DESIGNING AND THE CONSTRUCTION OF TRADITIONAL AND INNOVATIVE 3D PRINTED RADIOTHERAPY MASK

By

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CERTIFICATION

This to certify that the dissertation entitled

Designing and the construction traditional and innovative 3D printed radiotherapy mask

Is the bona fide record of research work done by

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3D	Three dimensional
CT	Computed tomography
MRI	Magnetic Resonance Imaging
STL	Surface tessellation language
OBJ	Object
NEX	Number of excitation
CAD	Computed aided design
ABS	Acrylonitrile Butadiene stryrene
MITK	The Medical Imaging Interaction ToolKit
MYR	Ringgit Malaysia
USD	United State Dollar

ABSTRACT

Perspex or thermoplastic devices are moulded directly to patient anatomy especially for immobilization when patients undergoing brain or head and neck radiotherapy. Some studies found that direct moulding can be distressing for patient and the shells do not always fit perfectly. A treatment shell able to generate directly from three dimensional (3D) printer with the help from a computer.

This paper focuses on improving the flexibility and quality of the existing treatment shell. The innovative custom made treatment shell was then designed and printed by using 3D printer.

To segment the surface of the patient's head from CT or MRI datasets, computer algorithms were used. After segmentation, 3D model which is suitable for printing on 3D printer is constructed. The material used to construct the prototypes were acrylonitrile butadiene stryrene

Innovative custom made treatment shells allow end users to choose any shape to cover any region depends on patient's condition such as swallowing on cheek. The flexibility of the treatment shells were increased gives good impact to treatment deliver.

ABSTRAK

Perspex ataupun *thermoplastic* merupakan sejenis alat cegah gerak yang biasa digunakan oleh pesakit kanser otak atau kepala dan leher semasa menjalani rawatan radioterapi. Untuk mendapatkan bentuk kepala dan leher pesakit, acuan akan diletakkan pada muka pesakit secara langsung. Menurut beberapa kajian yang telah djalankan, acuan secara langsung akan menyebabkan peningkatan kederitaan pesakit serta acuan yang dihasilkan tidak menyedang dengan tepat. Dengan menggunakan teknologi pencetakan 3D yang dibangunkan baru-baru ini. Alat cegah gerak dapat dicetak daripada komputer dengan menggunakan model pesakit.

Kajian ini focus kepada menambahbaikan fleksibiliti dan kualiti alat cegah gerak yang sedia ada. Alat cegah gerak yang inovatif yang telah direka akan dicetak dengan menggunakan 3D mesin cetak.

Permukaan kepala pesakit berbentuk imej CT ataupun MRI akan dibahagikan dengan kawasan lain dengan bantuan algoritma komputer. Selepas menyelesaikan pembahagian kawasan, model 3D yang paling sesuai akan dipilih dan digunakan untuk dicetak oleh mesin cetak 3D akan dibina. Bahan yang digunakan untuk mencetak merupakan *acrylonitrile butadiene stryrene.*

Alat cegah gerak inovatif ini membenarkan pengguna mereka bentuk yang sesuai bagi menutupi kawasan tertentu bergantung kepada keadaan pesakit sperti kebengkakkan di bahagian muka. Fleksibiliti alat cegah gerak meningkat boleh membawa impak positif semasa pesakit menerima rawatan radioterapi.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Immobilization of patients is crucial during radiotherapy treatment delivery. By immobilizing the patients, accuracy of the radiation will be improved. Therefore, a reproducibility delivery of dose to tumor is assured and adjacent normal and healthy tissues are protected. (Gerber, B.S., Marks, et al., 1982).

Stereolithography is the name of 3D (three dimension) printing which given by Charles Hull, the inventor of 3D printing in the early 1980s (Schubert, Van, Donoso, 2014). He was making plastic objects from photopolymer. Later, he founded the company 3D systems, which developed the first 3D printer, called a “stereolithography apparatus.” World first 3D printer, SLA 250 was introduced in 1988. Hull’s work, as well as advances made by others researchers, have revolutionized manufacturing and is poised to do the same in many other fields. (Gross, BC, et al., 2014).

3D printing is a method of manufacturing objects by depositing and fusing plastic, liquids, ceramics, metal and even living cells in layer to produce a 3D object. Basically there are three different types of manufacturing technique for example, additive manufacturing, rapid prototyping and solid free form technology. The only different between inkjet printer and 3D printer is that a 3D object is produced. (Schubert, Van, Donoso, 2014).

3D printer follows the instruction of STL file to build the foundation of the object by moving along the x and y axes. Then, to build the object vertically, the printer head is move toward z axis layer by layer. That is the basic set up for 3D printing. (Ursan, Chiu, Pierce, 2013).

There are several benefits of using 3D printing in medical applications including customization and personalization. The advantages of 3D printing are to produce custom-made medical product and equipment such as implants, fixtures and surgical tools which bring positive impact during the patients' surgery, recovery and implant. (Banks, 2013). Figure 1.1.1 showing a 3D printer is printing a kidney to replace patient who has kidney failure.

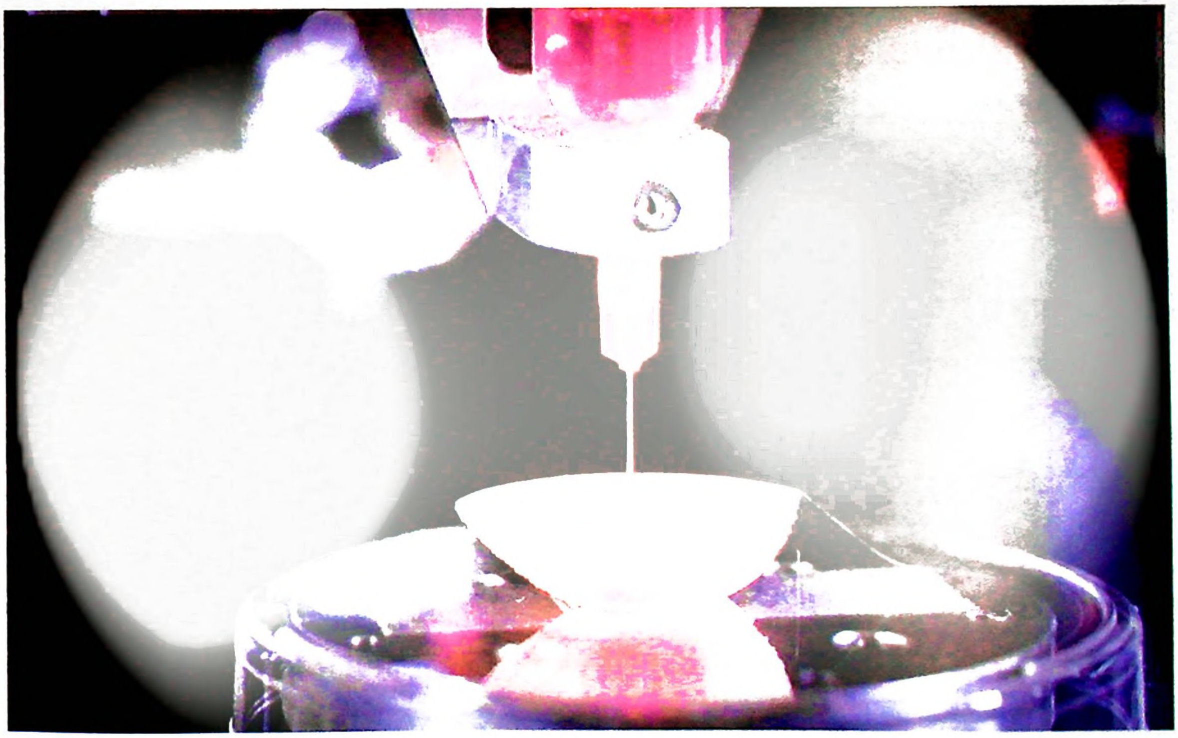

Figure 1.1.1 3D printer is printing a kidney by using biomaterial.
Note. How 3-D Printing Body Parts will Revolutionize Medicine. http://www.popsci.com/science/article/2013-07/how-3-d-printing-body-parts-will-revolutionize-medicine

3D printing also has the ability to increase the cost efficiency. Traditional manufacturing methods remain large scale production for less expensive;

however, the cost for small production is becoming more and more competitive because of 3D printing. (Schubert, Van, Donoso, 2014).

