EVALUATION OF 3D PRINTED C1 AND C2 MODEL FOR USE IN A CERVICAL FIXATION EXPERIMENT

Natthapon Bijaphala[1], Gun Keorochana[2], and Phornphop Naiyanetr[1]
[1]Department of Biomedical Engineering, Faculty of Engineering, Mahidol University, Nakhon Pathom 73170, Thailand
[2]Department of Orthopedic, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Bangkok 10400, Thailand

ABSTRACT

Posterior fixation of C1 and C2 vertebra is a technique for restoring the stability of the C1 and C2 joint. Normally, this operation composes of placing one pair of screws at the lateral mass of C1 and other pairs at either the pedicle or the laminar of C2. After that, the screw head is attached to a stabilizing plate. Thus, the surgeon needs to drill holes into the vertebra with the risk of damaging the spinal cord or blood vessel. To reduce risk during the operation, the 3D print drill guide is being proposed as a navigation tool. Still, an experiment to compare normal free-hand operation and a drill guide operation requires multiple identical subjects. Therefore, this experiment proposes and evaluates the use of the FDM 3D printed model as a substitute for cadaver. The 3D file of C1 and C2 are reconstructed from the Dicom file of 1 mm slice thickness and increment. 20 C1 and 40 C2 models were 3D printed using ABS materials. Then, they were 3D scans and measures for the error in the shape and size of the drill guide attachment area. The results show that there is less than 1mm in average error and standard deviation in the observed areas for both C1 and C2. The author concludes that the accuracy of the 3D printed model sufficient for use in future drill guide experiments.

Keywords: 3D print model, Cervical spine, Evaluation, C1-C2 fixation

1. INTRODUCTION

C1 and C2 are the first pair of bone in the cervical spine. It joint provides most of the motion in the head movement [1, 2, 3]. It also protects the spinal cord that connects the brain to other nervous systems and blood vessels that goes to the brain. Because of these important functions, the loss of stability in these joints or bones will cause damage to the spinal cord. The spinal cord damage to this area is the most severe spinal cord injury [4, 5]. The patient can become paralysis from the neck down and needed personal care. Therefore, internal fixation of the two bones is needed to restore the C1-C2 joint stability. The anatomical name and structure of C1 and C2 used in this study are referred to the figure 1. Below

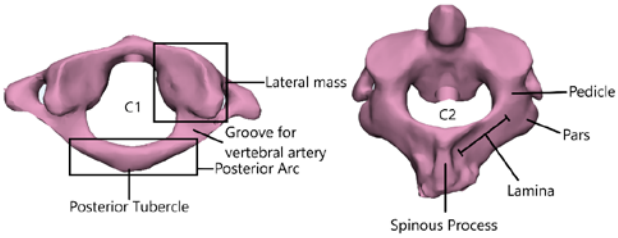

Figure 1. Anatomy of C1 (Left) and C2 (Right)

One of the C1-C2 fixation methods is a technique called Goel and Hams. In this technique, two pair of screws is drill into the C1 and C2 body from the posterior end. The screw head is then attached to a stabilizing plate or another rigid stabilizer[6, 7, 8, 9, 10, 11]. While simple in concept, in practice there are many potential risks to further injure the patient from wrong screw placement[12, 13]. Thus, multiple uses of fluoroscopy are used to determine and navigate the drilling process. The C-arm fluoroscope machine also takes up a significant area in the operation room and obstruct the flow of the operation.

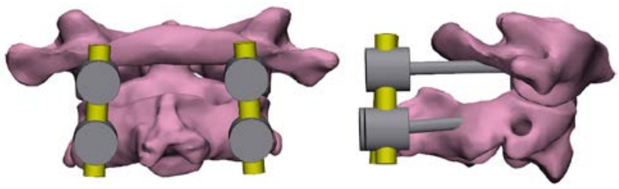

Figure 2. Goel-Harms C1-C2 fixation technique

3D print drill guide or surgical guide is one of the alternative navigation systems aim to lessen the cost and simplified operation. The technique uses the combination of Ct scan and 3D print technology to create a patient-specific guide[14, 15, 16]. First, the patient's bone is scan in a CT scan machine. Then the image is reconstructed into a 3D model. The surface of the bone is inverted to create a tight-fitting surface of the guide. The drill and screw placement will also be pre-plan during the designing of the guide. Therefore, lessen the time uses in the operation room.

