Additive Manufacturing in Surgical Education

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Abstract

In this era, surgical equipment have come a long way from bulky knives and blunt scissors, to the new age delicate scalpels that come in different sizes depending on their uses, different forceps and scissors. Surgeries are intricate procedures that need precision, accuracy and the ability to work with fragile body parts, in order to assist the patient with swift healing and recovery. Burrholes are one such type of procedure wherein the neurosurgeons relieve the pressure on the brain by making small holes in the skull. The pressure caused on the brain is due to build up of fluids such as blood, which then compresses the brain tissue. The process itself is an invasive technique so appropriate sterile instruments are mandatory in aiding the neurosurgeon to perform a successful surgery. But each surgery must be practiced thoroughly before commencing it on the patient. Hence, junior surgeons require appropriate materials to practice being able to conduct a surgery successfully. In this report, it shows how 3D printing can essentially cut down the costs that come with purchasing cadavers that are too expensive to be used for practice. There are different forms of 3D printing, the uses of 3D printing in the medical field and their limitations. With the progression in medical technology, we know that 3D printing will aid in assisting many people, but most importantly practicing surgeons and other junior health professionals.

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Section One

The Topic

1. Introduction

1.1 BACKGROUND

Burrhole surgery is a procedure where small holes are created using a specialised drill known as a craniotome by a neurosurgeon. This is used to relieve pressure inside the brain when there is extensive fluid build-up such as blood which causes the brain tissue to be compressed (John Hopkins Medicine , 2022). Burr hole surgeries are also performed to aid in drainage of blood from the brain after a traumatic injury, removal of shrapnel or other objects that are stuck to the skull, inserting of a medical device such as a neural implant and lastly to conduct a biopsy. (Healthline, n.d.).

Surgeries are complex, delicate, and invasive procedures which do not leave room for errors when executed in real life situations. To practice various types of surgeries, junior or even experienced surgeons conduct surgical procedures such as sutures on grapes or latex gloves to mimic how real skin behaves (Figure 1). Animal parts are also used to imitate human tissue such as chicken feet which replicates the tendons in a human body or pig feet and chicken breasts to practise stitching the fine blood vessels. Other methods of practice include obtaining a cadaver which mimics the anatomy and physiology of the real patient. However, it is expensive to practice on a cadaver where some cadavers could cost about $3000 AUD. The preparation procedures for a functioning cadaver are also difficult as there are certain qualifications that must be completed, which includes certain qualities such as the fidelity of the skin or status of the organs.(Surgery.com.au, 2021).

The existence of traditional methods to practise surgeries might prove dysfunctional in replicating the experience of performing a surgery on a human body. In a line of profession where accuracy, knowledge and delicacy are vital, it is crucial that the junior surgeons have access to realistic and affordable simulators to practise their skills on.

1.2 PROJECT AIM

This reports aim is to discover opportunities for how 3D Printing (3DP) can be used for surgical education and its complex practices in the most efficient and affordable way. To achieve this the report introduces a literature review in Section One, looking at the current and emerging tech in additive manufacturing, showcasing its limitations and usefulness. The second section of this report will follow the research undertaken, the approach and the procedures used with an analysis of the result. Section Three will cover how the results are related to the literature and what next steps to take with the opportunities and design implications that will follow, finally ending with a brief conclusion of the findings. This project is in collaboration with HBI to expand to a commercialised and developed version of the current 3D printed Burr Hole model they have (Figure 2 & 3).

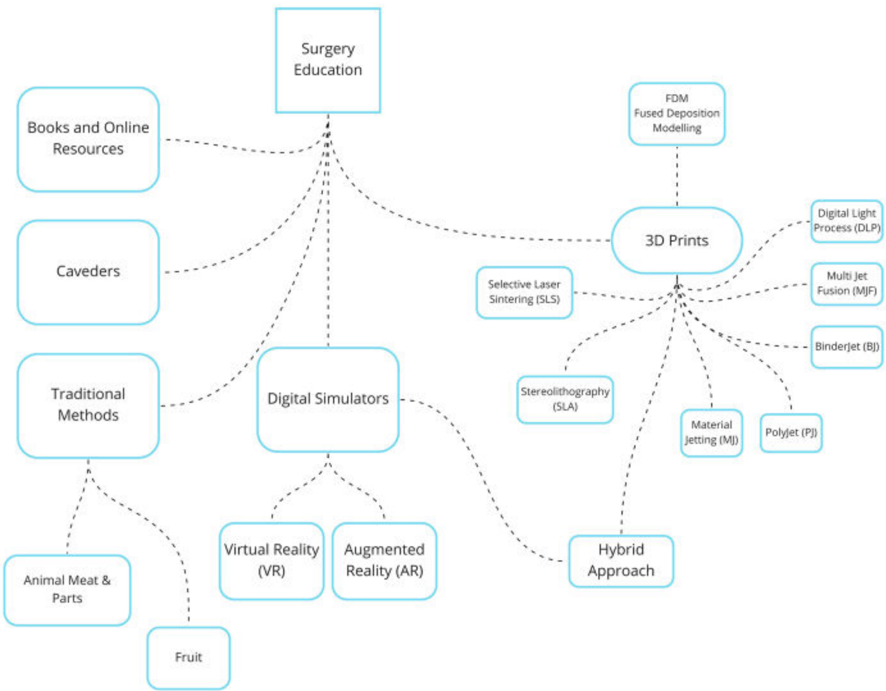


Figure 1: Current surgical trianing methods

2. Literature Review

2.1 INTRODUCTION

Additive Manufacturing (AM), also known as 3DP, is one of the fastest growing markets in rapid manufacturing, considering that it is expected that AM will be proficiently used in the medical field. This literature review focuses on the effectiveness of 3D printing in surgery education as an alternative to traditional practice methods. This review includes the efficiency of emerging technologies and the limitations that follow them. The review contains literature as evidence to support the claims made in the previous sentence. Although the paper is targeted at specifically Burrhole models, other forms of surgical procedures that use 3D printers will be addressed as they all use similar methods.