Through continues open source development, 3D printing technology has actually enhanced productivity and its qualities such as resolution, accuracy, reliability and repeatability. Milling and forging are the traditional process of making any item, but 3D printing technology make a product within several hours by skipping traditional method. (Banks, 2013).

3D printing first applied in medicine to make dental implants and custom prosthetics since the early of 2000s. (Gross, BC, Erkal, et al., 2014) Since then, people started to pay attention on 3D printing technology. Bones, ears, exoskeletons, windpipes, jawbone, eyeglasses, cell cultures, stem cells, blood vessels, vascular networks, tissues, organ, as well as novel dosage forms and drug delivery devices are the item or product which published review recently. (Hoy, 2013; Banks, 2013; Schubert, Van, Donoso, 2014)

For the past decade, three-dimensional (3D) printing has become popular and expanded rapidly in health care discipline. 3D printing can be organized into several categories such as, tissue and organ fabrication, creation of customized prosthetics, implant, anatomical model, and even pharmaceutical research regarding drug dosage forms, delivery and discovery. With this technology, it helps to revolutionize health care. (Ventola, 2014).

3D printing has also unlocked its usage in radiotherapy. A custom made bolus for electron radiotherapy is designed, fabricated and printed with methacrylate photopolymer resin. (Zou et al., 2014).

In 1982, Washington University School of Medicine used the orthopedic casting material to immobilize patients who undergoing radiotherapy treatment. Orthopedic casting material has proven less cumbersome and time-consuming than other products that time. (Gerber, B.S., Marks, et al., 1982). Nowadays, there are various types of radiotherapy masks in the market such as Orfit, VisiJet Clearn, EOS PA 3200 and Vero White plus.

Conventional thermal plastic comes with various sizes and it is perforated. The rigid sheets that soften and become malleable when heated in 70°C water bath. The sheet can be applied directly to any body part which needed to immobilize before it cold and harden again. (Gerber, B.S., Marks, et al., 1982). The temperature of the plastic does not burn but the patient may feel discomfort. (Gerber, B.S., Marks, et al., 1982). With the advancement of the 3D printing technology, the horrify experience and uncomfortable feeling can be solved by printing the radiotherapy mask.

1.2 Problem Statement

A survey conducted by Helen Bulbeck of the BrainsTrust recently had shown that 50% of the respondents felt that moulding the mask onto the patients' face are terribly horrify experiences. Additionally, 'potentially uncomfortable" is the term use by Macmillan website to describe the plaster process. (Laycock et al., 2014).

Moreover, a conventional thermoplastic mask could have more than 5 mm misalignment, that is something which cannot be accepted. (郑小康, 陈龙华, 徐艳丽, et al., 2001). Radiotherapy treatment delivered the dose to the tumours which surrounded by critical tissues, but thermoplastic masks have significant limitation in accuracy of repositioning. (Burton, Thomas, Whitney, et al., 2002). The Figure 1.2.1 shows two examples of CT images from different patients. The gap or space between radiotherapy mask and patients are clearly seen.

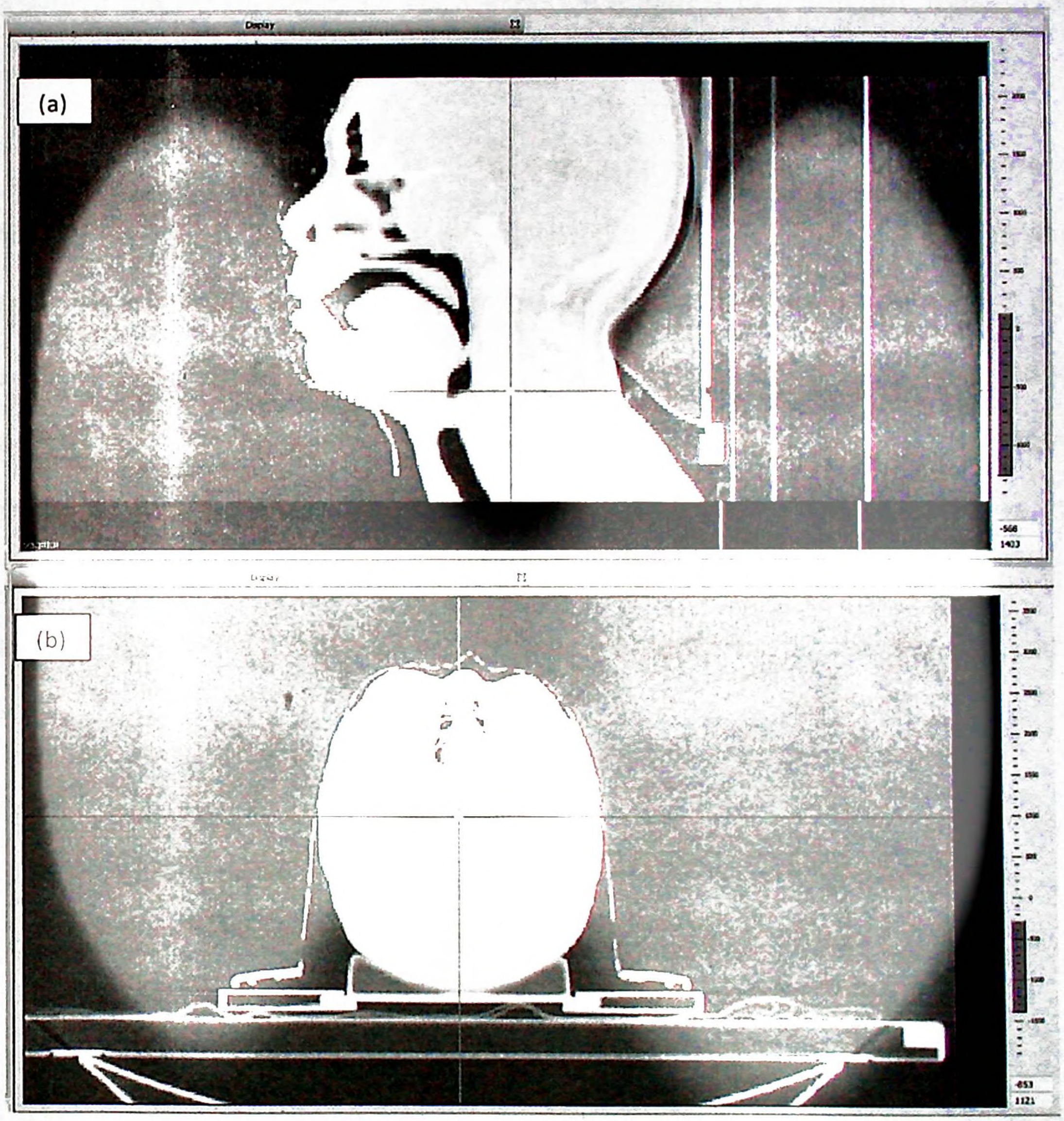

Figure 1.2.1 (a) A sagittal view of CT image for a patient which can clearly define the gap between radiotherapy mask and nose to jaw area. (b) The gap on the nose can clearly define in axial view for another patient. This can lead to certain amount of movement.

