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Design of a Patient Specific, 3D printed Arm Cast

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Abstract

3D printing is a manufacturing technique by which the material is added layer by layer to create a physical three-dimensional object. This manufacturing technique had primarily found uses in academic and commercial sectors for prototyping and product realization purposes. However, more recently the home consumer market has seen a surge in low cost printers bringing this capability to the masses. More recently 3D printing has seen considerable interest from the clinical sector, where alongside the synergistic use with medical imaging data, a whole generation of patient specific implantable technologies, splints/casts and resection guides can be created. Predominantly, clinical applications have focused on the use of 3D printing for bone replacement, however with the advent of more sophisticated multi-material printers, interest has now begun to move to applications in orthotics and orthopedic casting.

This study is to review and evaluate the feasibility of designing and realizing a more patient specific orthopedic cast to surpass current limitation with traditional fiberglass/plaster casts, through the use of advanced 3D modelling and printing techniques. To directly compare the efficacy of the traditional and 3D printed casts, we shall investigate critical parameters such as the time for manufacture, the overall weight of the final product, the accuracy off the cast relative to the patient's unique anatomy and additional user-centric metrics (comfort, aesthetics, etc.). The design examined made use of advanced mesh structures throughout the bulk of the cast, such that the device would require less material (by weight) during fabrication, could allow for tunable weight and mechanical properties and allow for air penetration to the person skin, thereby reducing discomfort due to prolonged moisture exposure (chaffing, bad smells, etc.). As the primary focus of this study is the design and product realization phases and we shall not assess metrics relating to patient recover time or experience.

Overall it was found that the 3D printed cast was significantly lighter, with improved water repellent and air circulation properties, as compared to a traditional cast. Through the use of high precision design/manufacturing techniques, the final device could be accurately reproduced to match the test patient's unique anatomy, thereby optimizing the orientation of the patient's bones during post fracture recovery. It was however found that the manufacturing time for the 3D printed cast was slower than traditional casting methods owing to the additional time during the design phase. In future work we aim to address this limitation and to devise a streamlined methodology such that a generic cast design can be adapted to patient specific anatomical data through parametric design algorithms.

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Ultimately, it was found that through the use of advanced design techniques, patient specific data and 3D printing, a custom orthopedic cast could be realized and with significant potential to augment current use of this technology for surgical intervention and improve patient outcomes. The use of advanced manufacturing in the medical field will likely enable more patient specific/user-centric treatment in the near future.

Keywords: 3D Printing, Cast, Rapid Prototyping, Additive Manufacturing, Patient Specific

1 Introduction

The study follows the process of the design and creation of a 3D printed, Patient specific orthopedic cast. This is being done to assess the viability of this as an alternative to the current casting methods of plaster and fiberglass.

The study included the use of 3D scanning, Model manipulation and optimization, and 3d printing, as well as being assessed for fitment, stabilization of the joint and feel of the cast.

2 Methodology

2.1 Background

The current method of stabilization in the instance of a bone fracture is a plaster cast initially, then after a review consultation, the cast is either replaced with a second plaster cast or with a fiberglass cast. The fiberglass cast adds extra durability as well as the ability to use a water repellent core so it has the ability to get wet (GUSTAVO CARDOSO VIEIRA 2006).

The current methods of stabilization, can occasionally have adverse effects due to the chance of movement during the wrapping process, causing the incorrect setting of the bone, as well as the chance of burns the soft tissue that is in contact with the cast as it generally uses an exothermic reaction to set the plaster once it has been applied. Further complications include compartment syndrome, pressure sores, skin infection and dermatitis. In each case, further medical attention would be required, in extreme cases surgery (Gregory P. Guyton 2005; Samuel A. Brown 2015).

From a design stand point the cast is something that is more functional then form, it provides stability of the compromised region to enable the healing of bone, and that is it. In recent years the fiberglass cast has had the ability to change the colour of the cast with a variety of colors that are pre died into the wrapping, but as this is an optional extra, it is not always available.

From discussions with clinical practitioners reveals short comings with the current methods of casting from a qualitative, end user's perspective, are as follows; showering, weight, itchy, dirty, attention drawing, driving, typing, working, smell. As the problems listed above show that wearing a cast impacts with the patient's life, and overall experience of the care. With the growing demand for better patient care, studies completed by (Carl R. Chudnofsky 2010; Kelly 2015; Konradsen, Nielsen & Albrecht-Beste 2009) that show an increased recovery rate with an earlier rehabilitation initialization, as well as the ability to use everyday events as rehabilitation, all lead to a better patient experience as well as reduced healing time.

Over the past decade, there has been a growth in popularity in the use of additive manufacturing, with interest from the medical sector for the ability to rapidly produce patient specific designs. This has led to the ability to have a patient specific cast that allows the patient to return to their everyday life with reduced impact on their abilities to live their everyday life. Other areas that have been looking at similar aspects of additive manufacturing for similar reasons, is sports technology (Collins 2016). With the ability to rapidly make changes and design a durable part that is of a complex geometry that could otherwise not be produced is allowing the industry the ability to create components that are optimized for their application.