An experiment to statistically compare the result of drilling operation using the standard free-hand technique and 3D printed drill guide technique is needed. These require a significant amount of repeatable test subjects.

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*Corresponding author Email: phornphop.nai@mahidol.ac.th Department of Biomedical Engineering, Faculty of Engineering, Mahidol University, Thailand.

However, It is impossible to find identical bone or cadaver in the amount needed to create the necessary sample size. A commercial anatomical model is expensive. Among the 3D print technology "fused deposition modeling" (FDM) is known to have the roughest finish. However, it is one of the cheapest and most available 3D printers and services in the market. Hence, this paper aims to propose and evaluate the author's idea of using FDM 3D print models to substitute cadaver as subjects for future surgical experiments and practice. While limiting the scope to subject for the drill guide experiment.

2. METHOD

This experiment proposes the use of the FDM 3D printed models to be used as subjects in the drilling experiment instead of cadavers. This consists of measuring the accuracy of the model in the area where the drill guide will attach to and a fitting test. As mentioned before the fixation technique of Goel and Hams is operated from the posterior end of the vertebra. The anatomy of the C1 vertebra allows only one screw placement site at the lateral mass; show in figure 3 below.

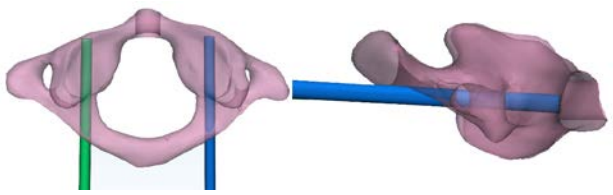

Figure 3. Screw placement of C1; Top view (Right), Side view (Left), Left Screw trajectory (Green rod), Right Screw trajectory (Blue rod)

On the contrary, the anatomy of C2 allows multiple sites for screw placement. The C2 has three sites at pedicle, pars, and laminar. The pedicle and pars screw placement is very similar but usually, the pedicle is more preferred; show in figure 4. Below. Thus, the experiment will be focusing on C1 lateral mass, C2 pedicle, and C2 laminar. Therefore, the area available for drill guide to attaching to is the posterior arch and tubercle in C1 vertebra and the spinous process and laminar in C2 vertebra.

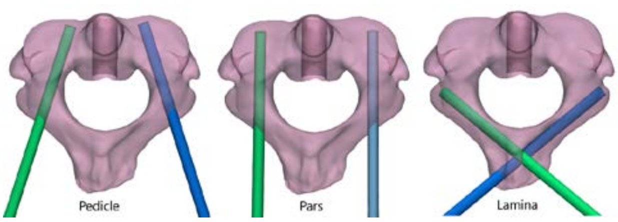

Figure 4. Screw placement of C2; Green and Blue rod represent the left and right screw trajectory respectively.

2.1 Model preparation

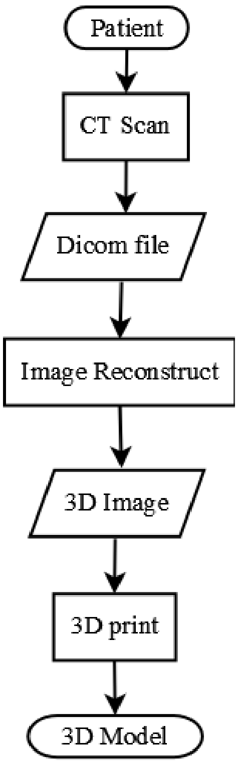

Figure 5. Flowchart of step to transforming CT scan into a 3D model

The 3D model file of the C1 and C2 is created from a CT scan of a 55-year-old male. The scan is export into a Dicom format with the following spec; resolution of 512x512 px with a pixel size of 0.352mm and slice thickness and increment of 0.5mm. The Dicom file is reconstructed into a 3D image by Materialize Mimics 22 software. Shown in figure 6. Below. The vertebrates were segmented automatically using the preset for bone.

