Introduction

A collaborative study was undertaken between the Medical Illustration Department and the Radiotherapy department at Lancashire Teaching Hospitals to investigate the potential of using 3D printing in the production of localised radiotherapy masks.

Radiotherapy on localised regions of the head requires a protective lead mask to be created in order to prevent X-rays from damaging the surrounding healthy tissue. The mask is currently created by making a thermoplastic mould of the patients face. When the thermoplastic has hardened the mould is removed and packed with plaster. A sheet of lead is then hammered onto the surface of the plaster mould in order to create a protective mask.

Movements in the patients face during the application of the thermoplastic can cause problems in the creation of a well fitted mask. Due to the process of taking a plaster impression from the thermoplastic mould only a low definition representation of the patient's face is possible (figure 2). This study investigates the possibility of using 3D scanning and printing in order to create a higher definition facial model, better fitting mask and improved patient experience.

Aims

- Increase the definition of the model in order to create a better fitting mask
- Reduce the time the patient needs to stay in the clinic
- Reduce the time spent by the clinician in the construction of the mask

Methods

Current Process

- The patient attends the Radiotherapy department for a mask fitting.
- An impression of the face is taken using thermoplastic (figure 1).
- Plaster is pressed onto the underside of the thermoplastic impression (figure 2).
- A lead sheet is hammered onto the impression to create a bespoke fitted lead face mask (figure 3).
- A small part of the lead mask is removed around the treatment area.

3D printed process

- The patient attends the Radiotherapy department for a mask fitting.
- A laser scan is taken of the patients face.
- The scan is processed to create a digital model of the patients face.
- The digital model is printed in 3D.
- The 3D print is delivered to the Radiotherapy department.
- A lead sheet is hammered onto the 3d print to create a bespoke fitted lead face mask.
- A small part of the lead mask is removed around the treatment area.

A digital model of the patients face was acquired using a laser scanner. The digital model was then imported into blender (a free opensource 3D application) (figure 3). The face region was then isolated by deleting any unwanted parts of the digital model (figure 5). This reduces the complexity of the model and reduces the amount of processing time. This also reduces the printing time and cost of materials.

The scanner generates a digital mesh of the patients face composed of thousands of vertices (co-ordinates), however the mesh is randomly organized (figure 6) which is not suitable for 3D printing, therefore a second digital mesh was produced by snapping to the surface of the scan (figure 7). This model was composed of clean, well organised geometry in order to produce an efficient and successful 3D print.

A thickness of 1cm was then added to the model by applying a solidify modifier (figure 8). The solidify modifier allows the user to define a thickness in millimetres to the surface mesh.

The model was then exported as an stl file (STereoLithography) ensuring that the scale was 1:1 and then sent for printing.

When printing the model it was necessary to include support structures in order to suspend the model as it was being printed. The support structures were left in place along with additional cylindrical columns in order to increase the strength of the model.

Results

The patient's appointment lasted approximately 5 minutes including time taken to verify the scan. Three prototype models were printed in 3D using an Ultimaker2.

The first prototype model was sent to the radiotherapy department where they attempted to hammer out the lead mask using the print as a base guide. Weaknesses in the support structures of the initial prototype (version1) caused the model to fail when the sheet of lead was hammered on to the surface, making it difficult for the mask to be completed accurately (figure 13). Additionally the digital scan dipped slightly over the eyes creating a small inward protrusion resulting in an uncomfortable fit. This was due to the patient's eyes being open during the scan; therefore the scan was repeated with the patient's eyes closed. (figure 14). The second prototype (version 2) was given a 5mm thick wall for additional strength and also included an indented area to indicate the treatment area to be removed from the lead mask. The structure of the print failed again when the lead sheet was hammered onto the surface.

A third prototype was created with a 10mm thick wall, which also contained several thick columns for additional strength. The model was sent to the radiotherapy department where they were able to successfully create the lead mask. The Lead mask fitted comfortably and was confirmed by the lead clinician to be safe to use for treatment. The final print time was 30 hours and a total of 200gms of print material was used at an approximate cost of £8.00.

Conclusion

- 3D printing can be used as an alternative to using thermoplastic moulding for the production of protective lead radiotherapy treatment masks.
- The 3D printed method reduces the time that the patient spends at the appointment.
- The laser scan eliminates the need for thermoplastic to be applied to the patients face.
- Laser scanners produce a high definition digital model of the face resulting in a more accurate 3D model than the thermoplastic mould method. This can then be used to create a more accurate, better fitting mask.
- The time spent on the production of the mask was reduced for the clinician however there were additional processes such as the digitisation and optimisation of the scan data and the 3D printing process.
- The print time was 30 hours allowing a maximum of 4 masks to be printed over a 1 week period per 3D printer. This was found to be acceptable with approximately 3 patients

requiring treatment masks per week.