2.2 TOPIC #1 – USAGE OF 3D PRINTING IN MEDICINE

There are multiple use cases of 3D printing in the surgical field starting with general medical education, surgical education, and patient education (Bartellas, 2015). Focusing on surgical education the most relevant parts of a 3D printed drillable skull is the skin, bone and dura layer all compromised of different materials (Waran, Narayanan, Karuppiah, Owen, & Aziz, 2014). In the surgical and general education section, 3D printing promises better understanding of the anatomy, supported as a common theme from reviewing the sources stating that trainees appreciated a kinaesthetic (hands on) approach to surgical education rather than reading (Garcia, Yang, Mongrain, Leask, & Lachapelle, 2017). This fact paired with the knowledge from Ruchira Garg and associates' study which showcased that the students preferred a 3D view on anatomy compared to higher quality 2D images (Meyer-Szary, et al., 2022). This means that 3D printing is highly effective in practical training scenarios including first use cases as well as reminder practices for experienced surgeons.

This fact is also supported by the results from Dr Novak and associates' study where they surveyed clinicians as well as other health professionals on the most important aspects of a 3D printed model, how realistic and the accuracy to anatomy is the most important for clinicians as well as other health professionals which is very beneficial as traditional methods are rudimentary (Fig 2) (Novak, et al., 2022). Application of 3D printing in neurosurgery in a case study where Weinstock et al. tested out 3D printed preoperative planning prints and found out that it was 98% consistent with the results from current imaging techniques (Meyer-Szary, et al., 2022). Using this technique more unconventional surgeries such as cerebral arteriovenous malformations and aneurysms can be replicated for trainee practice with quality accuracy and reduce training time while boosting confidence (Baskaran, Štrkalj, Štrkalj, & Di Ieva, 2016). However, this study was directed to high-fidelity model leaving a research gap in how lower fidelity models using cheaper materials do in terms of its consistency to the real surgical procedure.

Figure 2: Current 3D printed Burr Hole models by HBI

Figure 3: Surgeon drilling into a burr hole model

2.3 TOPIC #2 - CURRENT & EMERGING TECHNOLOGY IN 3D PRINTING

3D printing has introduced a new way of producing highly accurate representations of the human body and its intricate parts. With most 3D printers capable of only printing out of one material which reduces the quality and certain details needed. Nowadays, there are more printers capable of printing multiple materials at the same time (Waran, Narayanan, Karuppiah, Owen, & Aziz, 2014). The latest forms of 3DP include Fused Deposition Modelling (FDM), Stereolithography (SLA) and Selective Laser Sintering (SLS). These forms of 3D printing is easily accessible and available in most modern universities, hospitals and even at home. The other category is industrial forms of 3D printing which include PolyJet(PJ) and BinderJet(BJ) which are more expensive types of tech available in specialised locations and industries that require its technology (Garcia, Yang, Mongrain, Leask, & Lachapelle, 2017).

Printers can be further categorised into 3 subcategories described by Montreal Health Network as –

- Melting – Melting hard filament that is then extruded through a nozzle (FDM). This is the cheapest form of printing and easily accessible to anyone.
- Powder Solidification – Powdered materials are solidified using a laser to sinter the powder solidifying it, another layer of powder is rolled above this, and the process continues (SLS). BJ is the same principal but uses a liquid binder and both types do not require supports or scaffolding.
- Liquid Solidification – Oldest method of printing where a vat of liquid which is solidified using a ultraviolet (UV) laser with the help of mirrors and lenses while the platform moves down layer by layer (SLS). Similarly, PJ uses minute drops of liquid before curing using UV and moves about in the X and Y axes and the build plate moves in the Z axis like a FDM printer (Garcia, Yang, Mongrain, Leask, & Lachapelle, 2017).

To bring the most realistic features from a 3D print the greatest tech in 3D printing for anatomy is the Stratasys J750 Digital Anatomy. This material jetting printer (PJ) has an incredible selection of materials which include solid materials to biocompatible resin which can be mixed with several combinations to create new composites. With all these features the J750 can be deemed as "the best candidate for the development of innovative solutions for the surgical simulation field." (Marconi, et al., 2022) To create an accurate representation of various human body parts also requires advanced materials. As mentioned before the J750 utilizes specialised materials which come in Bone Matrix to mimic porous bone structures, Gel Matrix to replicate the thinnest and smallest vascular structures and finally Tissue Matrix which is the softest material in the 3D printing market.