Another consideration of thermoplastic mask is skin dose. The dose to the skin can build up easily throughout the whole face where the place covered by thermoplastic mask. The consequences of high skin dose during radiotherapy treatment delivery included erythema, desquamation and becrosis (Lee, Chuang, Quivey, et al., 2002). A recent study which has shown that there is slightly increased in skin dose using mega-voltage (MV) beam energy while using a radiotherapy mask. Kry et.al (2012) proposed that 16 percent to 40 percent of the maximum dose (D_{max}) increase with a radiotherapy mask. (Kry, Smith, Weathers, et al., 2011).

The aim of this study is to design and construct a prototype of radiotherapy mask which fulfills three features, flexibility, friendly and quality. This can be achieved by using the DICOM images which will be obtained after the patient underwent computed tomography (CT) and magnetic resonance imaging (MRI) scanning and computer which associated with 3D printing technology and software. Software needed to convert the DICOM images into STL format file before the mask can be printed. Hence, with the 3D printed mask, patients could avoid from terribly horrify experience and uncomfortable feeling. Three different designs which drafted by have shown Figure 1.2.2.

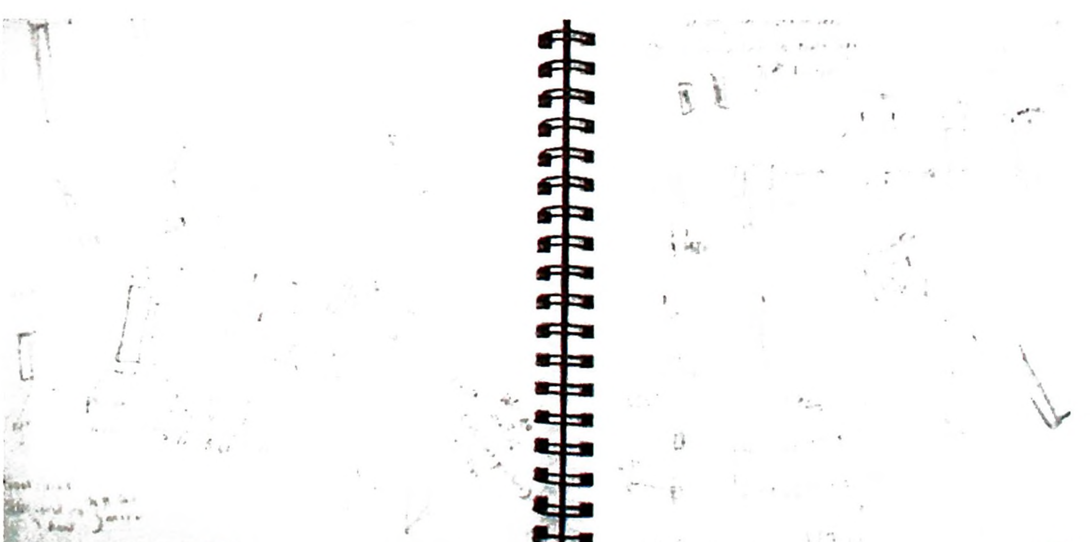

Figure 1.2.2 Designs were drafted with four major features flexible, friendly and quality.

1.3 Aim

To design and produce a prototype mask which is more accurate, flexible, friendly and quality mask (others body part) for end users (patient) who need it for radiotherapy treatment.

1.4 Objectives

- To design and construct traditional and innovation radiotherapy thermoplastic mask.
- To improve the flexibility of the existing radiotherapy thermoplastic mask using innovative design printed 3D printer.
- To reduce the waste material produced by traditional thermoplastic mask by using proposed new reusable mask holder.
- To increase cost effectiveness of the radiotherapy thermoplastic mask using proposed new design by reducing the material used.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

A semi structured interview did in Département de radiothérapie, institut Bergonié, centre régional de lutte contre le cancer; France showed a positive perception of radiotherapy mask. The patients describe the mask as a friend or protection for them. The anxiety (STAI-YB) and coping (WCC) scale scores showed that twelve out of 13 patients were received an advantage from problem which paying attention to coping strategies. (Arino, Stademaier, Dupin, et al., 2014)

In a recent study produced by Helen Bulbeck of the BrainsTrust recently had shown 50% of the respondents found the experience of moulding the mask onto the patients' face are terribly horrify experience. Additionally, 'potentially uncomfortable" is the term use by Macmillan website to describe the plaster process. (Laycock, Hulse, Scrase, et al., 2014).

According to Dr. Dubrowski, he told Canadian news website cbc.ca that 3D printing mask helps patient with high pain level or claustrophobia to reduce their anxiety and it is non invasive for them. (Sher D., 2014). Sharp et al. (2005) also stated that acute anxiety or state of panic caused by the mask making process coupled with ongoing stress of cancer diagnosis. (Sharp, Lewin, Johansson, et al., 2005)

The seven steps which used by Laycock et al. (2014) studies to produce 3D radiotherapy mask including masking, segmentation, binarisation, conversion to a hollowed out positive head, creation of negative shell, and conversion to surface-tessellation-language (STL) file. (Laycock, Hulse, Scrase, et al., 2014). The Figure 2.1.1 shows the simple steps had done by Laycock et al. (2014) studies.

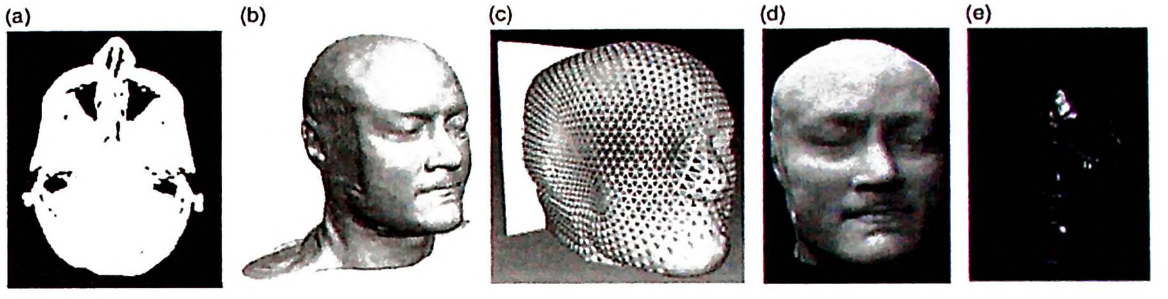

Figure 2.1.1 Mask was constructed by using MRI data. (a) Osirix was used to segmented the MRI slice images, (b) 3D computer model will then segmented from MRI dataset, (c)'negative' shell was edited. (d) The model of the head was printed and (e) 3D print of an example 'negative' shell.
Note. Towards the production of radiotherapy shells on 3D printers using data derived from DICOM CT and MRI: preclinical feasibility studies by Laycock S.D., Hulse M., Scrase C. D., Tam M. D., Isherwood S., Mortimore D. B., Emmens D., Patman J., Short S. C., Bell G. D... Journal of Radiotherapy in Practice 2014, p.3.
Disclaimer: This Figure is for reference purposes.

As mentioned in the study, a set of DICOM (Digital Communication in Medicine) data should be reconstructed thickness of 3.75 millimeters. To produce a 3D radiotherapy mask started by the procedure of masking. Images from DICOM will have existence of extraneous item or features. Masking is the first process to remove all of the extraneous item or features in the CT images. Simply using this step can avoid the problem such as supporting materials, image distortion caused by metal filling or teeth during auto segmentation process. (Laycock, Hulse, Scrase, Tam, et al., 2014).

