Design and Development of Modular Arm Cast Using Additive Manufacturing

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Abstract: The plaster cast and fiberglass cast are the popular elbow dislocation treatment method for immobilization. These are relatively heavy, non-removable, and poorly ventilated, hence might create skin diseases, irritation under the cast and joint injury, if not cast properly. It takes long preparation time and cannot be adjusted after casting, which may lead to improper healing in case if the bone gets little shift inside the cast. In this work, the orthopedics arm cast prototype is designed and fabricated by using additive manufacturing with ABS material. The core concept of the model is the elbow support and modular rings with a specific width added to achieve a specific support length. After properly positioning the patient’s arm the pressure on the arm can be adjusted by the small clamps with velcro straps. This has advantages over conventional cast that it provide cast adjustments, proper ventilation, washable, and reusable.

Keywords: Arm cast, modular rings, elbow immobilization, additive manufacturing

1. Introduction

An orthopedic plaster cast is a wrapped casing, made of bandage and glass wool, enveloping a fractured portion of the body to support broken bones for healing. The cast applied for the arm, wrist, and/or hand is called Upper extremity casts. The cast which envelopes the arm from the hand to about 2 inches beneath the armpit, retaining the fingers and thumbs exposed is called a long-arm cast. Similarly, the cast applied on shorter lengths on both sides of the elbow joint is termed as short arm cast.

Generally, the dislocation of the elbow occurs when the elbow joint is drawn apart. It can be partial or complete. Here we consider partial dislocation which can be referred to as a subluxation. The most common injury cause in elbow dislocation is impacted on the arm due to sudden fall. The impact force get transferred to the elbow through the forearm. So dislocation of the elbow occurs.

Generally, Elbow recaptures the original position by its nature, however if not, the orthopaedic [1] surgeon aligns it by applying force. The orthopedic surgeon applies cast plaster on this joint and support. Around four weeks are required for a complete cure for these kinds of injuries. The typical plaster casting process of elbow support is given below:

The components required for plaster forming include loosely knitted stretch fabric, cotton wadding, plaster or fiberglass [2] roll or sheets, stretchy bandages with clips or adhering tape,
high-quality scissors, and water. To start building up an elbow orthosis is to apply a protective layer using a loosely knitted stretch fabric. Then, for more comfort, the cotton wadding material is wrapped over the loosely knitted stretch fabric. The plaster sheets are soaked in water and applied over the wadding. The plaster is adjusted to the appropriate anatomical [3] position of the joint. In the last layer, the loosely knitted stretch fabric is wrapped with cotton wadding again and a stretchy bandage is used to secure the plaster. This procedure takes about 45 to 50 min. This is mostly done in the clinic and hospitals. The patient has to wait until the preparation of the cast. Moreover, it cannot be adjusted or modified after curing, which leads to skin infection, irritation, and sometimes swelling as the patient cannot wash or clean skin inside the cast. In the conventional method, the cast must be cut off and destroyed after only one use and it is being done incorrectly, it may injure the patient.

2. Problem Identification

Presently, there are arm cast and splints that are also made from additive manufacturing, but this technique is lengthy. The time required for CT scan or MRI of the patient’s elbow and hand, then preprocessing with computer software, and finally the additive manufacturing of patient-specific cast will add up to painful waiting time for the patient. Although a specific cast for each patient is the best solution, the cost and time required are the constraints, also the availability of all these systems under one roof is a major constraint. Due to these issues, there is a need of developing a modular arm cast for most of the patients having partial elbow or subluxation. The new concept should have attributes such as short preparation time, does not require specialist or skilled physician, adjustable and can also provide flexibility in adjustment during the healing process if required. The patient can be able to wash and clean his hand to keep himself away from irritation and infections, also provide proper ventilation. It will be designed in such a way that it can be reused, which reduces the cost for the patients. [4]

The rapid prototyping method is used for the fabrication of a prototype. The CAD model file is converted to the .stl file. Then this is submitted for slicing. In this process, the drawing made in the CAD software is approximated by triangles and slice containing the information of each layer that is going to be printed. [5]

Figure 1. Additive manufacturing Procedure
3. **Design Methodology** :

Initially, the types of dislocation of the elbow are investigated, which are:

a) Dislocation of Humero-ulnar joint.

b) Dislocation of Humero-Radius Joint.

c) Dislocation of Radio-ulna Joint.

During dislocation of the elbow, the ligaments may get torn. The ligaments act as cushioning for joints and also provide stability to joints. Proper healing of the joint will ensure natural alignment and stability. [6]

Table 1 shows the weight of the person and associated arm sizes at which the elbow joint can be fixed. The circumferential arm sizes at below and above elbow joint of samples of average Indian males/females. The size of the cast may vary at the particular weight ranges. Consequently, the size of the ring and elbows are divided into different sizes.

| Weight (KG) | Arm sizes (CM) |
|------------|----------------|
| 40-55      | 21-25          |
| 50-65      | 24-32          |
| 60-80      | 25-34          |
| 70-90      | 27-36          |