Although it can be assumed that these materials are best to replicate bone there are studies that counter this and acknowledge materials such as ABS or PETG to be superior to photopolymers while others claim that users found that (White Resin) FLW as well as Thermoplastic Polycarbonate (PC) on the FDM printer in terms of the visual, auditory, and haptic aspects of surgery on 3D printed temporal bone. Perhaps the participants found that the cost of Acrylonitrile Butadiene Styrene (ABS) or Polyethylene terephthalate glycol (PETG) is much lower and easier to access compared to the other materials which may have influenced them to select this. There are still many new materials and methods being implemented which can change and possibly label the best material for bone or any other part of the human body in the future (McMillan,, et al., 2020). An existing product that uses these materials is a 3D printed model created by V. Waran and company looks at a Burrhole model with an included a brain section (Figure 5&6). The creation process involved CT scanning a real patient and printing it out on an Objet500, a similar technology to the J750. However, it still boasts an expensive price tag of $2000 USD for the base and $600 USD per disposable insert (Waran, Narayanan, Karuppiah, Owen, & Aziz, 2014).

2.4 TOPIC #3 – LIMITATIONS OF 3D PRINTING

Aside from its vast benefits, 3DP has its limitations to be discussed as well as its surrounding qualities. Starting with user data compiled by Dr Novak and associates suggests that the main barrier to practicing surgical procedures being the lack of resources was seen as the highest rated answer (Novak, et al., 2022). The accessibility of high-end materials is only available to those in modern environments with the appropriate technology and knowledge as 3D printers requires extensive knowledge in CAD and other software which are needed to run the printer. The cost of certain printers goes well above what is affordable with flagship printers like the J750 going for $300,000 USD with liquid photopolymer ranging from $302.50 – $432.26/kg USD (Chen, Dang, & Dang, 2021). Not all hospital or medical centres can afford to have such high costs to train with 3D printed simulators and would have to get seek assistance from 3D printing services or other medical institutions for their models. Cheaper materials like ABS and PETG can be used as alternatives but do not produce the pristine finish like resin prints and limiting choice of colours and materials characteristics (Baskaran, Štrkalj, Štrkalj, & Di Ieva, 2016).
Another key limitation of 3D printing is the time it takes to print out a single part which is also constrained by The print bed which is generally small in most printers. With some prints taking hours the low-cost manufacturing process will take longer periods of time especially if the printing process requires post print processing (Baskaran, Štrkalj, Štrkalj, & Di Ieva, 2016).

Through this literature review it is evident that 3D printing has already begun to play a significant role in surgical training and will be the pinnacle of surgical training in the future. Although the technology comes with its own limitations, these weaknesses can be altered and reduced in the future as innovative technologies and methods are being developed.

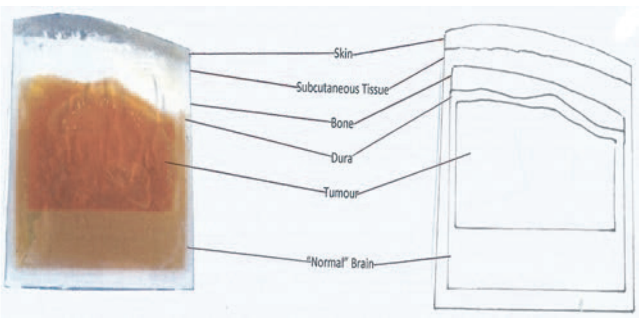


Figure 5: Cross-sectional view of model with tumor, and drawing delineating parts of the model.

Figure 6: Model being utilised by surgeon with skin being opened up using a perforator.

Section Two

The Research

3. Research

3.1.1 Outline

The research was based on a current project conducted by Mr Dissanayaka (P2) and HBI. This project as mentioned before looked at a simple 3DP burr hole simulator with a swappable drillable section. The new project task was a continuation of the development and commercialisation for this product where anyone can easily print it out and set it up.

3.1.2 Methods and Methodology

The type of research that was deployed includes a blend of semi-structured interviews and a supporting participant observation. The prime participants for the observations and interviews were doctors working in the neurosurgical space who were anonymised due to ethics. From now onwards they can be referred to as Participant 1 (P1) and Participant 3 (P3). The observation was done first where a video recording Participant 1 was taken as she set up and drilled into the skull with the help of Mr Dissanayaka. Since this topic was very specific to certain users where the target audience were junior surgeons who were unavailable, more experienced surgeons were brought in as participants. This study was done as a silent observation as it was focused more on Mr Dissanayaka's research. The observation helped gain an understanding of the background processes of the product and how long certain tasks took to complete. The study included 10 variations of the drillable section with different types of 3D printed materials as a part of Mr Dissanayaka's study. This meant the participant was given 10 chances to use the product and rate them on its realistic characteristics. However, the study organised for this paper only looked at how both Mr Dissanayaka and the participating doctor used the product.

Following the observation an interview was conducted with Participant 1, Mr Dissanayaka and Participant 3. Both participants are professionals in the neurosurgical space and have a lot to give in terms of knowledge. There were 6 questions prepared for the two doctors which asked in detail about the current product to get a better understanding of their perspective. The interviews were not recorded as it was prohibited so careful notes were taken during the process then formed into better wording, but the participants were happy to sign a consent form. The interview completed for participant 2 was slightly different due to the participant being the original creator of the product thus being asked more about the development of the product.

3.2 ANALYSIS & FINDINGS

To analyse the findings from the interviews which included long answers to questions, an affinity diagram was created. The diagram utilised the raw data and categorised them into themes and sub themes. As the interviews were not recorded the notes taken were used for this diagram. To further categorise the themes, they were grouped in focus areas – Realistic Characteristics, User Experience and Design Opportunities. This method allows to display what common themes and concepts can be found from each of the grouped sections of the interviews.