Segmentation is a step which uses to identify of the flesh air boundary. This step simply accomplishes by thresholding of the pixel intensity values.

Flesh air boundary is not contributed to 3D printed mask. (Laycock, Hulse, Scrase, et al., 2014).

Then, a conversion of the image to black and white is needed. The interior of head and neck turned white while the exterior turned black. White is the area will subsequently printed; black is the area filled with air and not going to be printed. An automatic flood fill operation was performed on this step. They called this step as binarisation. (Laycock, Hulse, Scrase, et al., 2014).

The procedures continued with a conversion to a hollowed out 'positive' head. Size of the head and neck reduced to a smaller version to save the printer materials. 3D erosion created a spherical structuring element of 6 mm radius. A 'positive' head was then created by setting the pixels of the eroded head and neck to black. (Laycock, Hulse, Scrase, et al., 2014).

A 'negative' shell was then created. The positive shell is used to create the negative shell by wrapping around the positive shell. To make sure a small tolerance for fitting was given to the shell, the head and neck are dilated slightly, around 1px. "... As the shell must be pulled over the head, there can be no parts of the shell which wrap behind the head. This is achieved by applying one multiplies infinity pixel linear dilation directed towards the plane at the rear of the head..." Laycock et al stated in his study. In other word, a line of white pixels running towards the plane at the image lower edge converted from each of the white pixel from the plane. (Laycock, Hulse, Scrase, et al., 2014).

After that, another conversion needed before a mask can be printed. The positive or the white area of the images were then converted to STL files using the Tomomask 'Export to STL' feature based upon a marching cubes algorithm.

Once the STL file produced, the final step of the procedure was to print the mask by using a Z-Corp 650 printer. (Laycock, Hulse, Scrase, et al., 2014).

If using MRI to obtain patient head and neck images, the recommended parameters must be TR 12.2 ms, TE 5.0 ms, TI 450 ms, wit field of view of 44 cm × 44 cm, and a matrix size of 256 × 224 with 1 NEX (number of excitation). Roughly 182 images could be obtained with a slice thickness of 2.0 mm and 0.55 mm slice gap within or less than twelve minutes. (Laycock, Hulse, Scrase, et al., 2014).

Although a custom make radiotherapy mask which printed by 3D printer can give accuracy in patient positioning (Laycock, Hulse, Scrase, et al., 2014), but it couldn't be reused. A reusable mask holder was then introduced. By reducing the material used to construct the mask, the cost will definitely reduce. In this study, the masks will be separated into few parts to reduce the usage of material but remained the accuracy of patient positioning.

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials

3.1.1 Three Dimensional (3D) printer

Three-dimensional (3D) printing is a manufacturing method in which objects are made by fusing or depositing materials such as plastic, metal, ceramics, powders, liquids or even living cells in layer to produce 3D object. Additive manufacturing, rapid prototyping or slide free form technology is the name refers to the process. (Schubert, Van, Donoso, 2014)

Depending on the 3D printing processes, there are varying printer technologies, speeds, resolutions and hundreds of materials. By using 3D printer, almost any imaginable shape can be built which could be defined in a computer-aided design (CAD) file. The 3D print head moving along x- y plane is to build the foundation of the object. The printer will then continue to follow instruction by moving the print head along the z axis to build the object vertically layer by layer (Ursan, Chiu, Pierce, 2013). Figure 3.1.1.1 shows a mid range 3D printer while printing object.

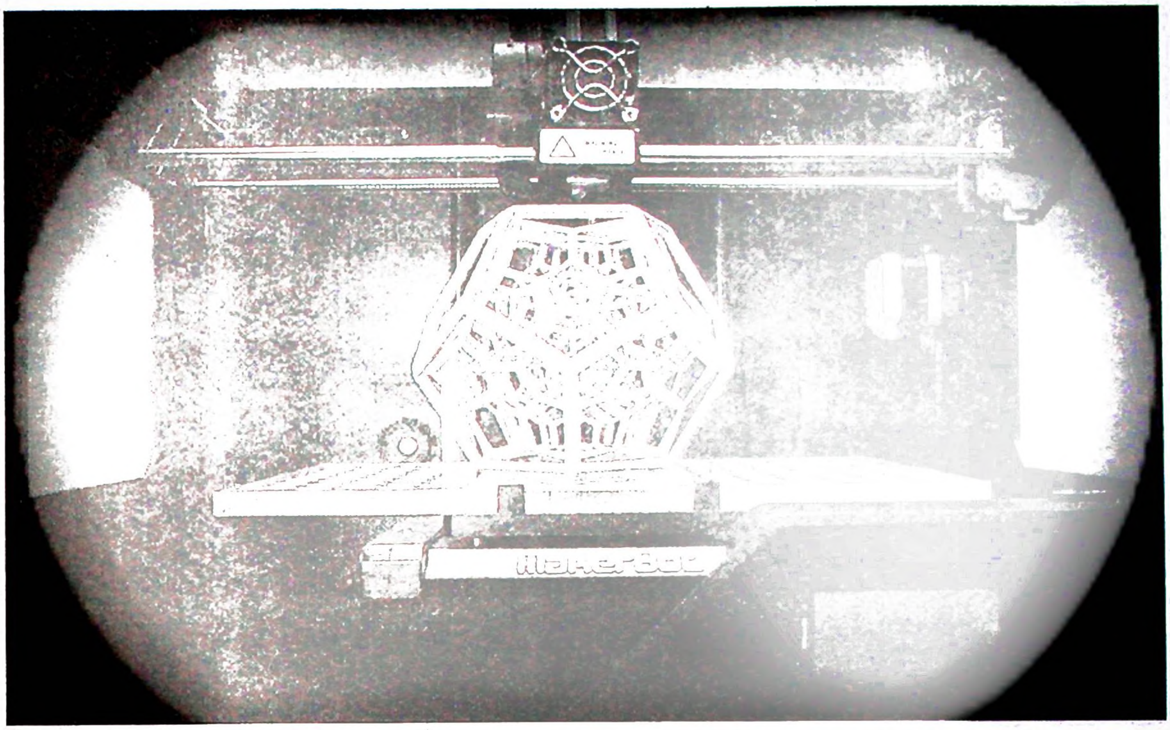

Figure 3.1.1.1 A mid range 3D printer, Maker Bot, printing an object.
Note. http://www.wired.co.uk/news/archive/2013-06/27/windows-81-3d-printing-native

3D printer is expected to play an important role in the trend towards personalized medicine, through its use in customizing nutritional products, organs and drugs. As the printer performance, resolution and available materials have increased, so have the application. This definitely becomes useful and potentially transformative tools in medical field. (Gross, Erkal, Lockwood, et al., 2014).

3.1.2 Acrylonitrile Butadiene Styrene

Acrylonitrile Butadiene stryrene (ABS) is a very common thermoplastic polymer. Its chemical formula is $(C_8H_8)_x\cdot(C_4H_6)_y\cdot(C_3H_3N)_z$. Polymerising acrylonitrile and styrene monomers which presence in butadiene synthetic rubber are the important ingredients used to produce ABS. It is glass transition temperature is approximately 105 degree Celsius. ABS is amorphous and therefore it has no true melting point (Plastic Properties of Acrylonitrile Butadiene Styrene (ABS), 2010). The chemical properties of ABS are showed on Figure 3.1.2.1.

