3D model in stl files into g-code files. During the slicing process, the 3D models were sliced into thousands of layers. Then later, the g-code files were inserted into the machine for printing. The slicer software that has been used is Ultimaker Cura 4.3 version.

Figure-5. The 3D printed prototype.

In making the model prototype, the parts design or the CAT part files were converted into the.stl files because the Ultimaker Cura, the slicer software for the Ender 3 machine, only understood stl files. All the STL files were opened in the Ultimaker Cura software, and few settings have been made. The temperature of the nozzle was set to 210 °C while the bed temperature was 60 °C. The setting was suitable for PLA filament material. For the printing definition or the layer, the printing height was set to 0.2 mm as the nozzle size was 0.4 mm.

The infill was set to 40% in this prototype as the 100% infill setting will consume much printing time and materials. Later, all the printed parts were assembled by using the riveting technique. A 1.75 mm diameter PLA pin was inserted through the hole, where two pieces were assembled. Then, each end of the PLA pin will be heated and push or ram to get a flat surface. The ends will cool down and harden, thus holds the parts together. It was the alternative as the screw can easily rust and even cause injury to the product's personality. For the mechanism, a rubber strip was attached to part 1 and part 4 using superglue; the rubber strip acted as a tendon. When the user flexes the hand, the rubber strip becomes shorten and pull the fingers close. Therefore, creating a pinching effect.

CONCLUSIONS

3D model of T-GEO was successfully developed by implementing the design process. Few conceptual designs have gone through selection based on the design's cost, comfort, functionality, and simplicity. The analysis helps to understand the performance of the product and further improvements to be made. The fabrication of the prototype using 3D printing technology indicated the PLA materials are sufficient for the development and cost-effective.

ACKNOWLEDGEMENT

This research was supported by Universiti Teknologi MARA (UiTM) under Grant No. 600-IRMI/FRGS-RACER 5/3 (106/2019). We thank and acknowledge the Ministry of Education, Malaysia, and our colleagues from the Faculty of Medicine and School of Mechanical Engineering, UiTM.

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