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Modeling and Analysis of Finger Splint for Mild to High-Grade Mallet Finger Fracture

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Abstract: Fingers tend to be most prone to injuries in falls, accidents, and burns, and de-spite this, the treatment options tend to be highly limited, costly, deprived of ergonomics conforming to the patient requirements. CAD modeling offers a considerable solution for providing a product design for patient-specific splint for musculoskeletal while three dimensional model simulations provides a way to build comfortable splints with the least material use and most efficient mechanical and thermal capabilities. This hence benefits us in reducing material wastage and reducing cost. Reduction in material results in efficient heat dissipation which in-creases the breathability of the patient's finger inside the splint and makes the splint sweat efficient and hence conforming to the patient requirements with in-creased ergonomics and maintaining hygiene

Keywords: Product Design, Splint, CAD, Simulation, PLA

1. Introduction

Injuries occurring in the upper section of Mallet Finger happens to be the most generally occurring limb athletic injury[1)] and is also common among various age groups. Phalangeal fractures are commonly found in 9-12 aged children and metacarpal fractures are more common to older adolescents[2)]. This injury tends to affect the lifestyle of the patient by disrupting him/her from their daily activities involving both domestic and professional work-related life[3)].

Current treatment measures involve both surgical and non-surgical treatments de-pending on the extent of the fracture[4)]. Studies show that at least 70%–80% of fractures in hand can successfully be treated without surgery[5)]. Non- Surgical treatment on phalangeal fracture involves treatment is closed reduction and splinting[6)]. Splints made of thermoplastics are applied to the affected joint of the patient to immobilize it. Splints can be pre-fabricated, but widely splint is cast on the patient's finger. It can be seen that the effect of splinting is dependent on the skills and experience of the trained professional. And in many cases with trained professionals, the outcomes have been not satisfying due to non-adherence correlating to decreased outcomes[7)]. In addition to being a labor-intensive task, it also creates a lot of waste, and material consumption is fairly high. Advantages of 3D-manufacturing orthosis include cost reduction, easier modification concerning patients' parameters, and faster fabrication[8)].

Judicious and Efficient use of additive manufacturing process (3D printing) can offer a reduction of weight hence increasing breathability, improvement in heat dissipation, and making comfortable splints for the patient[9)].Furthermore, FEA can be used as an accurate method for computational analysis[10)] also helping in saving time and cost[11)]. This paper brings a study and investigation on the use of 3-D modeled patient-specific splint in reducing material wastage and cost, making the use of previous investigations done on mallet finger injuries.

1.1 Injury on the Mallet Finger

This happens to be the most commonly occurring limb injury on the finger, in this kind of injury the ability of extensor of the finger is disrupted, causing inaction to extend at distal interphalangeal joint[12)].

This is caused due to either the rupture of the extensor tendon or avulsion fracture[13)] of distal phalange. With the inability to extend to the distal phalanx, swelling and tenderness can also occur and an extension lag ranging from a couple of degrees to a couple of dozens can also occur.

The injury can be caused by either a distal phalanx facing a direct blow or else due to blunt injury caused on the distal interphalangeal joint[15)]. This injury is seen common in teens and children and athletes.

This injury can derive economic disruptions involving both direct, indirect, and many other intangible costs which can differ with the severity of the injury. If left untreated, there can be functional shortfalls, impeding the whole hand in everyday motor tasks.

The treatment of the fracture can be done using two ways depending on the severity and type of fracture firstly surgically and secondly non-surgically, in most of the cases treatment using non-surgical are generally preferred over the surgical methods[16]. For Non-surgical treatment use of an immobilization device named Splint is made commonly. The splint is designed such that it immobilizes the affected region offering a limited flexion in some cases, while the avulsion fracture or tendon heals.

Currently used splints made of thermoplastics require the assistance of experts and in many cases with trained professionals also the results were not as desired. With material consumption being high and user comfort being disrupted, CAD modeling and simulation analysis can provide a way to eliminate the aforementioned issues.