The main concept is of changing the existing alternative of plaster or glass fiber cast to adjustable elbow arm cast. The model consists of elbow and Rings made of ABS plastic. Inside the ring, an arm holding clamps are provided better grip and positioning. Below the ring’s outer surface, the Velcro strips are given to adjust it properly according to the patient’s elbow. More than one ring can be added as per the patient’s elbow injury. [7]

At first, a ring along with clamps is prepared in 3D modeling SOLIDWORKS software. The arm size range of 24-32 cm is taken, for the average weight range of 50-65 kg. The ring circumference and elbow angle can be modified as the allowable angles of stabilization for the elbow dislocation are 0°-30°-90°-110°-130°. After making a solid model of all parts and finishing it, the data are translated into polygon STL format.
The fused Deposition Modeling method is used for prototyping after the STL file is made. We only used Acrylonitrile Butadiene Styrene (ABS) material for making the prototype of parts. Other medically accepted and skin-friendly material can also be used for manufacturing. [8] The material properties for the most suitable material for making cast are given in Table 2.

| Material                                      | Density gm/m3 | Tensile Strength (MPa) | Flexural Strength (MPa) | Impact Strength J/m |
|-----------------------------------------------|---------------|------------------------|-------------------------|---------------------|
| 1. (ABS) Acrylonitrile Butadiene Styrene      | 1.05          | 22                     | 41                      | 107                 |
| 2. (PC) Polycarbonate                         | 1.2           | 68                     | 104                     | 53                  |
| 3. ABSi (Acrylonitrile Butadiene Styrene – Biocompatible) | 1.08          | 37                     | 62                      | 96                  |
| 4. PC-ABS (Blend of polycarbonate and ABS)    | 1.2           | 41                     | 68                      | 196                 |
| 5. Nylon 12                                   | 1.01          | 32 MPa                 | 67                      | 135                 |

The prototyping [9] method used here is Fused deposition modeling (FDM). In FDM, a thin plastic wire is fed to the printer head which melts it and extrudes to deposit in approximately 0.25 mm
thickness. Medical-grade materials like ABS- Acrylonitrile butadiene styrene, polycarbonate, and blends are used. This is the most economical method as no post-processing or curing of plastic is required. While SLS and SLM are also most preferred according to the accuracy and finishing of the components, but the cost of machine and prototyping is expensive as compared to FDM.

3.1 Wall Thickness of Section:

The outer layer is subjected to impact force exerted by external bodies and internal distortion force by arm movement. Hence it has to be made to withstand these forces. The external force of 200N is considered for analysis, assuming the speed and weight of the hand, during impact.

MSC Nastran software's structural analysis module is used to determine the wall thickness. The ABS material is a blend of plastomer and elastomer, exhibits flexibility, and hence can be used for intricate shapes.

The wall thickness of the ring plays a very important role in this structure. It should be as light in weight, strong and stiff, and provides comfort to the patient.

![Figure 3 Structural analysis of the arm ring.](image)

The main factor for influencing weight is wall thickness. From the analysis, the maximum displacement is found to be 0.04 at 200N force with a maximum stress of 30MPa. Hence the Finite element analysis determined the allowable thickness to withstand in forces and impact.

4. RESULTS AND CONCLUSION

The proposed concept for different sizes of arm casts can be designed and manufactured. In this work, we built the rings, elbow, clamps, and sliders using the FDM 3D printing technique. The manufactured parts are shown in figure 4. After the trials, significant results are observed as it fits
well, provides good ventilation, support, and light in weight. The total weight of the proposed arm cast is 310 gram which is 1/3rd of the weight of a traditional plaster cast.

Figure 4 Additive manufactured RP of Armcast Elbow and attached Ring (top), Arm holding Ring with Clamps (bottom).

The modular arm cast prototype made using the FDM type of additive manufacturing is acceptable in the treatment of dislocation of the elbow and can be a better substitute for conventional plaster. [11] This modular arm cast can be reused after sterilization.

This new cast consists of a modular ring that can be attached with the elbow cast on either side, to adjust the length requirement. The inside clamps will surround the arm and grip it by fastening the Velcro belt. This provides good support, ventilation [12], flexibility in assembly, ease in assembly. Thus this arm cast can be a better alternative to the traditional casting system. The modular cast is found to be lighter, well ventilated, durable, with adjustable lengths, and avoids fungal infection to the skin. This gives a better experience to the elbow dislocation patients, as compared with traditional plaster.

One of the main advantages of this proposed designed cast over a current patient-specific cast is that it provides reusability. This new design will give quick treatment to the patient having elbow dislocation for good flexibility to adjust and wash, even in a worn position.
5. FUTURE SCOPE

Little modification at the snap joint was required as the projected part for the snap joint was too hard. Being thermoplastic material the shape can be adjusted with the use of glue or a hot gun. The POP plaster or glass wool plaster does not exhibit this modification. However, there is always a scope for further modifications for developing it as more robust and flexible. [13]

The following are the few suggestions for future studies:

1. A thorough study of the arm size and shapes of the human is required and accordingly, groups can be made and arm cast for respective groups can be fabricated.

2. The possibility of use for surgical injuries to be explored.

Finally, this work focused only on the size range of 24-32 circumference of the arm as further ranges will have to be tested. The inputs from various medical professionals and patients are required in the future [14] for developing a more compatible and flexible design.

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