Theme	Sub Theme	Keywords & Tagged Concepts
Realistic Characteristics	Familiarity	Feedback, Haptic, Real, Realistic, Basic, Complexity, Layers, Size, Process, Memory, Guide, Cost
User Experience	Experience	Giving, Feedback, Haptic, Real, Professional, Experience, Benefit
	Set Up	Ease of use, Professional, Long duration, Confidence, Difficult, Process
Design Opportunities	Improvements	Scenario based, Essential, Professional, Guide, Integrations, Confidence, Limitations, Variety, Feedback, Haptics, Ease of use, Orientation, Layers, Complexity, Error, Ecosystem
	Dislikes	Orientation, Scale, Size, Real, Basic, Process, Sections
	Likes	Systematic, Haptic, Orientation, Preference, Size, Benefit, Guide, Personal, Experience, Professional

Figure 7 : Affinity Diagram results for interviews

Realism was mentioned as a main theme by all participants when asked about how the current product can be improved. On par with realism both doctors (P1&P3) believed that the drillable section produced the correct amount of haptic feedback or described by Participant 1 as 'chatter'.

Direct Quote

"Participant referred to the sound and haptic feedback of the drilling procedure as 'chatter' which is very close to what it feels like when drilling into real skull bone." (P1 Appendix Section Figure 2)

Other observations included the aspect of the product guiding and boosting user confidence mentioned a few times in the Improvements and familiarity sub themes. This was mentioned by all participants. Similarly, the observation displayed results targeting the realism and orientation of the product (Figure 7 & Appendix Section Figure 2&4).

During the observation it was noted that the enjoyability of the product also depended on the material and how realistic it was (Appendix 1 Figure 1). Materials that were not deemed realistic enough was not pursued by the participant any further whereas materials that the participant liked was drilled thoroughly.

The orientation was intended to be kept fixed as most participants did not care how the product was placed except Participant 1 who addressed that the model be placed in such a way that the drillable section is facing upwards towards the user (Appendix Section Figure 2). Time was also a key factor most participants considered. The task of removing the sections and replacing it also the task of fixing the base and removing it were all done in a basic way. Removing the section took an average of 67 seconds or between 1-2 mins including any space in case of error based of the observation (Figure 8).

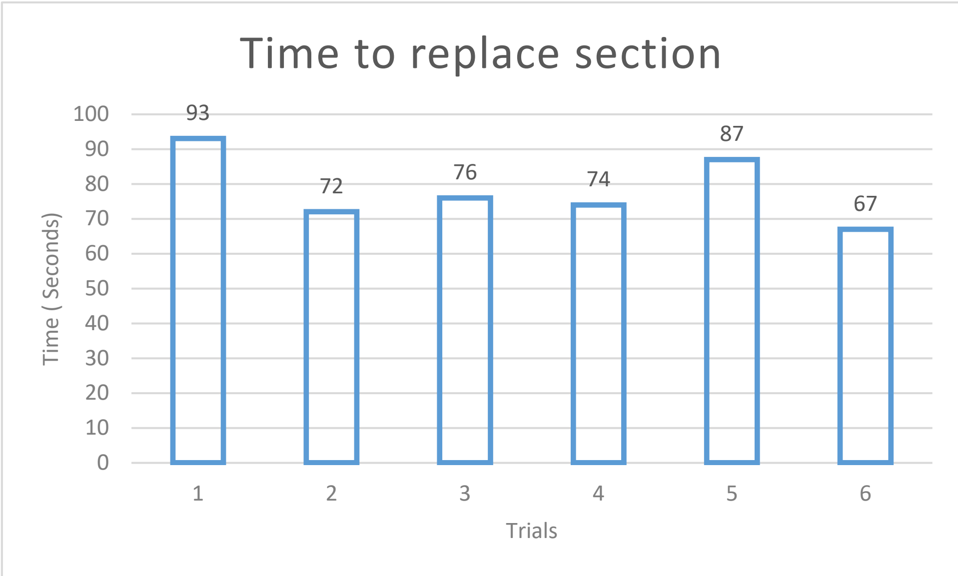


Figure 8 : Time it took to replace drillable section of current burr hole model

	Set Up	Drilling	Cleaning	Replacing
Description	Placing the base near the edge, and section is ready to be drilled	Drilling into the bone skull section	Cleaning up the residue from drilling	Replacing the model with another with a new section ready to go
Participant Visual /Physical Interaction	Moving the product towards the edge of the table | Adjusting the clamp to fit onto the product base as well as the table and squeezing trigger to create a tight hold	Participant is using left hand to hold the product in place while using the drill to penetrate the printed skull	Participant moves dust away from the hole by using the drill tool or their fingers	P3 has to hold the head in a sideways position where the screwdriver can go in at an angle and remove the 4 screws holding the section together | P3 releases the clamp
Observed Comments	Product has to be orientated to fit the participants orientation so they can drill comfortably | Even though that the product is fixed there is a slight wobble | Participant changes their orientation twice	Participant has to move fused bits by hand or use the drill to scratch of these bits | Sometimes a screeching noise is made when drilling | Participant likes touse their thumb as a stopper while	The material creates a lot of dust on the product itself as well as the table and floor, the air vac does an ok job of cleaning	P3 takes about a minute or so to remove the screws and replace the drilled section with a fresh one
Participant Comment	The drilling is loud and can be annoying	"We need something to stop the smelling, the problem feedback on this one is the way that the dust sticks together is not, not, um, anatomically realistic." "Otherwise the right hardness in reality, you feel you pop through, you can feel that you're through because it's, there's a big difference between. Where the bone is and where the bone is not, which I didn't get "	"It's better than any model I've ever seen anyway." "You see, normally what you're is, get that washed away."	