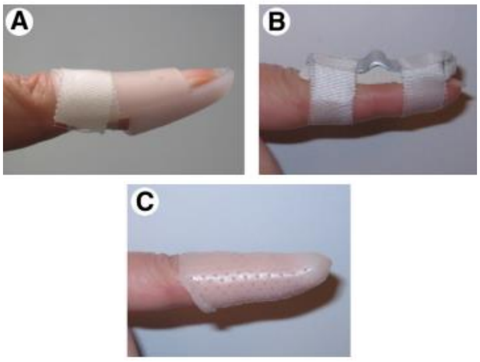


Fig. 2: Current treatments (A) an example of Stack split; B)making use of Dorsal aluminum; (C) by the means of Custom thermoplastic[17]

2. Design and Methods

2.1 Splint Material Selection

Multiple considerations for the materials for splints were made, in accordance that they can prove better than the thermoplastic splints applied previously, The materials include PLA (i.e., Poly-lactic-acid), ABS (i.e., acrylonitrile-butadiene-styrene), Polyurethane and polycarbonate, etc. As splint can't be passed on from patient to patient, wastage generation and composting ability were considered to be key criteria in material selection. According to a medical survey done by the N.A.M.C.S in collaboration with A.A.O, on an average 670,000 kg of waste occurring due to fractures, is produced per year[18]. PLA on the other hand is biodegradable, as it is derived from natural sources, and hence can be composted after its use, and has several uses in medical and packaging industries.[19]

Other Advantages of PLA**:**

1. Eco-Friendly
2. Bio-compatibility
3. Energy Saving
4. Processability

PLA is made using renewable sources which include corn, wheat, Rice hence is biodegradable, And compostable. Along with this during its Production it consumes CO2

Lactic acid is the main PLA Degradation Product which non-toxic organism itself

About 25–55% reduction in energy consumption takes in PLA against those of petroleum-based polymers.

It has an efficient thermal processing ability due to which it can be processed via multiple techniques.

Hence PLA is used for investigation in this study as it is suitable for the manufacturing of temporary fixtures for biomedical applications[21]

2.2 Modeling of Splint

The Personalized splint measurements were taken using the parameters derived from the index finger[3] of the user given in Figure 3.

Using Solidworks (2017) CAD modeling platform and the measurements of parameters taken from the patient's index finger, the splint has been constructed. The user can clinch his fist during some operation with the material not removed which can result in pushing of the skin of the region of mid-phalanx inside the splint to prevent this and provide some space is added to the design present on the back of splint. The front is provided with an open section for ventilation to occur so that air can pass and help in reducing sweat and will also provide opening to ensure washing. The upper face reaches to the proximal interphalangeal joint which will allow the patient to ensure flexion on the joint of the finger preventing any problems in the recovery. Finger regions have been kept exposed to the environment so that they can function during the recovery stage which could have not if thermoplastic settling was done. Slots and holes are provided in the splint so for the reasons of increasing breathability, reducing the weight, increasing limited flexibility, increasing heat dissipation and airflow which hence reduces sweat collection[22]

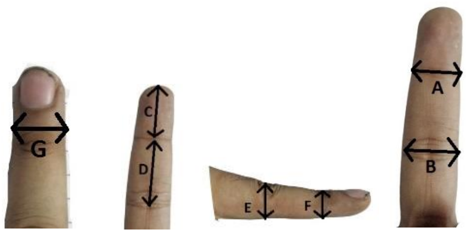


Fig. 3: (A) 7 parameters that were measured to create the CAD model of the splint

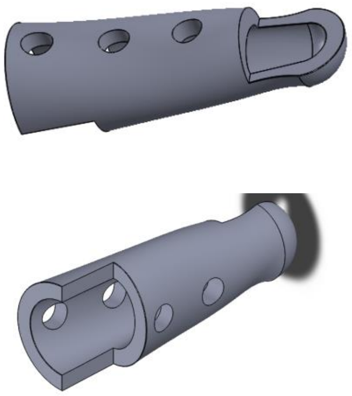


Fig. 3: (B) CAD model of the splint

The benefit of using Computer-Aided Modeling was that user’s finger was not exposed to heating environments where thermoplastics are straightly set on their fingers. Splint’s optimum thickness was taken 3.2mm providing a volume reduction of 35% against commercially available splints[23].

2.3 Analysis and Simulation of Splint

Finite element analysis has been conducted using ANSYS as it been used previously[24], to get desirable results.