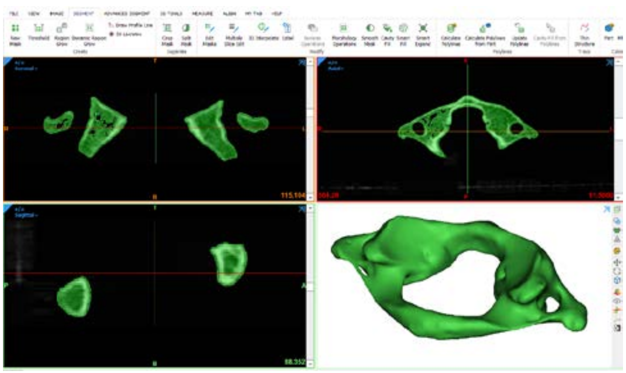

Figure 6. Reconstruct of C1 from Dicom file by Mimics software

Then on the 3D image, a hole was created to be used for attaching to the experiment base. After that, the model was 3D printed with UP Box+ machine with ABS material using the default setting. That is consists of 0.2 mm layer thickness, infill of 20%, and a nozzle diameter of 0.4mm. The 3D print machine has a layer resolution of 100 microns with a precision of 11 and 2.5 microns in the XY-axis and Z-axis respectively. A total of 20 C1 and 40 C2 models were printed. All models were printed with raft and support. This is removed by hand after the print. No sanding or any surface finish technique is applied to the printed model. The 3D printed model is shown in figure 7. Below.

Figure 7. The figure of 3D Printed C1 (Left) and C2 (Right) vertebra

2.2 Measurement

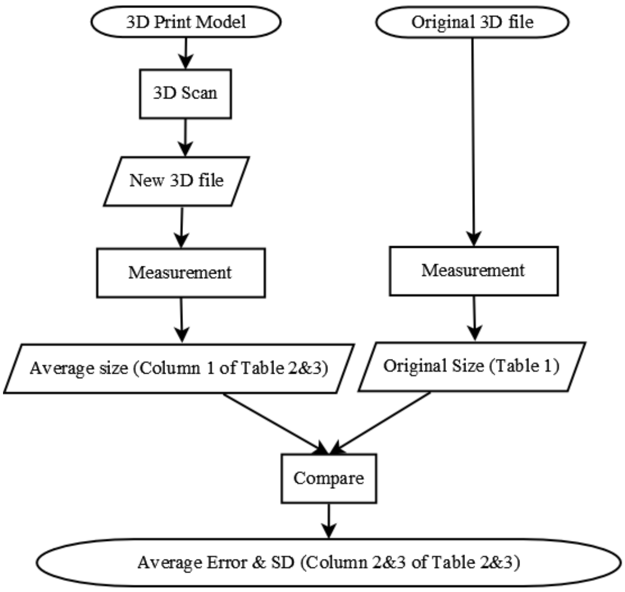

Figure 8. Flowchart of step to measure the accuracy of the 3D print model

The 3D printed models are scan with a Medit Identica Hybrid dental 3D scanner. While the manufacturer did not tell the accuracy of the scan in the specification sheet, the machine passes the ISO12836 standard. According to the standard, the machine should give an accurate result within 7 microns. The scan is performed automatically by Collab 2017 ver. 2.0.0.4 software. The scan file is then loaded into Materialize 3-Matic 14 software for measurement. Next, the result from the scan model is compared with the measurement of the original file.

The measurement area for C1 is the thickness of the posterior arch and the thickness of the posterior tubercle shown in figure 9. Below. The thickness of the posterior arch is divided into 3 areas; the thickest middle area and the thin area where the groove for the vertebral artery on both sides (end of the orange area in figure 9). This measure gives the general profile of the posterior arch and tubercle.

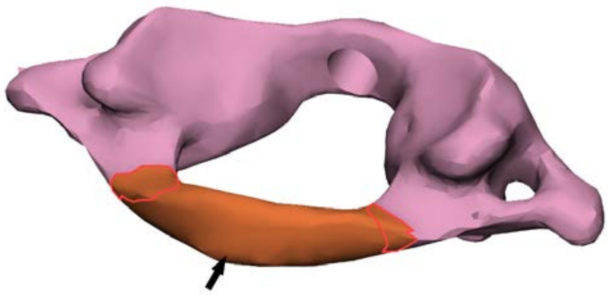

Figure 9. C1 measurement area; the orange highlight is the posterior arc and the black arrow is the posterior tubercle

At the top area where the two laminar of the C2 vertebra join together and created the spinous process, there a crest that runs from the middle of laminar to the top of the spinous process. This crest structure provides a very good attach point for the guide. Thus, the measurement area for C2 is the spinous process and the laminar crest. This consists of the height and width of the spinous process and the length of the laminar crest from the middle of the laminar to the spinous process; shown in Figure 10. Below.