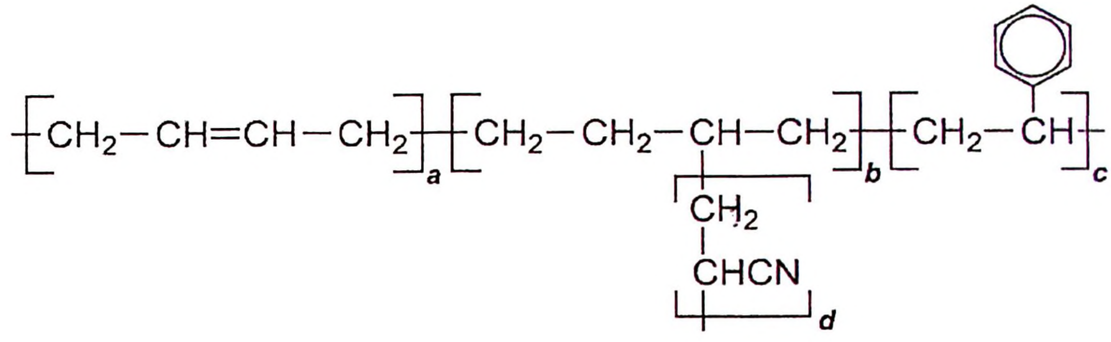

Figure 3.1.2.1 A chemical formula of ABS. Elastomers another name for ABS name after its elastic properties.
Note.http://www.essentialchemicalindustry.org/polymers/polymers-an-overview.html
Disclaimer: This Figure is for reference purposes.

It can vary proportionally from around 14 to 31 percent of acrylonitrile which have the similar amount of butadiene. In other words, 40 to 60 percents of base material is styrene and exists as long chains cross linked with shorter chain of styrene-co-acrylonitrile. This makes a material that is easy to produce, has a high tensile and impact strength. It is also able to be both moulded and printed with ease. (ABS Plastic Explained, 2015).

ABS tends to be a slightly translucent beige colour, but the material can be coloured easily. While this does not have too many adverse effects, it can lead to a slight stiffening of the feedstock filaments. Stiffening of the feedstock filaments can lead to problems in the actual feed of the material from the reel if the stiffness becomes too much. The ideal ABS feedstocks are colour varieties and the thickness needs to be as thin as possible to ensure correct feeding of the material. (Harper C.A. 1975)

Most importantly, ABS not only demonstrated for IMRT dose verification but it can also be used as a tissue equivalent phantom material for other dosimetry purposes in radiotherapy. This is because fluence maps and dose distribution generated by treatment planning system (TPS) and measured in ABS IMRT phantom was found comparable from both numerically and spatially with RW3 IMRT phantom. (Kumar R., Sharma. S.D., et al., 2010)

3.1.3 The Medical Imaging Interaction Toolkit (MITK)

A free open-source software system for development of interactive medical image processing software which used to convert DICOM images into STL file. The Medical Imaging Interactive Toolkit including the combination of Insight Toolkit (ITK) and the Visualization Toolkit (VTK) with an application framework. The main objective of MITK is to providing support for an efficient software-development of methods and application dealing with medical images. (Research Platform, 2014)

MITK application comprises broad range from the implementation and evaluation of custom research work. One of the examples is to use algorithms to the development of the entire solution for clinical studies or commercial use. MITK can be used to support the development of therapy planning and imaged-guided therapy (IGRT) applications. This make the software itself not limited to medical image processing task which only supporting medical diagnosis (Research Platform, 2014). The interface of MITK showed on Figure 3.1.3.1.

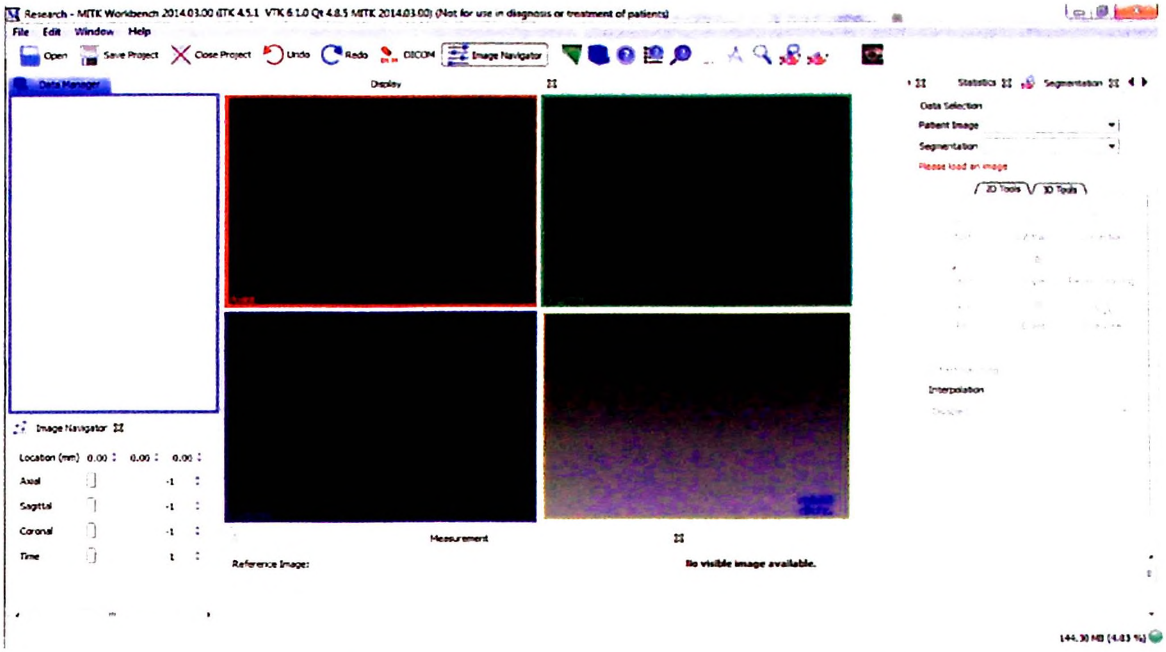

Figure 3.1.3.1 MITK is one of the powerful software which works very well in segmentation for 2D and 3D images.

Central data repository, synchronized 2D and 3D rendering of the repository, interactive manipulation of images or derived data, and a set of useful GUI widgets are the concepts of interactive application which introduce in the de-facto standards Insight Toolkit (ITK) and Visualization Toolkit (VTK). (Research Platform, 2014)

MITK offers an infrastructure for end-user application based on the OSGi inspired C++ component framework BlueBerry (former OpenCherry). With the application framework support, end users can be easily conFigured for our own special requirements and extended with plug-ins at all levels of the application. (Research Platform, 2014)

At the application level MITK distributed with an application called MITK Workbench. This allows medical end-users to perform regular image processing tasks such as visualization of 3D and 3D+t images, rigid and deformable fusion (registration) of multiple image volumes or interactive organ segmentation. (Research Platform, 2014)

The reasons of choosing MITK as the software in this study are because of its six core features. MITK has consistent views on the same data. In other words, three orthogonal 2D-views and a 3D view and data consisting of a green surface will be visible and green in all views (as contour lines in 2D, as a surface in 3D). MITK helps to coordinate the position, orientation. colours, etc. automatically when view the basic VTK. (Toolkit Features, 2014)

With the help of interaction concept, it constructs complex interaction mechanisms based medical application, especially for manual and semi automatic segmentation, for intervention planning and assistance systems for medical intervention (image guided therapy or surgery). (Toolkit Features, 2014)

Undo concept is one of the important features of a good user interface in interactive application. Correcting a false instruction is often time consuming if there is no undo concept. Undo and redo functionality is a fundamental design decision and cannot be easily added at a later time. Thus, MITK concepts offer undo and redo functionality for interaction and processing tasks. (Toolkit Features, 2014). The general undo-/redo-concept is based on the inverse command strategy which requires the interaction objects to issue operation and send to operation actors that actually perform the operation. (Archer Jr. J.E., Conway. R., Schneider F. B., 1984)

MITK organized of all application data in a central, hierarchical repository (DataStorage). The hierarchy allows representing logical relations, such as the ventricle is part of the heart. The data items also descript by arbitrary "properties" (key / value ist), for communication between program modules or to control rendering. Last but not least, the loading and saving of the hierarchical repository including all item properties. (Toolkit Features, 2014).