Static Analysis. Static Structural Analysis on the splint was done using ANSYS 2016, Material taken was as mentioned PLA, with Young’s Modulus 2850 MPa, Yield Strength 26.05 MPa Poisson’s ratio 0.3 were defined as the mechanical properties during the testing of the splint. The maximum pressure applied on the splint was taken to be 0.66MPa[25].

The splint’s rear face was taken as the fixed geometry shown in Figure 4 (A) and the tip of the splint was tested with the value of pressure applied taken 0.66MPa as shown in the Figure 4 (B). The impact of holes on the splint’s strength was also investigated.

Thermal Analysis. Given splint was investigated for temperature distribution and total heat flux distribution was calculated. Using ANSYS 2016 Thermal analysis (steady state) was performed on the splint. Splint’s interior was taken to be at 34 ° Celsius[26]. The ambient air temperature was taken to be 22° C, convection coefficient 10 Watt/meter^{2}K. and total thermal heat generated by the body of the user was taken as 110W with a surface area of 2m^2 [27-28].

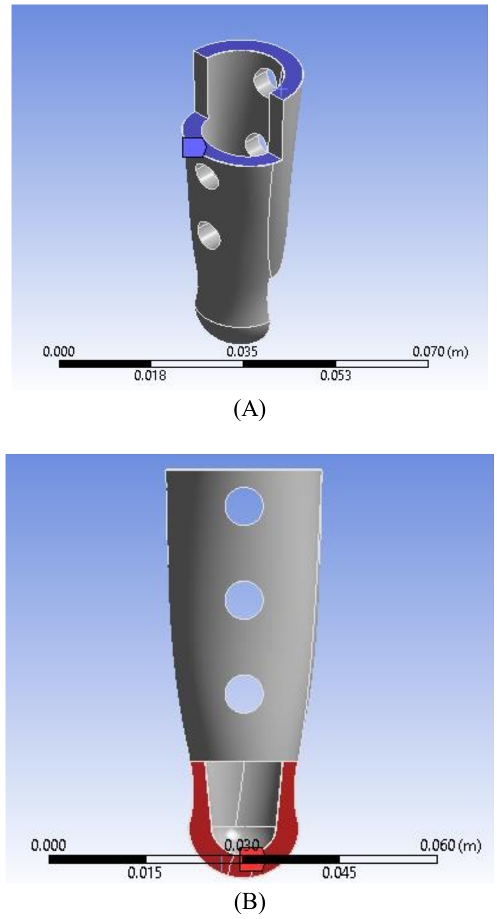
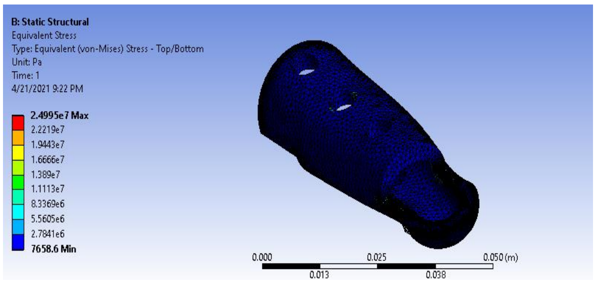


Fig. 4: (A) Fixed Geometry (B) Application of pressure

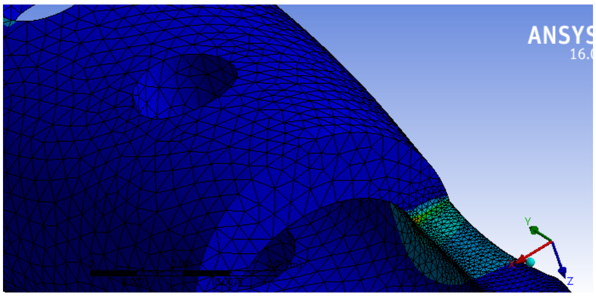
3 Result

The modeling of the splint was done is Solidworks 2017 using the parameters given in section 2.2. In the simulation of the splint, the fixture was taken as the rear part of the splint and was consistent during both thermal and static analysis. To implement the mesh convergence study in the simulation, the pressure value was applied at the tip of the splint (or front) as shown in Figure 4