- Further studies should be carried out in clinical practice to determine if patient satisfaction is improved and to determine the feasibility of 3D printing replacing current thermoplastic moulding techniques.

Figure 1: Thermoplastic sheet being applied to the patients face

436x311mm (300 x 300 DPI)

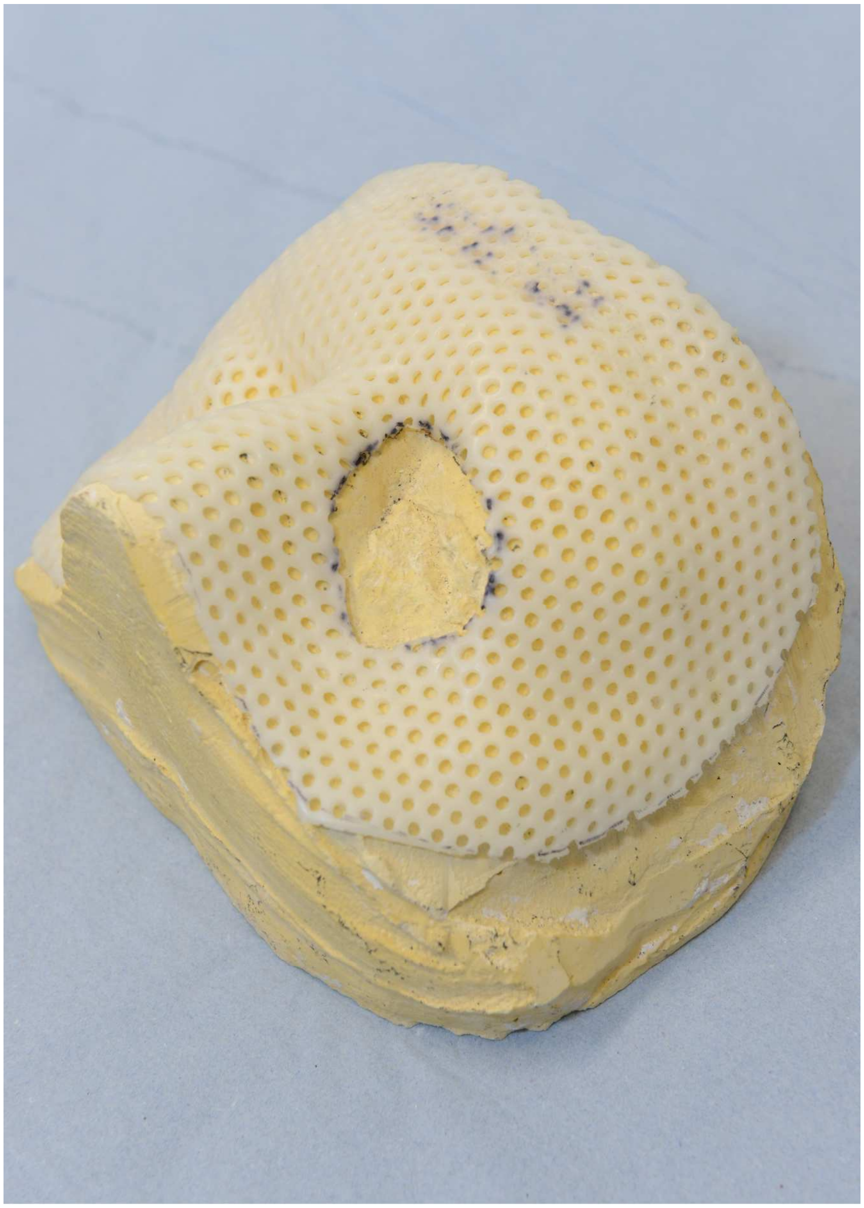

Figure 2: The thermoplastic sheet on the plaster impression

296x414mm (300 x 300 DPI)