Figure 9 : Simplified storyboard of observation with participant comments

The observation was analysed by finding the temporal events in the procedure and labelling and timing them from the video. However when using ELAN to catregorise the parts it was found that the audio was consistently affected by the drilling noise and how it was recorded so ELAN was not used for this set of data. The video that was recorded was transribed as much as the program Descript could make of it and gave a few key points mentioned by the surgeon (Figure 9).

Section Three

Discussion and Design Implication

4. Discussion

The major point identified by the observation was that the participants felt as if the model lacked in complexity due to the lack of layers but also countered this statement from Participant 1, agreeing that this was most likely the best 3D printed simulator they have ever tried. Realistic features in the model play a key part where the more realistic the model is the more engaged the user would be as shown by Figure 1 in the Appendix section , where the user spent more time on certain materials as she felt it was better. Another key point that arose from the testing included the issue of dust falling everywhere due to the material the current product is using. This could also be a major problem as it could interfere with the drilling procedure. A key point mentioned by all participants was the way the head was orientated with some liking adjustability, however this can be deemed as a personal preference since most participants did not mind the current position. Most of the data collected by the tests matched with the literature review, especially proving the limitations of 3DP. As it was mentioned before that 3D printing had the limitation of taking time to print and this can be clearly seen in the interview with Participant 2 (Appendix Section Figure 3). He stated that the duration to print one single head was 3 days whereas the drillable sections took around 3-6 hours depending on what machine it was printed on. This would be a major pain point for low level manufacturing as the time taken to manufacture each completed product with 10 pieces would take multiple days.

Research gaps that were answered in the study conducted included the confidence levels of the participants (P1&P3) using a 3D printed simulator as well as a low fidelity one. The literature review did not cover any products that were low fidelity but products in the more expensive range, this proved that even low fidelity models can be used for surgical training after some improvements (Models printed using FDM). A major gap in research was how new trainees thought of the current product and how they would use it as well as improve it. The study was not conducted with junior surgeon since they were not available. This can be tested in the future iterations of the product to improve the design even further.

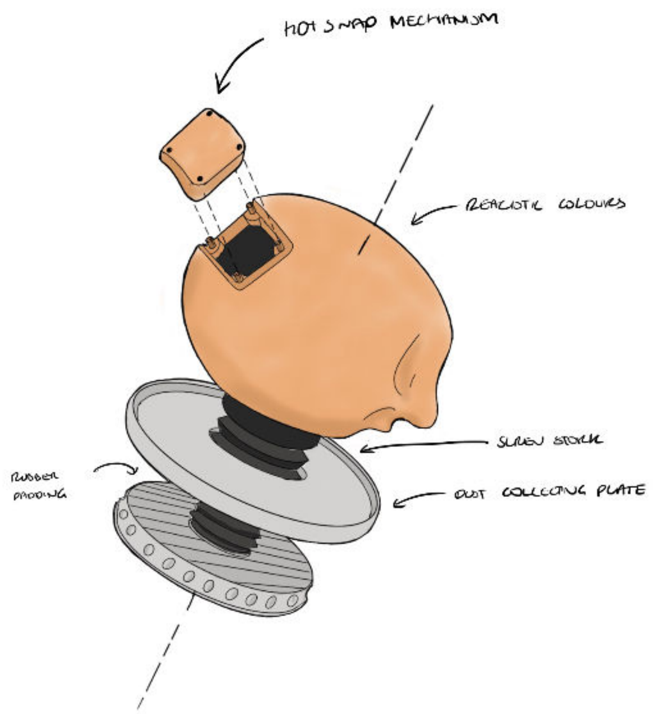
5. Design Implications

The research highlighted multiple limitations of the product as well as the benefits of using 3D printing in surgical education. The use of high-fidelity models on the J750 or equivalent is not always efficient and can come quite expensive for most people especially in remote locations. The findings control the design by focusing on the realistic characteristics of the model and how it can enhance the training experience of new trainees.

3 Design opportunities were discovered form the study –

- Opportunity to boost confidence levels of trainees due to lack of experience, this can be improved by having design that focuses on the ease of use.
- Opportunity to simplify the training procedure as study found that simplicity in design works best.
- Opportunity to have realistic characteristics in simulations due to current design not having enough. This can be done by adding more features of the human head.

