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Application of Additive Manufacturing in Orthopedics for TFCC Tear

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Abstract:- In the field of orthopedics, the use of additive manufacturing (AM) has skyrocketed. Anatomic models, surgical instruments and tool design, splints, implants, and prosthetics are all examples of AM applications. A review of several research papers reveals that patient-specific orthopedic procedures have a wide range of applications and can help guide future development. This work aims to figure out how to make the most of additive manufacturing applications in the orthopedic field. It also explains how to prepare a 3D printed model using this technology and gives examples of orthopedic applications. In the field of orthopedics, AM provides a versatile solution in which customized implants can be molded to the appropriate shape and size, allowing for replacement with customized items. This technology creates a 3D model of the patient's anatomy that can be used to conduct mock procedures and is useful for extremely complex surgical pathologies. A plaster cast is mainly used for the treatment of fractures but it has some side effects such as itching, burning sensations, etc., so an alternative made of PLA material(which is devoid of the mentioned side effects) is developed. This model is developed for curing TFCC(Triangular Fibro Cartilage Complex) tear which is a type of fracture that may take as long as 12 weeks to heal. The model is designed in such a way that it should fit any person no matter what the size of their hand is. It simplifies the surgeon's job and improves the operation's success rate. By allowing for infinite geometric flexibility, AM allows for a better fit implant for each patient Various scanning methods are used to capture the status of bone defects, and this technology is often used to print the model. It produces a precise physical model that can be used in medical education, surgical preparation, and training. Since each patient's data is unique, this technology will aid in the resolution of current issues.

Index Terms- *3D printing, Additive manufacturing (AM), TFCC.*

I. INTRODUCTION

Additive manufacturing (AM), also known as 3D printing, is a transformative approach to industrial production that enables the creation of lighter, stronger parts and systems.

It is yet, another technological advancement made possible by the transition from analog to digital processes. In recent decades, communications, imaging, architecture, and engineering have all undergone digital revolutions. Now, AM can bring digital flexibility and efficiency to manufacturing operations.

Additive manufacturing uses data computer-aided-design (CAD) software or 3D object scanners to direct hardware to deposit material, layer upon layer, in precise geometric shapes. As its name implies, additive manufacturing adds material to create an object. By contrast, when you create an object by traditional means, it is often necessary to remove material through milling, machining, carving, shaping, or other means.

Although the terms "3D printing" and "rapid prototyping" are casually used to discuss additive manufacturing, each process is a subset of additive manufacturing.

II. PROBLEM IDENTIFICATION

A fracture is a complete or partial break in the bone. It is a commonly occurring problem among people all around the globe. The treatment for a fracture is mostly immobilization by using plaster casts which are made up of plaster of Paris. Plaster of Paris can be used not only for the treatment of fractured bones but also supports sprained ligaments, inflamed and infected soft tissues. There are many complications or side effects in using plaster casts. plaster casts are widely used among people for fracture reduction. Most of them are unaware of the complications the plaster casts can cause. Patients with diabetes or sensory impairment are those who need particular attention at the time of plaster application and later. The side effects of plaster of Paris include itching, ulceration, and rashes. It can also cause some severe complications such as deep vein thrombosis. compartment syndrome, soft tissue swelling, pressure sores, and venous congestion.

- *Triangular Fibrocartilage Complex*

The Triangular fibrocartilage complex is the area between the radius and ulna, the two main bones that makes up the forearm. A TFCC tear is an injury in this area. It is also caused by the slow breakdown of cartilage in TFCC usually due to aging, accidents, or an underlying condition such as rheumatoid arthritis.

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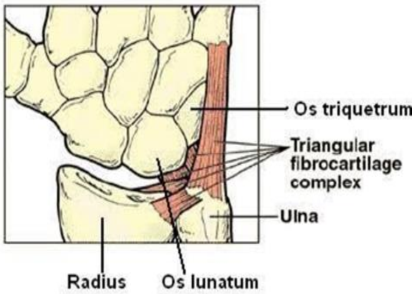

Fig1. Triangular fibrocartilage complex

The main symptom of a TFCC tear is pain along the outside of your wrist, though you might also feel pain throughout your entire wrist. The pain may be constant or only appear when you move your wrist or apply pressure to it.