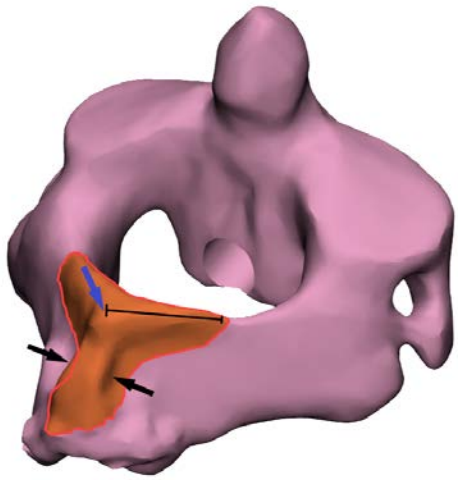

Figure 10. C2 measurement area; black line show length of the laminar crest, black arrows show the width of the spinous process and blue shows the highest point of the spinous process

2.3 Drill guide design and Fitting test

The drill guides were plan for 3mm screw placement using Materialize 3-Matics software. The attachment part of the guide is created by reversing the surface of C1 and C2 vertebra; shown if figure 11. Below. The guide is then

3d printed with a layer resolution of 100 microns using Perfactory desktop XL form Envision tec. This machine is a DLP style 3D printer with a projector resolution of 1400x1050 pixels and native/virtual pixels size of 71/36 microns. The material used for the print is called E-guide tint. It is a material uses for creating a dental drill guide. Since it a biocompatibility class 1 material that can resist against disinfectant, gamma rays, and autoclave without deformation or damage.

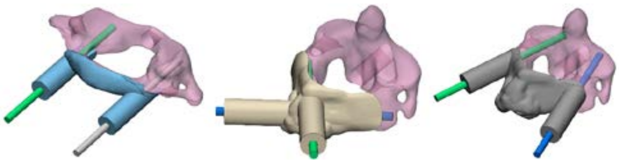

Figure 11. Designed drill guide in order from left to right; C1 lateral mass, C2 lamina, and C2 pedicle

The model is fit to an experiment base to allow it to sit upright and stable when test fitting the drill guide. Then the drill guide was attached to the model. Next, the pressure was applied at the inlet hole on each side of the drill guide. The guide is observed if it can stay fit to the model or wobble and slide off the model; shown in figure 12. Below.

Figure 12. From left to right; C1 lateral mass, C2 laminar and C2 pedicle

3. RESULTS

Table 1 shows the size of the original C1 and C2 files that are used for 3D print. These measurements are a reference for the printed model to compare. The average size, average error, and SD of the printed models are shown in table 2 and table 3. For table 2 is the result of 20 C1 models and table 3 is the result of 40 C2 models.

Table 1. Value of the original C1 and C2 file

Measurement	mm
C1 Posterior arc thickness (middle)	8.5
C1 Posterior arc thickness (left)	4.17
C1 Posterior arc thickness (Right)	4.26
C1 posterior tubercle thickness	7.82
C2 Spinous process width	4.62
C2 Spinous Process Height	11.35
C2 Length of the laminar crest (Left)	11.56
C2 Length of the laminar crest (Right)	11.95

Table 2. Result of C1 measurement (n=20)

Measurement	Average size (mm)	Average Error (mm)	SD (mm)
Posterior arc thickness (middle)	8.512	0.021	0.144
Posterior arc thickness (left)	4.187	0.017	0.084
Posterior arc thickness (Right)	4.314	0.054	0.112
Posterior tubercle thickness	7.851	0.031	0.098

Table 3. Result of C2 measurement (n=40)

Measurement	Average size (mm)	Average Error (mm)	SD (mm)
Spinous process width	4.606	-0.013	0.065
Spinous Process Height	11.434	0.084	0.126
Length of laminar crest (Left)	11.435	-0.124	0.218
Length of laminar crest (Right)	11.918	-0.021	0.280

Off all the 20 C1 model tests with the C1 lateral mass drill guide, only one model show wobble when pressure was applied at either side of the inlet. Yet, it still able to stay attached to the model. On the other hand, all 40 C2 models did not show any wobble and stay tightly fit for both the C2 laminar guide and the C2 pedicle guide.