5.1 CONCEPT #1 – ADJUSTABLE BURRHOLE SIMULATOR

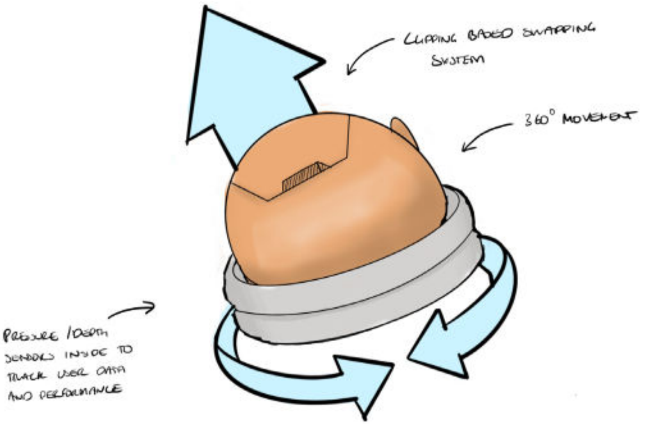


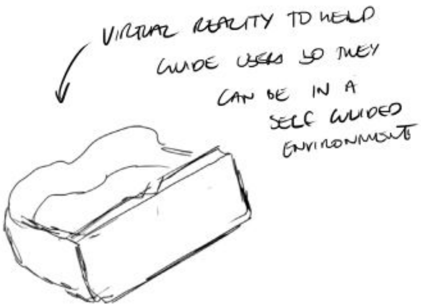
The first concept looked at making the product stress free and adjustable. The height of the model can be adjusted using the screw stork that's in the centre. The two cogs clamp down on a desk corner to securely keep the model in place. This was done in response to the current simple clamping system which was too basic. The swapable drillable section was designed in such a way that it is easy to remove using pegs and stays in position using gravity making it a screw free system. This was in response to the tedious job of removing screws in the current model. Another benefit of this model includes an integrated dust collector under the head which can help collect falling dust while drilling helping with user confidence and less mess during the procedure.

The limitation of this model was the sheer size of the product as it a large portion of the human head as well as the screwing mechanism the product would weigh a lot and may be difficult to package and carry around. Also due to the size the printing times of this product would be incredibly high as mentioned before a single print of the head section was 3 days.

5. Design Implications

5.2 CONCEPT #2 – VR BURRHOLE SIMULATOR





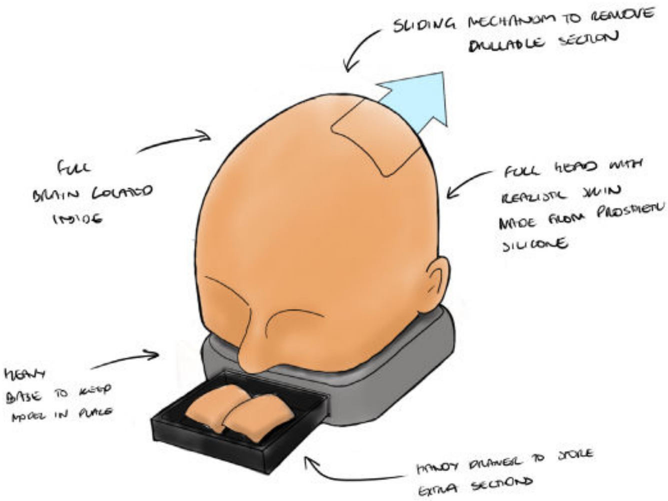
The second concept looked at simplifying the idea by going for a smaller and plainer approach. This design is intended to integrate Virtual Reality (VR) and the physical model together where the VR will compensate for the size. This design will use depth or pressure sensors in the body to measure the user performance telling the trainer their performance index, such as how hard they are pushing, accuracy and whether they pierced the dura layer or not. Using VR will also help trainers to focus on the users who are struggling as VR will guide them through the tasks. This design also utilises a hot swapping mechanic with a clipping system for the drillable section. VR technology was chosen as the original creator wanted more features to be added to the design. This will help make it stand out from traditional methods of training.

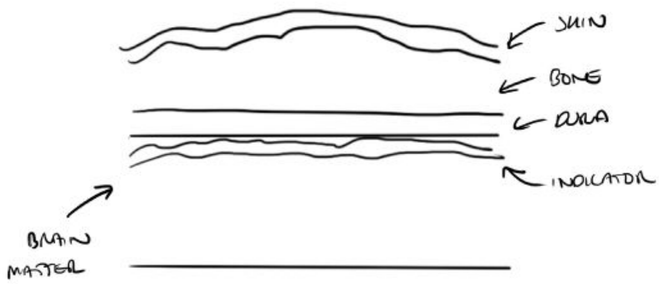
The limitations of this design include the lack of a full-sized head which was mentioned as very useful by the participants as well as the ability to clamp fixed on a table.

5.3 CONCEPT #3 - WHOLE BURRHOLE SIMULATOR

The final concept looked at bringing all the realistic characteristics in a single model. As most participants wanted to see more layers and depth to the models, the final model looked at adding layers to the head as mentioned by P1 & P3. The layers mentioned included a layer above the bone (skin layer), a layer below the bone (dura layer) and layer below that to act as an indicator to let the user know they have drilled in too far. Another aspect of design 3 includes a full-sized brain, meaning more surgeries can be practiced on this model and it is not just limited to burr hole simulation. Along with that the design incorporates a wide variety of orientations where the user can move the head to any orientation of their preference.

Limitations of this design include the size as this design would be significantly larger than the other two meaning it will be harder to manufacture as well as carry around and travel with. This model requires different approaches to manufacturing since it also includes the full scaled brain.





6. Conclusion

This report explored the topic of additive manufacturing in surgical education and the key opportunities it gave because of the research and study conducted. The study was done in collaboration with HBI and their current burr hole model, with the aim of improving and commercialising the product. Current methods of surgical training included using simple items such as fruit or animal parts or even expensive cadavers which are tough to come by.

The literature review looked at the current and emerging technologies in 3D printing with technology such the Stratasys J750 Digital Anatomy which uses resin to create highly detailed prints perfect for the medical field but at a hefty expense. The literature review found that using the most expensive technology in 3D printing does not yield the best results all the time. The review also allowed the paper to explore how 3D printing is used in the medical field and the limitations.