III. OBJECTIVE

The main objective is to design a splint that has lesser complications compared to plaster casts. In this research, the splint is designed for correcting the tear that occurred in the triangular fibrocartilage complex (TFCC). TFCC tear causes pain along the outside of the wrist though pain may be felt through the entire wrist. First, to understand the problem a study has to be done. So, a survey has to be undertaken to know the nature of the fracture, its causes, and the treatment involved in curing the fracture. Another important condition is knowing the disadvantages in using plaster of Paris and decreasing the side effects in the product to be developed.

The splint should be developed in such a way that it should fit all the age groups and any person no matter the size of their hands. As mentioned earlier the material should be selected in such a way that it doesn't reflect the side effects caused by plaster casts.

➢ *Plaster of Paris*

Plaster of Paris, quick-setting gypsum plaster consisting of a fine white powder (calcium sulfate hemihydrate), which hardens when moistened and allowed to dry. Known since ancient times, plaster of Paris is so-called because of its preparation from the abundant gypsum found near Paris. Plaster of Paris does not generally shrink or crack when dry, making it an excellent medium for casting molds. It is commonly used to precast and hold parts of ornamental plasterwork placed on ceilings and cornices. It is also used in medicine to make plaster casts to immobilize broken bones while they heal, though many modern orthopedic casts are made of fiberglass or thermoplastics. Some sculptors work directly in plaster of Paris, as the speed at which the plaster sets gives the work a sense of immediacy and enables the sculptor to achieve the original idea quickly. In medieval and Renaissance times, gesso (usually made of plaster of Paris mixed with glue) was applied to wood panels, plaster, stone, or canvas to provide the ground for tempera and oil painting.


Fig 2 Plaster of Paris powder

Plaster of Paris is prepared by heating calcium sulfate dihydrate, or gypsum, to 120–180 °C (248–356 °F). With an additive to retard the set, it is called wall, or hard wall, plaster, which can provide passive fire protection for interior surfaces.

➢ *Disadvantages of Plaster of Paris*

- Prolonged immobilization in a POP makes the skin under the cast vulnerable.
- The dead skin is not removed and leads to scaling.
- Other complications like:
- ulceration
- maceration
- itching, can result.
- Even burns can be caused by the exothermic reaction.
- Staphylococcal infection of the underlying skin can result in dermatitis.
- Cast syndrome, associated with body jacket casts, involves obstruction of the third portion of the duodenum from duodenal constriction caused by stretching of the superior mesenteric vessels.

➢ *The symptoms are*

- nausea
- vomiting
- fever
- electrolyte imbalance.
- The most dreaded complication, however, is compartment syndrome and the resulting sequelae of Volkmann's ischaemic contracture.

IV. COLLECTION OF IDEA

A. *SURVEY DATA-1*

The Survey-1 is all about finding the frequent type of fracture occurring to the patients. We decided to take a survey in our city. The survey was taken because some data was required before designing the product and the product should meet the patient's requirements in the future. To begin, as a field survey team comprising of 2 people, we started to interact with the residents of our city, with the aim of collecting data from people who suffered from a hand fracture in the past. Many people provided valuable insight and stated the type of fracture they had suffered and also provided the reasons for their fracture. The survey also included the age of the patient, gender, place of injury, period of recovery. In the survey, we also wanted their feedback for two important questions. The two questions were:

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- *Disadvantages of Plaster of Paris (POP)*
- *Opinion On 3D Printed Equipment As Alternative To POP*

Table 1 Survey-1

S.NO	AGE	GENDER	CAUSE OF INJURY	PLACE OF INJURY	PERIOD OF RECOVERY

Disadvantages of Plaster of Paris?

Opinion on 3D printed equipment as alternate to POP?

- *SURVEY – 1*

Table 2 Survey-1

S. No.	Patient	Age	Gender	Cause of injury	Place of injury	Period of Recovery
1	Sathya	26	Male	Playing football	Hand (wrist)	6-12 weeks

- *Disadvantages of plaster of Paris?*

Occurrence of Skin allergies & Rashes, Rotten smell from the skin, and inability to perform their routine tasks with a heavy POP splint around their wrists.

- *Opinion on 3D printing equipment as an alternative to POP.*

- I - More welcoming to wear a handy, light-weighted, and made out of an efficient material.
- II - Open to opting for it as it doesn't cause any side effects.

B. SURVEY DATA-2

The second survey is all about choosing the measurement for designing the hand-cast. Our research is based on the idea "ONE SIZE FITS FOR ALL" and hence we had to take a survey on certain parameters of hand measurements to design the cast that suits effectively for everyone. This time the data was collected with the help of thread and a measuring tape. The first step was to take measurements of certain parameters from the hand. The parameters include:

- Wrist Circumference
- Palm Circumference
- Palm Length
- Hand Length
- Mid Fore Arm Circumference

All these measurements that were taken were compared with the standard values which were obtained with the data from the internet. The measurements were taken from an inch tape. And for easy calculation, the data was converted into centimeters. In the case of measuring the circumference, a thread was used and converted the value by placing it in the inch tape.