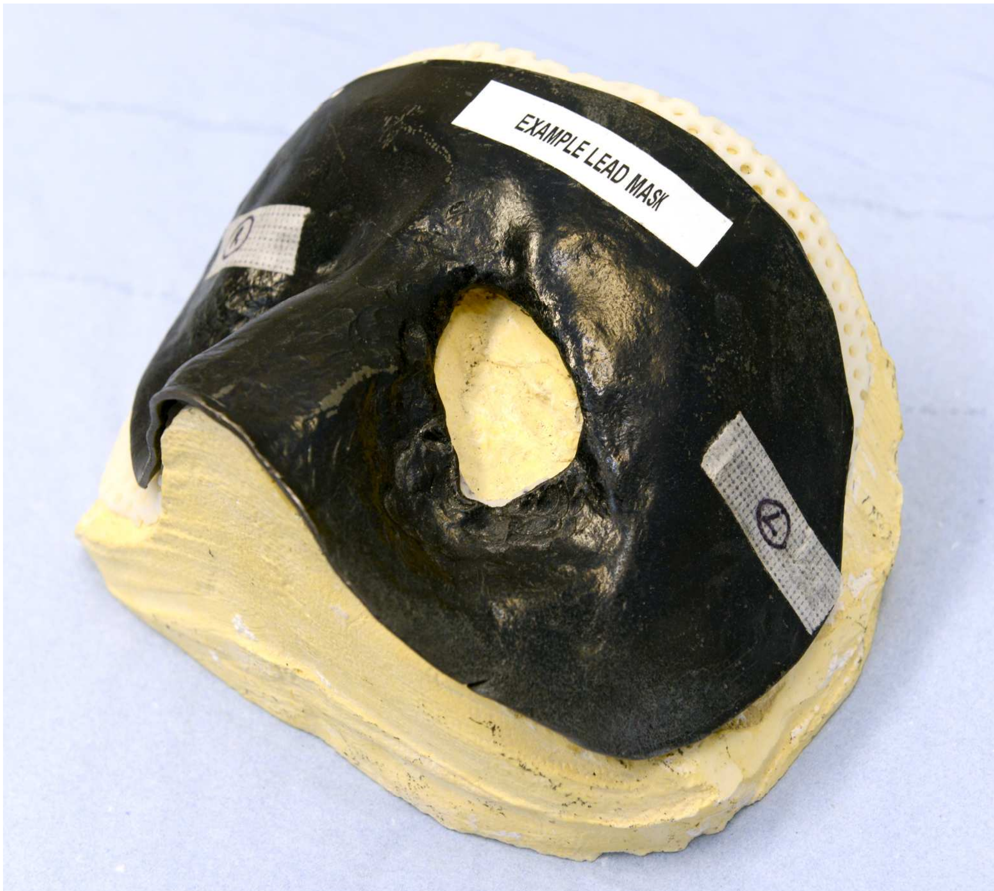

Figure 3:The final lead treatment mask

348x311mm (300 x 300 DPI)