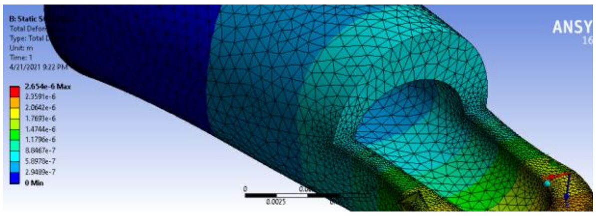
In static analysis results of Von Mises deformation and Von Mises equivalent stress-plots were calculated after continuously refining the mesh. Stress and Deflection value was calculated using ANSYS 2016 to embed the best mechanical properties to the printed splint. Obtained Stress and deflection plot can be seen in the Figure 5A, B & C. Stress concentration was observed in the corner between the rim of the upper part of the splint and the rim containing the tip as can be seen in the Figure 5B. Above region was also the region where maximum stress was measured. The highest value of the deflection was derived at the pads rim.



(A)



(B)



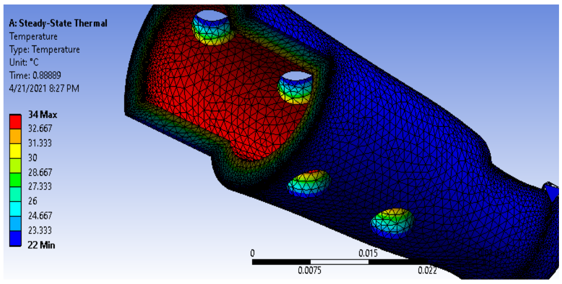
(C)

Fig. 5: (Up to bottom) (A) Equivalent Von-Mises stress distribution (B) Maximum Stress Region (C) Total Deformation distribution

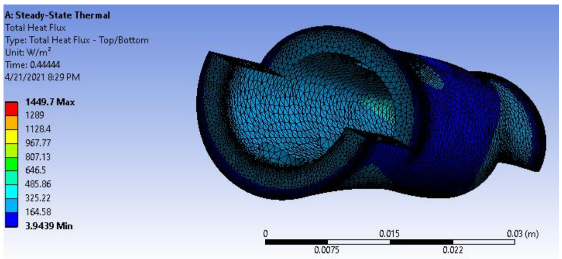
For product designing of the splint, the thickness was taken to be 3.2mm which pro-vided reduction of material and hence increased breathability.

It can be seen in the static structural simulation that maximum stress (Equivalent Von mises stress) occurred in corners of the front rim touching the upper body rim with a magnitude 24.9 MPa which tends to be under the yield strength (26MPa) and hence showing that under the given thickness the material can perform well in distributing the load and withstanding real patient conditions. The maximum deflection (von mises) can be seen on the tip of splint which is 2.64e-06m (0.00264 mm) again showing that under the given thickness the splint performed better than the previous studies.

The results of total heat flux and temperature distribution across the splint and temperature distribution of the splints were analyzed and simulated whose results have been provided in Figures 6 A & B, in can be seen that the splint perform efficiently in heat dissipation and distributing the temperature.



(A)



(B)

Fig. 6: (Up to bottom) (A) Temperature Distribution (B) Total Heat flux

The design was implemented with placement of holes and it can be seen that it not only reduced weight and increased breathability but also helped in improvement of heat dissipation and hasn't cost us reduction in mechanical parameters of the splint, hence proving to be a good trade in the splint

4 Conclusion

Applying the principles of Product Design, an efficient splint design was modeled on CAD modeling software (solidworks), it was investigated and verified that under the given material and parameters, the splint worked well in Static Structural analysis and Steady-State thermal analysis, the placement of holes helped in increasing breathability and didn't affect the mechanical parameters of the splint hence it can be used to increase the efficiency of a splint. The Material PLA not only will help in contributing its worth to the environment but also proved efficiently under simulations and was verified to be used as a material for the development of splints instead of the previously used thermoplastics. The results of this study will give the path to the interdisciplinary study between the medical and engineering industry to utilize advanced modeling and manufacturing methods for the development of sustainable splints and other related products.

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Nomenclature

CAD:	Computer Aided Design
PLA:	Poly-lactic-acid
ABS:	acrylonitrile-butadiene-styrene
MPa:	Mega-Pascal
NAMCS:	National Ambulatory Medical Care Survey
AAO:	American Academy of Orthopedics

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