- *SURVEY – 2*

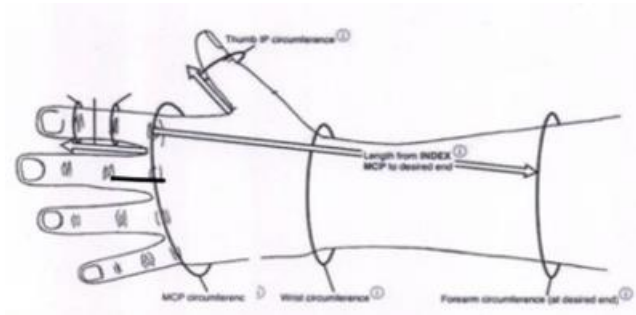

Fig 3 Measurement of hand

V. DATA ANALYSIS

A. Analysis From Survey-1

The details from the survey-1 were analyzed thoroughly before drawing a conclusion. The first survey was important as it provided us with a clear idea about the frequent type of fracture that had occurred among the people. It was found that the TFCC was the most occurred one of all hand fractures. The possibilities of boxer and finger were far low compared to others. During the analysis, it was found that nearly 50% were injured with TFCC tear. The report of survey 1 is shown below.

SURVEY-1 REPORT
Total no of patients - 42
Number of males - 22
Number of females - 16
Number of children – 4
No of patients suffered from TFCC tear - 20

B. Analysis From Survey-2

The second survey helped to finalize the information on the design. To complete the design the measurements of certain parameters were needed and it was obtained with the help of survey-2. By comparing it with standard parameters, the measurements to design the hand-cast were taken. In the case of the palm circumference, XL size is selected as the large group of people had that size. And XXL size is selected in the case of Palm length. In the case of Wrist, circumference M size is preferred. The report of survey 2 is shown.

Table 3 Survey

Name	Age/Sex	Arm Length	Palm Length	Wrist CF	Hand Length	Mid-Forearm CF
Akilesh	22/Male	28.2 Cm	11.3 Cm	16.8 Cm	45.7 Cm	27.6 Cm

**CF- circumference*

➢ *PALM CIRCUMFERENCE*

Table 4 Palm circumference

Standard size (cm)		No. of patients
S	17.8-19	9
M	19-20.3	7
L	20.3-21.6	15
XL	21.6-24	11

➢ *PALM LENGTH*

Table 5 Palm length

Standard size (cm)		No. of patients
S	6-6.5	0
M	6.5-7.5	0
L	7.5-8.5	4
XL	8.5-9.5	10
XXL	Above 5	28

➢ *WRIST CIRCUMFERENCE*

Table 6 Wrist circumference

Standard size (cm)		No. of patients
S	15.24-16.51	12
M	16.51-17.78	28
L	17.78-19.05	2
XL	19.05-20.32	0

➢ 4.MID FOREARM CIRCUMFERENCE

Table 7 Mid forearm circumference

Standard size (cm)		No. of patients
S	18.3-21.6	6
M	21.6-24.9	11
L	24.9-28.2	21
XL	28.2-3.5	4

C. Data Collection - Summary

Thus the overall summary from the data collection is that the most frequent type of fracture is TFCC. And thus we selected to design the health care equipment for that fracture. From the feedback, we concluded that many people are most welcome to a change in treatment for the types of fracture. During the feedback, it was really surprising to know the various disadvantages of POP. Many complained about the POP that it causes sweating, ulceration, rashes, and they felt discomfort as it is difficult to perform their routine tasks. Moreover, they cannot be on their own while wearing POP as it causes much trouble to them and also they need assistance from someone all the time. Overall the data collection procedure helped us to gain more confidence in the research.

VI. DESIGN PROCESS – INITIAL STEP

Fig 4 Scanned copy of hand

To design the hand-cast, the basic elementary step needed is to obtain a scanned image of the hand. In order to obtain the scanned copy of the hand, the hand should be scanned into a 3D scanner.