4. DISCUSSION

From the result shown above, the author noticed that the average error for both C1 and C2 is less than 0.5mm. This is expected from the fact that the 3D file is reconstructed from a Dicom file of 0.5mm slice thickness and printed with a 0.2mm layer thickness. The Up box+ machine claims to have XY resolution of 11 microns (0.011mm). While the result shows a greater value, it is not enough to overwhelm the resolution of the Dicom file. The fitting test also shows that the drill guide able to attached to the printed model. Therefore, the author concludes that an error of less than 0.5mm is acceptable.

The SD value in the C1 result did not change much throughout all measurement areas, even though the measured area contains a rough surface finish from the removal of the support.

On the other hand, in C2 the length of laminar has the highest SD value. Author judge that these increases came from the small cross-section of the area cause heat to accumulate in the area during print. The heat may cause a delay in the hardening of the extruded material and reduce the sharpness of the printed model. Although there is an increase in SD value, it is insignificant when compared to the overall shape of the spinous process and laminar crest.

As usual of the FDM printer, the rough surface of the printed model can be seen and feel to the touch. Especially, the surface that connected to the support. However, the result shows that it only has a minor effect on the accuracy of the model. Thus, the author expects it to have little to no effect on the future drilling experiment.

The UP Box+ 3D printer used in this experiment is a professional-grade machine that aims for business use. This causes the print quality to be good. Although the author expects any well-maintain FDM 3D printer should be able to print models with enough quality to satisfy these conditions. Nevertheless, the rough surface and a low layer resolution of the FDM printer might not satisfy a more demanding condition such as in the dental field.

Although the result shows an accurate reproduction of the outer shape and dimension of the bone, the inner structure is neglect. The thickness of compact bone and the density of cancellous bone has a significant effect on the surgeon's perception and feedback during the operation. These structures can be imitated with the shell(perimeter) thickness and infill density setting. While infill structure is a simpler structure than a cancellous bone structure. It should be able to replicate the same mechanical properties. Though, the author suggests a further experiment in finding infill pattern and density that can create similar mechanical properties to a given density of cancellous bone.

The difference in the mechanical properties of bone and ABS plastic is also a significant factor. ABS plastic is a more ductile material than bone. It also can melt from temperature generate from a moving metal tool such as a spinning drill bit or saw blade since it a thermoplastic.

5. CONCLUSION

This paper verifies the idea of substitute cadaver with affordable FDM 3D print models as a subject for a medical experiment or study. As the author already mentioned in the discussion, the result shows that the model is accurate enough that it will not cause a fitting problem with a drill guide created from the same 3D file. With the repeatability provided by the 3D print model, a medical experiment that requires comparing two or more methods on the same subject can be assembled and prepare more easily. Nevertheless, a further experiment in creating the inner structure to optimize the perceptive and feedback the surgeon received is needed.

6. ACKNOWLEDGMENT

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Natthapon Bijaphala was born in Nonthaburi, Thailand in 1992. He received the B.Eng. in Biomedical engineering from Mahidol University, Bangkok, Thailand in 2015. Currently, he is studying a Master degree in the Department of biomedical engineering, faculty of engineering, Mahidol university of Thailand. His interests include medical devices and a 3D pint.

Gun Keorochana received the Doctor of Medicine (first class Hons.) from Siriraj Hospital, Thailand. Diploma of postgraduate from faculty of graduate studies, Khon Khan University, Thailand. Diplomat; Thai board of orthopedic surgery from Srinangarin Hospital, Thailand. Spine surgery from the University of Califonia, Los Angeles, USA. Currently, He works as an Assistant Professor at Ramathibodi Hospital, Mahidol University.

Phornphop Naiyanetr received the Doctor of Medical Science in Biomedical Engineering from Medical University of Vienna, Austria, Master of Engineering in Biomedical Engineering from Mahidol University, Thailand, and Bachelor of Engineering in Electrical Engineering from Mahidol University, Thailand. Currently, he works as an Assistant Professor and director of Cardiovascular engineering and artificial organ laboratory (CardioArt Lab).