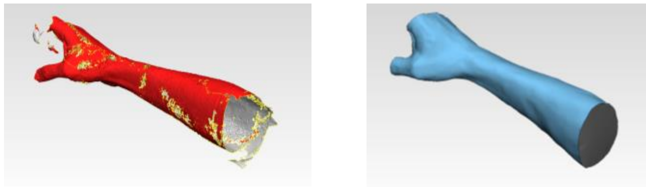
Using the design concepts referred to at (Yvonne Dittrich 2013), it shows that the end user will have an overall great satisfaction when they have had input in to the design process, user centric - collaborative design, this also shows that having the understanding that something has been design specifically for them, it increases the overall acceptance of the product.

Applying these concepts, the medical industry has been mentioned in papers such as (Otawa *et al.* 2015; Sutradhar *et al.* 2014; Yamada *et al.* 2014) however the collaborative design is something that hasn't been taken into the mass customization conceptual space mainly the speed of converting medical imaging data to usable CAD file for use in additive manufacturing. With the use of 3D scanning and increased software and 3D printing capabilities, these concepts can be applied. This has limitations as not all designs behave the same, so some analysis will have to be done on each design to dictate the thickness as well as accessibility.

2.2 Methodology

The methodology will be describing a case study that was performed in conjunction with the school of Occupational Therapy at Deakin University. The partnership between schools is critical for the project's success as the healing position is critical to ensure the bone is healed correctly and no other damage is caused (ANNE S. BOYD, HOLLY J. BENJAMIN & CHAD ASPLUND 2009).

The initial 3D scan of the arm was obtained using the Kreon Technologies Braces Solano scanner. The Software package that was used for this was the Polygonia 3D



(a) (b)

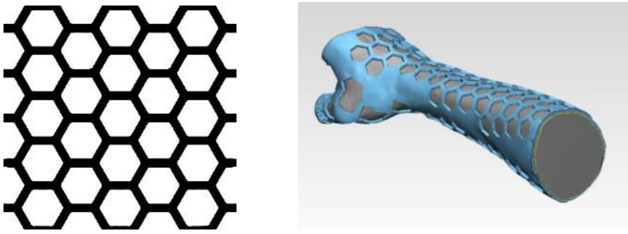
Figure 1:

(Kreon 2016). This allowed a very accurate surface model on the patients arm with an accuracy of 30 μm, this is achieved by a laser line width of 100mm using the triangulation method of scanning. This also has a speed of upto 40,000 points per second. This scanner uses the an articulated arm to measure the orientation the the scanner. This led to a few issues with the scanning the full circumference of the arm. Once the correct position and access to the entiety of the arms surface was obtained, the scan took less then 120 seconds to have an accurate model of the arm that would be accepable for processing (fig 1 a).

The position that is optimal for the recovery of bone in the hands is the dart thrower's (wineglass) pose (Carl R. Chudnofsky 2010); this is to allow all of the tendons to be positioned in a way that will allow them to not shorten or loosen from being stationary for an extended period of time. As well as making sure there are not any undue stresses that are applied to the compromised area. Another reason for the pose is to allow enough space in the cast to retain the use of the fingers and thumb, to a restricted degree, while the cast is being used.

Although the scan was completed relatively quickly, the ability to hold an exact position for any amount of time without any movement is extremely hard. Because of this, the scan was completed holding onto a handle loosely, while also making sure the dart throwers position was kept. This reduced the amount of errors that would have otherwise been experienced. This part of the process is key as an accurate model is the only way the cast will fit correctly, and comfortably. As shown in (fig 1 a). the scan produced an inverted surface model as well as areas that needed to be patched and smoothed. The processing of the surface model was done using Materialise's 3-matic STL (Belgium) software. This allowed for the arm model to be cleaned as well as constantly checked from the original surface model as a way to ensure accuracy. Following the cleaning of the surface model, a solid body model was created to check for errors (fig 1 b). this was then trimmed to the required lengths for the cast. In this instance it was between the point of two thirds up the length of the forearm, the palmer crease and the Thumb IP (Interphalangeal) joint. These boundaries where recommended by the School of Occupational therapy as they are the general bounding sections for the orthopedic casts.

Using the cleaned and bounded model, the surface of the model can be extruded to the required thickness and extracted as a separate part. This gives the ability to adjust



(a) (b)

Figure 2:

the thickness of the cast, that will be determined by the design that is later used and the environment the cast will be exposed to, to ensure the best treatment is given.

Following the boundary definition, the pattern is pre-selected by the patient. For this case the patient chose a repeating hexagonal pattern (fig 2 a). The pattern selection is a major part of the process with the collaborative design concepts that are at the core of the projects ideology. The ability to choose a design for the rehabilitation device and customize it for yourself will, in theory make the process and experience of wearing the device more enjoyable. The pattern plays a major part of the design allowing the ability to retain the rigidity of the cast but also the removal of unwarranted sections to reduce the weight (fig 2 b). Another benefit of having the case as semi-enclosed design allows for access to the skin if there is an irritation, and allows airflow to ensure there is no chance for the skin to become infected.