After obtaining the scanned image of the hand, the hand model has to be converted into a 2D wireframe model. This is converted with the help of the design software. The wireframe model is:

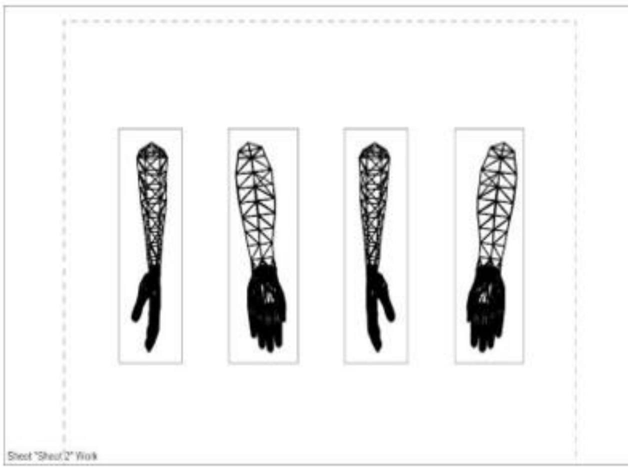

Fig 5 Wireframe hand model

➢ DESIGN OF HAND-CAST

After obtaining a 2D wireframe model of the scanned hand, the next step is to design the hand-cast. We developed the hand-cast model by obtaining the dimensions from the cast that we had made.

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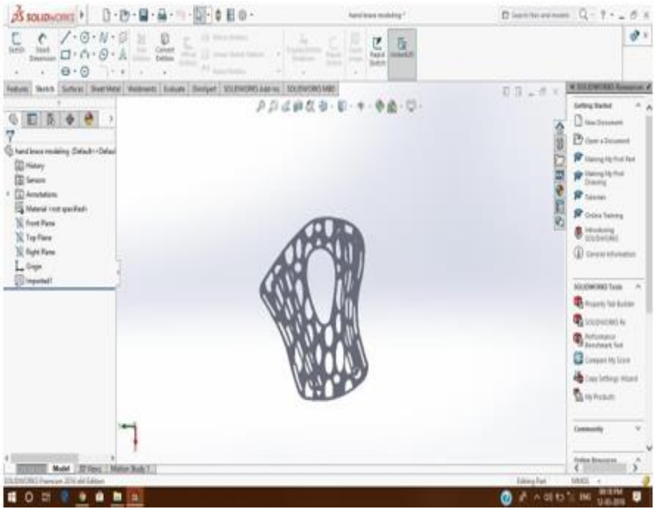

Fig 6 3D Model of Hand-cast

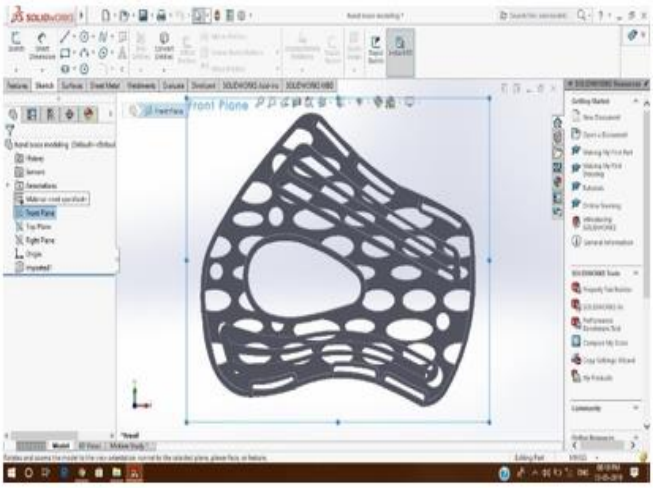

Fig 7 3D Model of Hand-cast

The material for the product demands the material to be mouldable, attractive and moreover, it should have better aesthetics. On top of that, the material should be light in weight, easily removable, personalized, and with the chance of providing a possibility to bath with it. The material of the product should overcome the disadvantages of the POP. And it should be one of the filaments used in AM technologies. Hence we went through journals that account for the filaments used in additive manufacturing technologies. There were various filaments used in them. Out of them according to our needs we shortlisted two materials namely:

- Polylactic Acid (PLA)
- Acrylonitrile Butadiene Styrene (ABS)

These are the two most commonly used filaments in rapid prototyping. The major difference between them is the temperature of attaining the semi-transition state. In the case of PLA, it attains semi transition state at 65°C whereas the ABS material attains the semi-transition state at 120°C. Our research is mainly dependent on molding the material into the shape of the hands of the patients. Hence to mold the material we should dip it into the hot water. So it is comfortable to insert the hand-cast in the water of temperature 65°C than 120°C. Moreover, the ABS filament is too costlier than the PLA material. This helps us to produce the cast at a lower rate so that it can meet the requirements of every patient who is suffering from a fracture. The completed product should be of low cost and also it should easily be available for emergency cases. Hence the PLAs material is more suitable than ABS. In the case of selecting the PLA material, color can also be selected by the patient, as there is white, black, brown, and red color. The overall cost of the product will be reduced by selecting the PLA material. Furthermore, it satisfies the condition that the material should be adjustable and user friendly as it should be intact to everyone, ultimately satisfying our motto, “ONE SIZE FITS FOR ALL”.