The study conducted based of the literature review included 3 interviews with 2 being specialists in the neurosurgical field and the original creator of the HBI burr hole simulator. A single silent observation was also conducted along with Mr Dissanayake's study where a surgeon used the current model. The study helped gain an understanding of the current model and how it held up against professional opinion. The interviews helped understand what the surgeons wanted in a simulator and what they're thoughts were on current simulators o similar level they have tried.

The study allowed to create a discussion talking about what the study meant and how it is related to the literature. The study found out that the main pain point behind the current simulator was the lack of realistic characteristics. The study also related to the literature, especially proving the limitations of 3D printing. These findings developed 3 key design opportunities which were then formed into concepts addressing the solutions from the study. The concepts looked at simplifying the procedure for the trainees and help increase the confidence levels of the new trainees. The concepts help bring the physical side of training along with the trainees existing book knowledge to a whole new level with incredible detail and lower prices effectively.

Section Four

Appendix

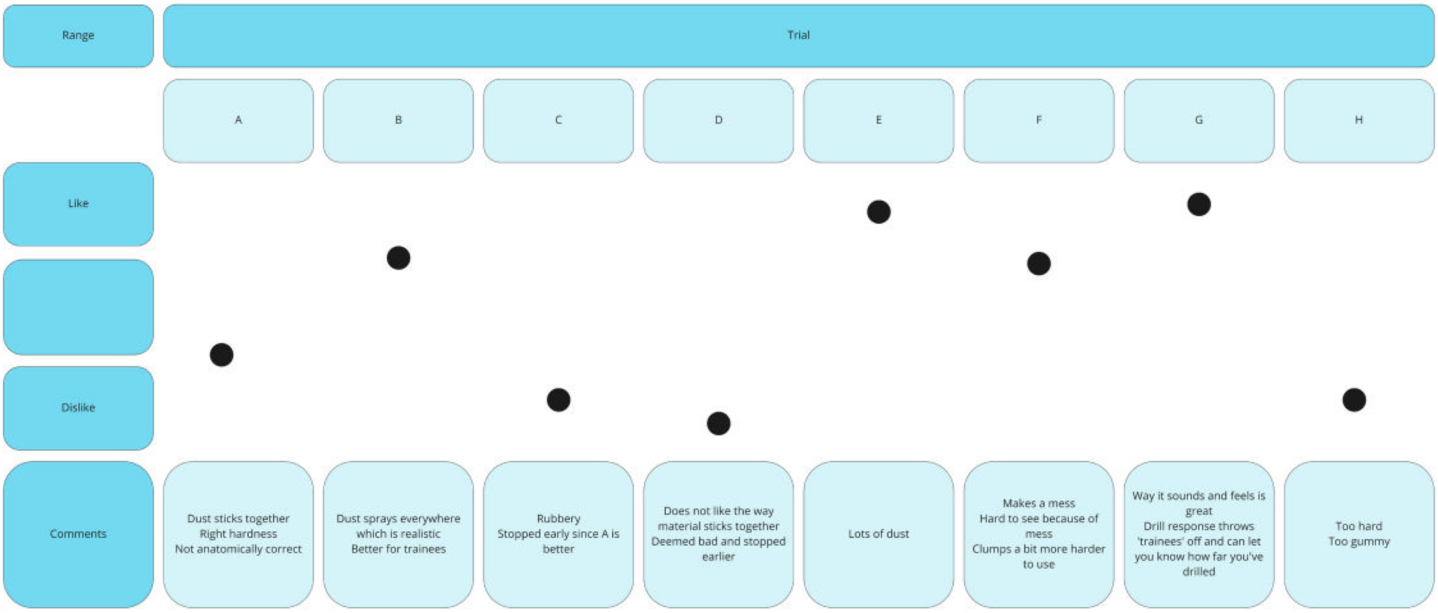


Figure 1: Emotional response to different materials in the drillable section

Figure 2: Participant 1 Interview + Observation Consent Form

1 ID 7 RESEARCH REPORT I INTERVIEW #1 EXISTING BURRHOLE MODEL OUTCOMES-ADDITIVE MANUFACTURING IN SURGICAL EDUCATION

1.1 CONSENT

This interview/observation will focus on the user experience of the burr hole model created by Mr. Dissanayaka and what improvements are needed to create a commercialised and developed version of the product.

The interaction will be recorded for educational purposes.

The information is to be used for the purpose of research in this subject only and for design ideation. Your responses I involvement will not impact your relationship with QUT in any way.

Your involvement is voluntary, and they are free to withdraw from the study at any time without question. Any personal information will be kept confidential and anonymised (unless given consent to release personal information)

Please sign below once you have read and understood the statements above

02/09/2022

1. How many years of experience do you have as a surgeon?

   a. Less than 2 years
   b. Less than 6 years
   c. More than 6 years

2. Do you find the product easy to set up? Why? (Printing it out, assembling the parts, cleaning up)

Participant believes the product is easy to use and set up at conferences or remote locations. Participant believes the clamping system is good and works well

3. Is the product useful? How? (Does it do what you want it to do)

Yes, it can be useful in training

4. Does the product replicate a real surgery? How? (Weight, handling, how you hold it how it feels.)

Participant believes that the product replicates the real feel of drilling into bone with the material PETG applied as the drillable piece. Participant referred to the sound and haptic feedback of the drilling procedure as ‘chatter’ which is very close to what it feels like when drilling into real skull bone.