Using the solid body model that was extruded from the surface of the arm, the pattern can be applied to the cast model. This is done by creating a UV map of the models surface and creating a surface mask of the pattern, this is applied to the model. Using the design mask the areas that not required can be removed from the cast model. This gives a model such as the one in (fig 2 b). As the design needs to be of a certain rigidity, the ends of the cast where then filled in as a solid boundary to ensure there was enough strength in the part.

To ensure the model was accurate, the model was again checked against the initial scan and the solid model of the arm. As this would be an exact model of the arm, small tolerances are applied to the cast as to allow for the body's natural expansion and contraction that are experienced as part of the temperature and fluidic regulations.

The model was taken into a separate software Autodesk's Mesh Mixer (USA) to perform another error checking function and further surface smoothing to reach the desired surface finish. As the cast is designed to be a fully enclosed device as well as being a rigid structure, the cast cannot be printed in one piece. The ability to apply the cast in an easy and safe way led to the cast being segmented along the sides of the cast throughout its length (Figure 3). This gives the ability to safely apply the cast in a two stage process. The application of the cast, similarly to the method of fitting a thermoplastic cast, secures the thumb and braces the wrist, then the top section of the cast is applied and attached to the bottom section. This can also be completed with

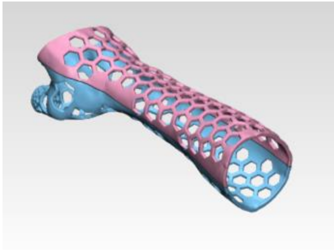


Figure 3:

the 3-matic STL software as well, but using multiple software packages was used to make sure the file was still accurate and would be able to be printed in the correct orientation.

The print orientation is determined by the design as well as the spacial requirements / restrictions that are placed on the part by the printer. The orientation of the part will determine the end strength of the cast as well as the time it will take to print the file. Design optimization is important as having a design that will not require or minimal support will reduce the time it will take to produce the model. For this cast the print was orientated with the joint / separation to the printer base. The was done to ensure the best surface finish of the cast as well as minimizing the amount of support that is required to ensure the print doesn't fail.

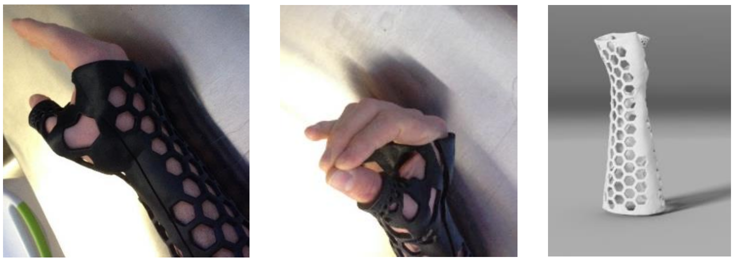
3 Results

The functionality of the cast was assessed by the school of Occupational Therapy, some of the concerns are the methods of closure of the cast, with alignment pins printed on the initial cast, they subsequently broke quickly as the texture of the prints acted as a locking mechanism. With strength being the issue, a thicker, more robust fixation method will be designed in further work.

The fit of the cast was excellent, shown in the pictures below, as well as the rigidity of the cast, even though the cast was not mechanically fixed. This was a concern as the initial scan was not perfect. This showed an area for improvement within the project and further development will have to be completed.

Shown in figure 4 a & b, the ability to pinch is still there but the thumb is restricted as well as any movement in the hand itself, allowing only the hand and the bending of the thumbs IP (Interphalangeal) joint.

One Issue that was shown by the fitting, was the thumbs IP (Interphalangeal) joint diameter was not taken into account when modeling the section to support it. This was modified quickly with the use of a heat gun to soften the plastic to widen the opening. This also shows the ability to make small modifications to the cast, something that is not possible with a plaster or fiberglass cast.



(a) (b) (c)

Figure 4:

4 Summary and Conclusion

The resulting cast created using this method has shown that the concept is a viable system for the fixation and stabilization for injuries where a cast or splint is required. The case study revealed some aspects of the design process that need to be taken into account in the future.

With further work on each of the sections of the design process the ability to create a patient specific, custom designed cast is something that will be able to provide an accurate, more consistent and stable alternative to the current methods for casting and splinting.

One of the areas that requires the most work for improvement is the time the print takes to produce the part. This is something that will change as the printing technology is improved, however with the time it takes to produce a part, it is still a viable method for a secondary cast after the initial cast to stabilize the bone after fracture and allow the swelling to reduce.

Overall the cast is lighter, more durable and allows better air flow to better the user experience during the rehabilitation of a fracture. This will be shown with a user analysis study currently in the experimental phase.

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