3.1.4 NetFabb Basic

Netfabb Basic is a software which custom made for additive fabrication, rapid prototyping and 3D printing. STL-files, slices-based files and various formats are able to view, edit, repair and analyze. Although Netfabb is software which provides true file edit, repair and analysis capability with additive fabrication industry, rapid prototyping and 3D printing but there are limitation for basic (free of charge) version (Netfabb, 2010). Netfabb Basic interface showed at Figure 3.1.4.1.

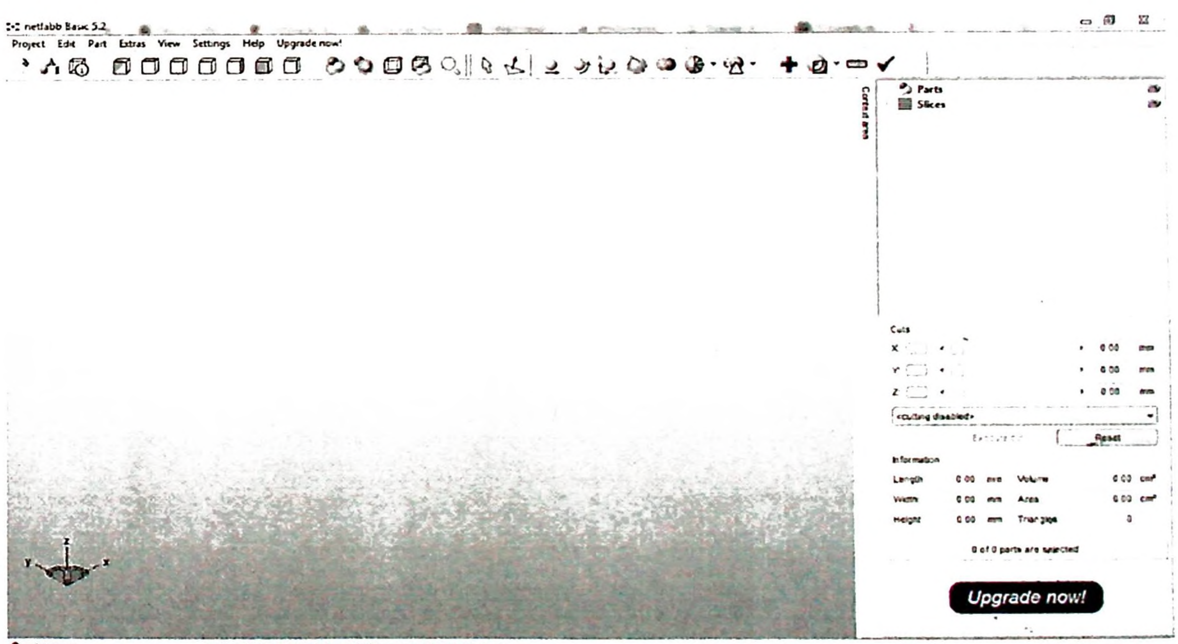

Figure 3.1.4.1 Upgradable Netfabb Basic version able to unlock more powerful editing tools including merge selected part, shells selected part, Boolean operation and more.

Some features in the basic version are including advanced model browsing and STL management, automatic part fixing, mesh editing and analysis. This basic version also allow user to edit slice, assure the quality and measurement of the model, last but not least packing and machine preparation. (Netfabb, 2010)

3.1.5 Autodesk Meshmixer

Meshmixer is part of Autodesk, a global leader in innovative design software and services which developed by Ryan Schmidt. Meshmixer is one of the popular software which use for 3D modeling. It has a clean and provides a user friendly environment for easy learning. The interface showed below. It helps to compose new 3D models from existing meshes. (Meshmixer, 2011). The Figure 3.1.5.1 show the clean interface of Meshmixer.

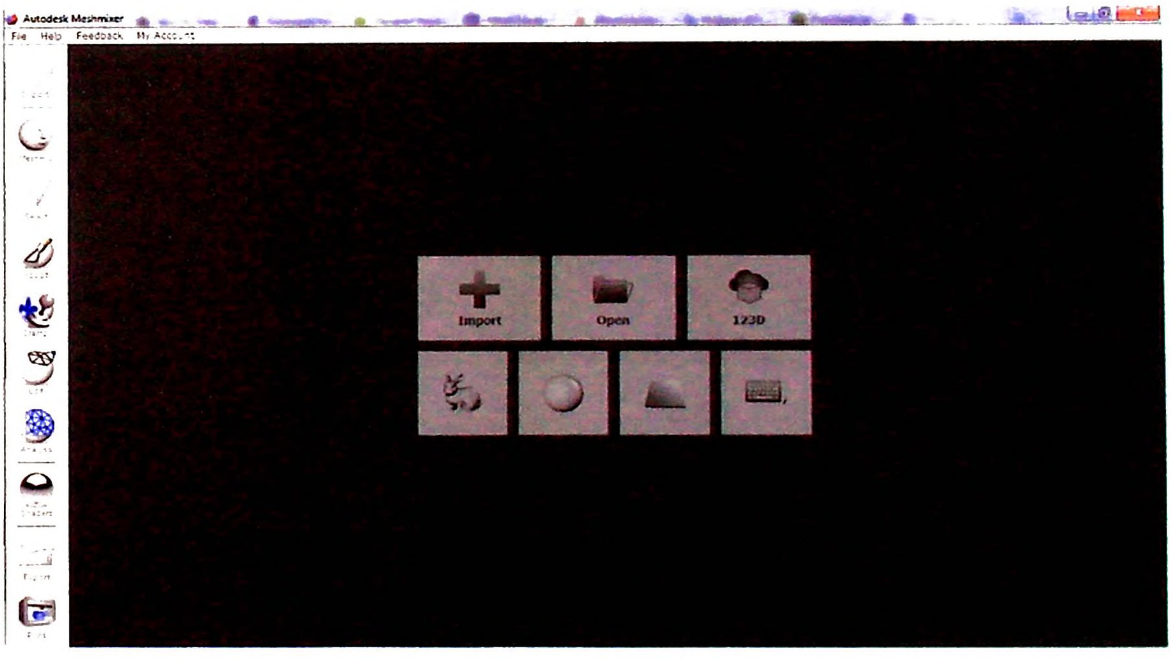

Figure 3.1.5.1 An user friendly and clean interface providing easy learning and designing environment.

3.1.6 Autodesk Inventor

Inventor developed by Autodesk, a computer-aided design application for creating 3D digital prototypes used in design, visualization and simulation of products. Integrated motion simulation and assembly stress analysis environment are included in Inventor. Various loads, friction characteristics and dynamic components can run dynamic simulation tests to check how a product will work under real world conditions. To deliver an exceptional modeling experience, impactful additions to the 3D modeling environment are the main objectives for Autodesk Inventor (What's New in Autodesk Inventor 2015, 2014). The interface showed below at Figure 3.1.6.1.