5. What do you think needs improvement & why? (Better colours, silicone skin, more features?)

Adding scalp in the future, it would be best to add 2 layers above the drillable part meaning there’s a layer to cut through with a scalpel like the real procedure. Another layer below the ‘skin’ layer which can replicate the dura layer of the brain where it can be scratched off. Another layer below the skull piece to act as an indicator to the user that they have drilled too far deep and punctured the brain matter. Participant did not like the current orientation of the device as when training the burr hole section is usually faced upwards and not towards the sides.

6. What do you think of the current 3d printed simulators like the BrainBox? (What are the limitations, room for improvement, what works well)

Participant has not tried any other forms of 3D printed burr hole simulators in her career. Participant has only tried a Virtual Reality computer aided simulations which utilizes a pen like tool which can be used inside a closed of chamber. Participant found it was very good in terms of haptic feedback which was a bug in the system that causes the pen tool to vibrate when drilling.

Figure 3: Participant 3 Interview & Consent Form

1 ID 7 Research Report | Interview #2 Existing Burrhole model Outcomes – Additive Manufacturing in surgical education

This interview/observation will focus on the user experience of the burr hole model created by Mr Dissanayaka and what improvements are needed to create a commercialised and developed version of the product.

The interaction will be recorded for educational purposes.

The information is to be used for the purpose of research in this subject only and for design ideation. Your responses / involvement will not impact your relationship with QUT in any way.

Your involvement is voluntary, and they are free to withdraw from the study at any time without question. Any personal information will be kept confidential and anonymised (unless given consent to release personal information)

Please sign below once you have read and understood the statements above

Mr Nalinda Dissanayaka | 02/09/2022

1. Who were you targeting with the product? (target audience,)

Participant was targeting junior neurosurgeons and people interested in neurosurgery

2. What problems did you encounter in the development process? (printing times, costs, colours)

Participant believes the beginning of the process was challenging as he could not determine the exact size and orientation of the skull that would work well for the users. Participant did not know how large the drillable section should be and had to experiment to determine the appropriate size. From observations by the participants, he has found that the current orientation is idea for both left-handed and right handed users.

3. What improvements would you like to see in future iterations of the product? (Added features, realistic colours)

Participant would like to see anonymous scan data used for future iterations that way it's not targeting a specific user. The overall size of the product needs to be minimized to fit in a smaller packaging body. Printing times are too long at 3 days just for the head and about 4-6 hours for the drillable piece.

The clamping system works well with a 180-degree orientation as the user can clamp in any direction they would like, most users that was tested on liked the clamping system so far.

Participant would like to see different types of surgical procedures done in one model not just limited to the burr hole. Clipping system to go with the drillable piece instead of the current method. Adding AR feature to help build up the user's confidence as the product is intended for junior neurosurgeon with no real experience in burr holes.

4. What do you think of the current 3d printed simulators like the BrainBox? (What are the limitations, room for improvement, what works well, observations participants views)

Other models that are out are very expensive but have more intricate details. Participant agrees with the observation results but thinks that time will be the biggest enemy since printing just one head will take 3 days, when printing say 50 orders that would take a very long time. From observation the participant believes that the orientation is usually a personal preference from the Doctors as most users do not care.

Figure 4: Participant 2 Interview & Consent Form

1 ID 7 Research Report | Interview #3 Existing Burrhole model Outcomes – Additive Manufacturing in surgical education

1.1 Consent

This interview/observation will focus on the user experience of the burr hole model created by Mr Dissanayaka and what improvements are needed to create a commercialised and developed version of the product.

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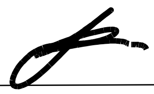
Please sign below once you have read and understood the statements above



02/09/2022

1. How many years of experience do you have as a surgeon?

   a. Less than 2 years
   b. Less than 6 years
   c. More than 6 years

2. Do you find the product easy to set up? Why? (Printing it out, assembling the parts, cleaning up)

Yes, participant said that they would be confident in setting up the product if sent to them by themselves. Participant felts that the clamping system could be improved especially if it was integrated with the product that way, making it easier for the user.

3. Is the product useful? How? (Does it do what you want it to do)

The product is very useful for junior neurosurgeons in training as their first trial of the Burrhole procedure, it is also useful for non specialist surgeons as well

4. Does the product replicate a real surgery? How? (Weight, handling, how you hold it how it feels.)

Yes, product does feel realistic to use but would like to have more layers to the model especially the dura layer. Participant believes it would be useful to have a different type of system to attach the drillable piece into the skull but says it depends on the scenario. If there are multiple junior surgeons practicing, then screwing the plates would not be that efficient but it is not that much of a hassle. Something like a clip system would work better but not essential.

5. What do you think needs improvement & why? (Better colours, silicone skin, more features?)

Participant wishes it had a dura layer or a layer below the bone to know when to stop drilling as the drill bit just goes through and there is not way to know the bit has reached the end yet. Participant wishes there was blood squirts when drilling into the bone. Participant mentioned that the head size was good as it gave a bit more to the model, to improve increasing the size would be beneficial for the trainee to use as a guide as well.

6. What do you think of the current 3d printed simulators like the BrainBox? (What are the limitations, room for improvement, what works well)

Participant has not tried anything similar in his experience and believes it would have been extremely beneficial when studying to become a surgeon. Participant thinks the BrainBox is too small as a burr hole simulator model and not that realistic as it does not cover the outer layers of the head meaning it does not cover more of the surgical procedure.

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