Fig 8 PLA Filament

➢ *PROPERTIES OF POLYLACTIC ACID*

- High Mechanical Strength
- Low Toxic Level
- UV Resistant
- High Mechanical Resistance
- Good Barrier Properties
- Specific Gravity -1.27
- Melting Point - 150°C to 160°C
- Tensile Strength – 59MPa
- Flexural Strength – 106MPa
- Elongation at break – 7.0%
- Rockwell Hardness – 88HR

VII. FABRICATION

The final product is printed in the 3D printers with the help of Fused Deposition Modelling (FDM) through additive manufacturing. In precession to 3D printing the design of the product takes place. To design the hand-cast various steps are to be carried out. The steps have some procedures before the finalized product is produced in the design software. The design software will be in the XXXX format which will be converted to a particular format depending on the type of printer selected to print the hand-cast in the PolyLactic Acid Material (PLA). The printing of hand-cast takes certain hours depending upon its feasibility and surface texture.

➢ *Experimental Setup*

The apparatus that we feel would be optimum for printing the hand-cast is Raise 3D V2 printers. These printers have full-color touchscreen monitoring control which is used to monitor and control the printing process. The incredible feature of these versions of printers is that they have a maximum z layer resolution of 10 microns. The input is given in the form of an STL file. The STL file is obtained by converting the 3D model into it. The STL file is opened using the slicing software. The next step is setting up optimum values for the various parameters in the printer.

The parameters include:
- Ink Fill
- Layer height
- Speed
- Build volume
- Maximum Temperature
- Travel speed
- Bed Temperature

These parameters are set before processing the product. Each parameter is essential for the completion of the product. Once a value in parameter gets changed the end products get any flaw. Hence while entering the input parameters one should be very careful. After setting up the parameters the G-code is generated by the software. The G-code is the common name given to the numerical control programming language. It tells the computerized machine tools to develop a product. Then the material should be loaded into the printer. The material PolyLactic Acid (PLA filament is used to print the product. Finally, the printer can be operated started by selecting the G-code. The approximate time for printing the product would be around 7-8hours. These filaments get deposited layer by layer to produce the hand-cast. The hand-cast is produced by layer by layer technology which in turn prints the hand-cast from exterior to interior edges. The FDM is better than injection molding as it takes less time and is cost-efficient.

VIII. CONCLUSION

It is clearly evincive that the occurrence of fractures is largely common in all parts of the world. And hence there is a need for the proper treatment of fractures. The only treatment for fracture has been POP so far. But the study shows that there are many disadvantages to it. Hence it is concluded that an alternate material to POP is the need of the hour. While selecting an alternate to POP, we had the task to select the type of fracture to implement the hand-cast. Hence a survey has been taken and the most frequent fracture was identified as TFCC fracture.

Fig 9 Raise 3D V2 printer

FUTURE SCOPE

We have come up with a solution to replace POP with PLA materials and designed a product for the treatment of Triangular Fibro Cartilage Complex(TFCC)Tear. The designed hand-cast can be used for TFCC tear or other similar wrist fracture that requires a POP cast for treatment at present. This design can be subjected to various design analyses before printing them and any modifications can be made if necessary. The disadvantages of its traditional treatment methods were identified and it has been overcome in this product. We took a survey in the city of Coimbatore and concluded about one frequent type of hand fracture. In the same way, a survey can be taken in other cities, to find out other similar fractures and design a product suitable for that using the PLA material and an alternate method of treatment can be produced. Using this similar method, a hand cast for Colles fracture can also be made. If further studies are made, cast for other body parts can also be made. To be more precise, casts can be developed for any kind of fracture and can be of good use to people. Medical Field is developing in all corners of the world, but unfortunately, fractures have the same old kind of treatment. Hence we should come up with innovative ideas such as this one to help millions of people suffering from fractures and other kinds of problems and provide a feasible solution to treat them better.

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