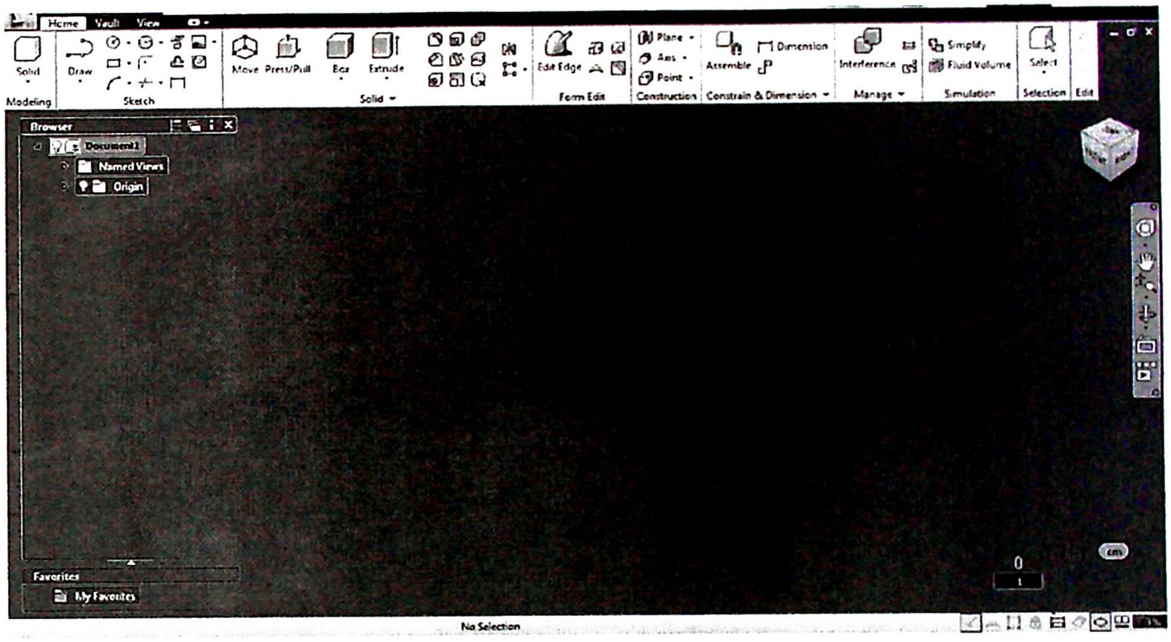

Figure 3.1.6.1 An user friendly and clean interface providing easy learning and designing environment.

With the preset simulation tools, it helps users to optimize strength and weight, identify high stress areas, identify and reduce unwanted vibrations and size motors and actuators to reduce energy consumption. Parametric studies and optimization technology are the application lets users modify design parameters from within the assembly stress environment and compare the various design options. The 3D model will then update with the optimized parameters. (What's New in Autodesk Inventor 2015, 2014)

Specific file formats like part (IPT), assemblies (IAM) and drawing view (IDG or DWG) can be easily import and export. A tool uses to create and publish simplified 3D representations, intelligent connection points and additional information in native file formats for AutoCAD MEP (mechanical, electrical and plumbing) called Building Information Modeling (BIM) exchange tools has been introduced in Inventor. (What's New in Autodesk Inventor 2015, 2014)

The Inventor Construction Environment provides fault-tolerant import of large STEP and IGES data sets. Quarantine holds entities containing geometric problems, such as surface silvers and mismatched boundary curves. PDF files, 3D part and assembly models in SAT format or create STL file for output to stereolithography and 3D print machine are one of the interesting features which within Inventor. (What's New in Autodesk Inventor 2015, 2014)

3.2 Methodology

3.2.1 Design and Print Traditional Radiotherapy Mask

I divided this method into four simple sections, design template, create smooth polygon model, make mesh and combine, last but not least, export and print.

In Laycock's study, the head and neck of CT (computed tomography) scan was reconstructed as a slice of 3.75 mm. While for head and neck MRI scan, it could performed by using the parameter of a 3D fast spoiled gradient echo sequence, TR 12.2 ms, TE 5.0 ms, TI 450 ms, with a FOV of 44 × 44 cm, and a matrix size of 256 × 224 with 1 NEX (number of excitations). A total of 182 images with a slice thickness of 2.0 mm and 0.55 mm slice gap were obtained with a scan time of less than 12 minutes (Laycock, Hulse, Scrase, et al., 2014). In this study, CT images were reconstructed with 3 mm thickness.

Designing template is the first section. To design the template for radiotherapy mask thermoplastic holder, a caliper was used to measure the existing mask holder precisely. Figure 3.2.1.1 showed a caliber was in used during measuring existing mask holder up to three decimal points in millimeter or centimeter.

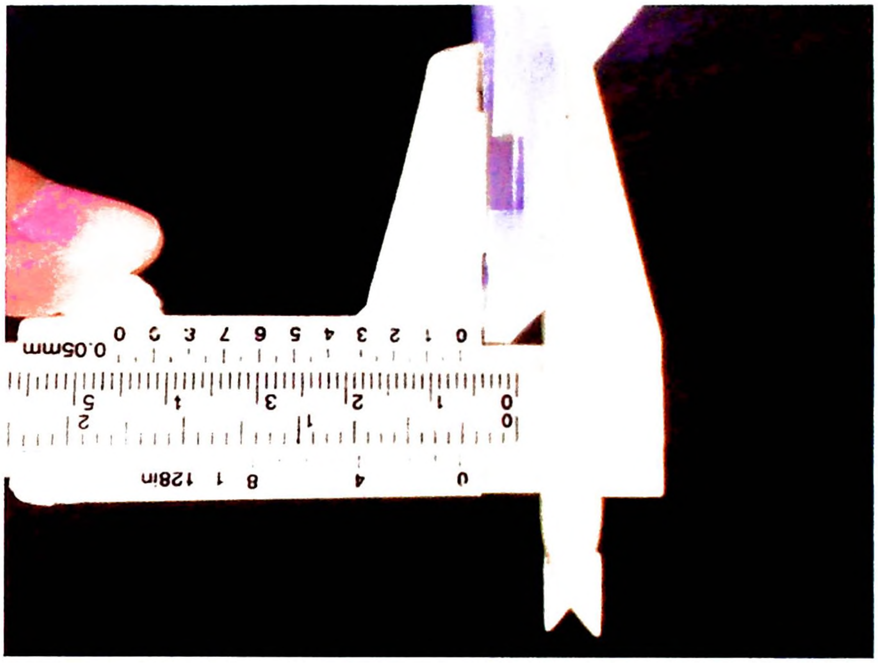

Figure 3.2.1.1 A caliber need to be used in measuring the dimension of the mask holder because it can provide up to tree decimal point. The thickness of the mask holder is 6.200 millimeter.

The measurement of the holder which obtained earlier was then converted into Autodesk Inventor 2015. A 3D mask holder was constructed as shown in the Figure 3.2.1.2. Then, the 3D mask holder exported into STL file format and ready for the next step.

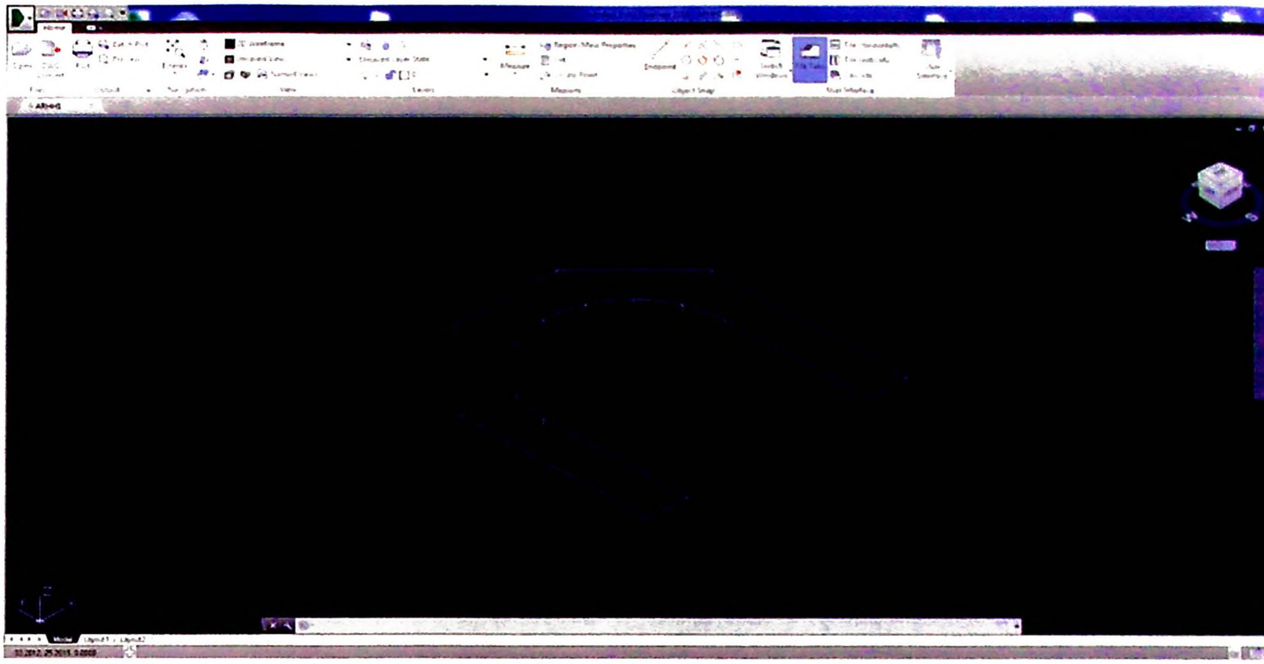

Figure 3.2.1.2 The dimensions of the mask holder was converted and constructed into 3D form.

Move on to section two which is creating a smooth polygon model of the patient. Before we can create a smooth polygon of a patient from the reconstructed CT images, there are few steps which we have to do. All reconstructed CT images transferred to MITK. External (Facial and body shape) of the patient was selected by using the upper and lower bound which are 56 and -196 (Threshold is -160). Figure 3.2.1.3 showed the 3D volume selection for threshold -160.

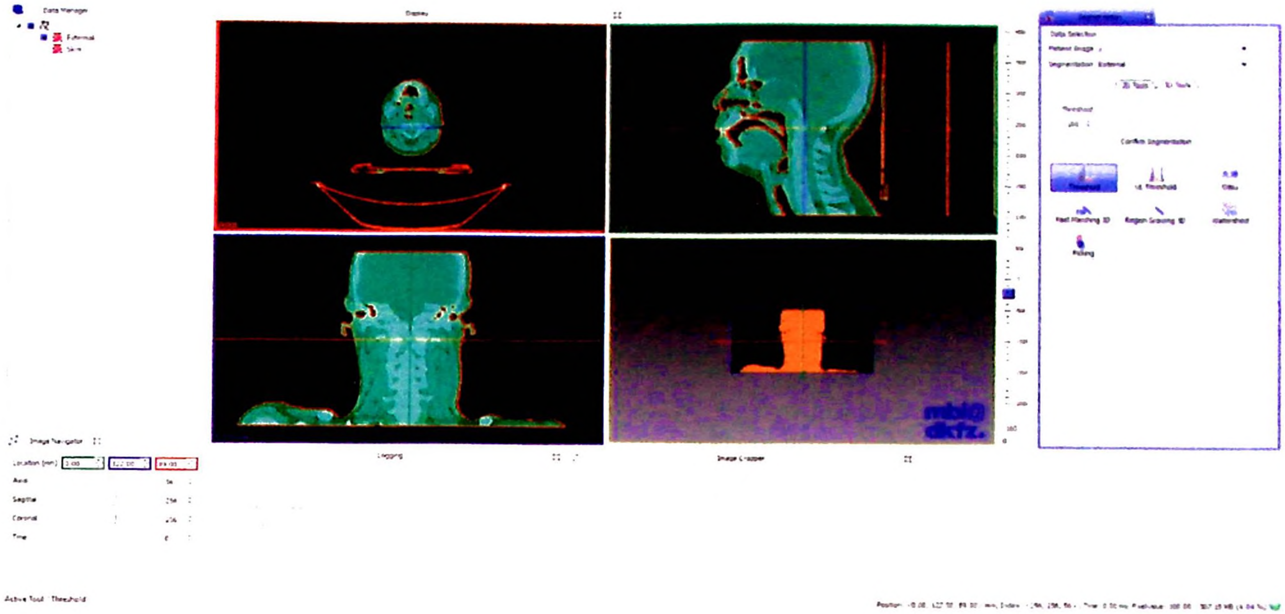

Figure 3.2.1.3 The threshold -160 for all reconstructed CT images were selected in MITK. There are some parts which couldn't be selected.

You will notice that, there are some cavities (holes) couldn't select automatically. To ease the later process, cavities (holes) must be selected as well. Combination of 2D Fast Marching and interpolation of 3-Dimensional was chosen. Figure 3.2.1.4 showed that the cavities (holes) were selected.

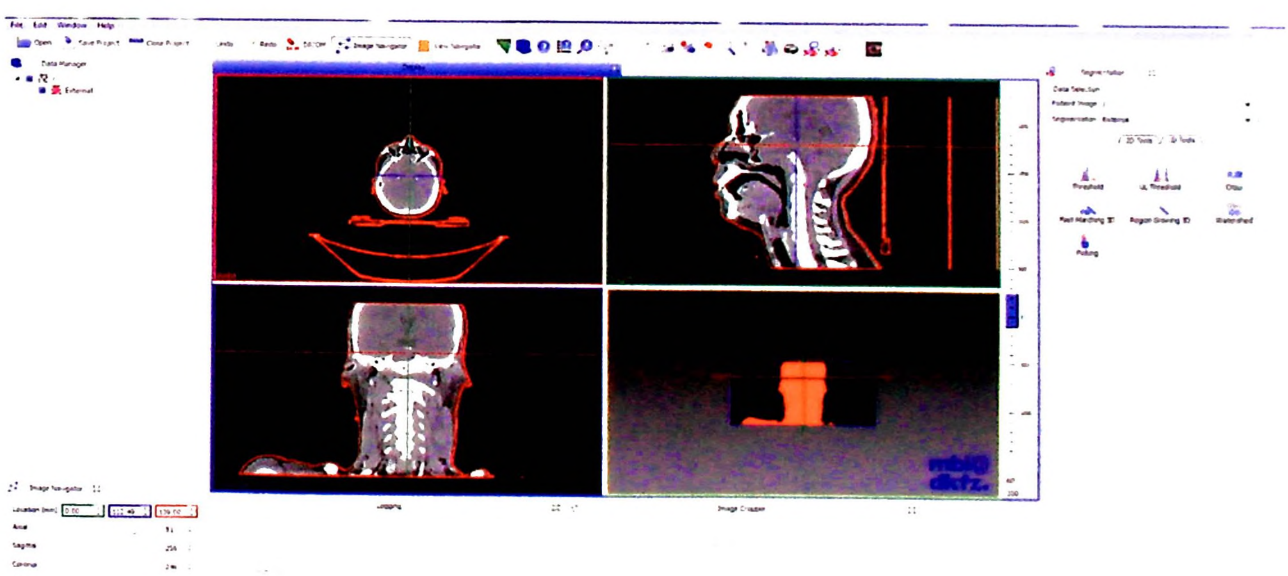

Figure 3.2.1.4 All cavities (holes) were selected.