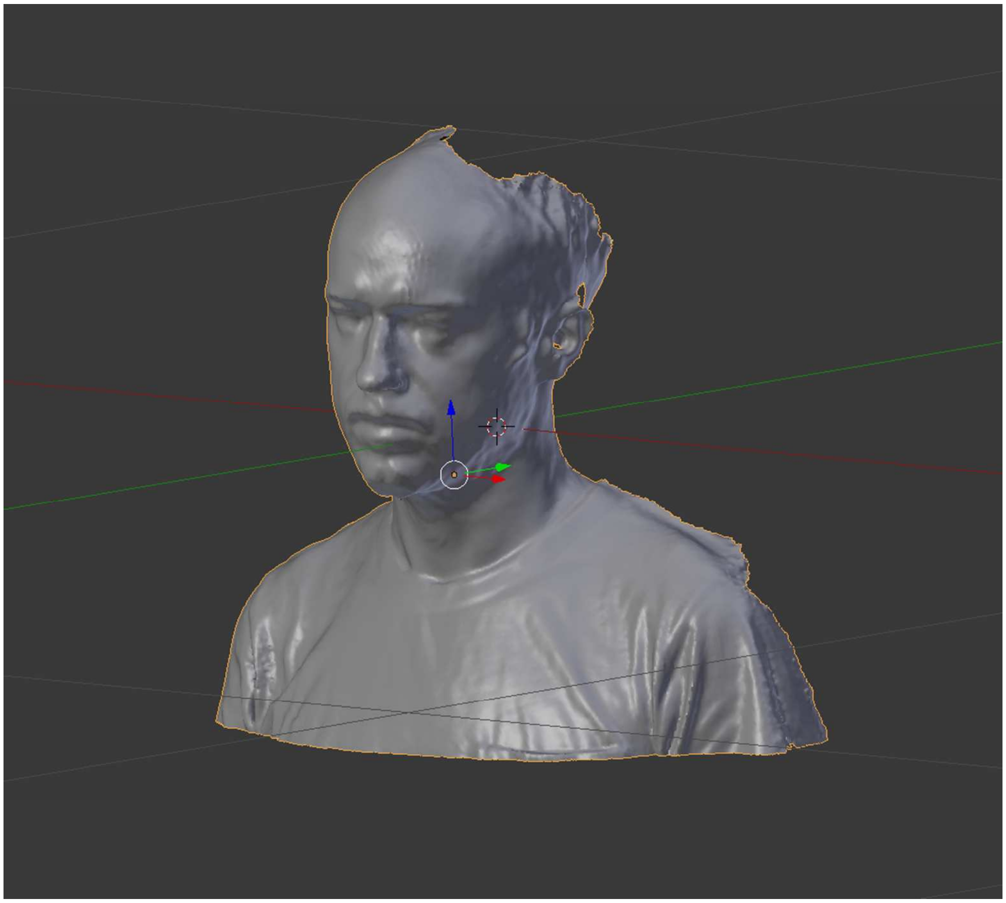

Figure 4: The laser scan imported into blender.

383x342mm (72 x 72 DPI)

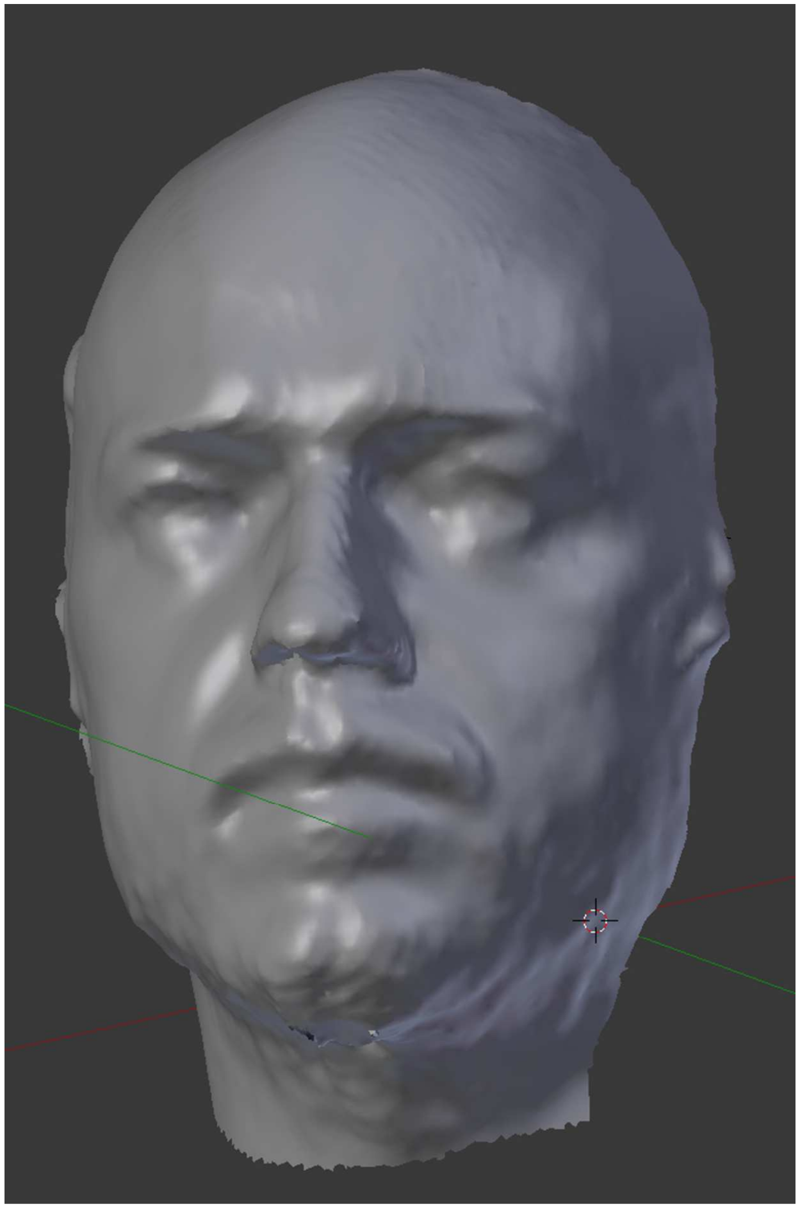

Figure 5: The face isolated by deleting any unwanted geometry.

244x371mm (72 x 72 DPI)

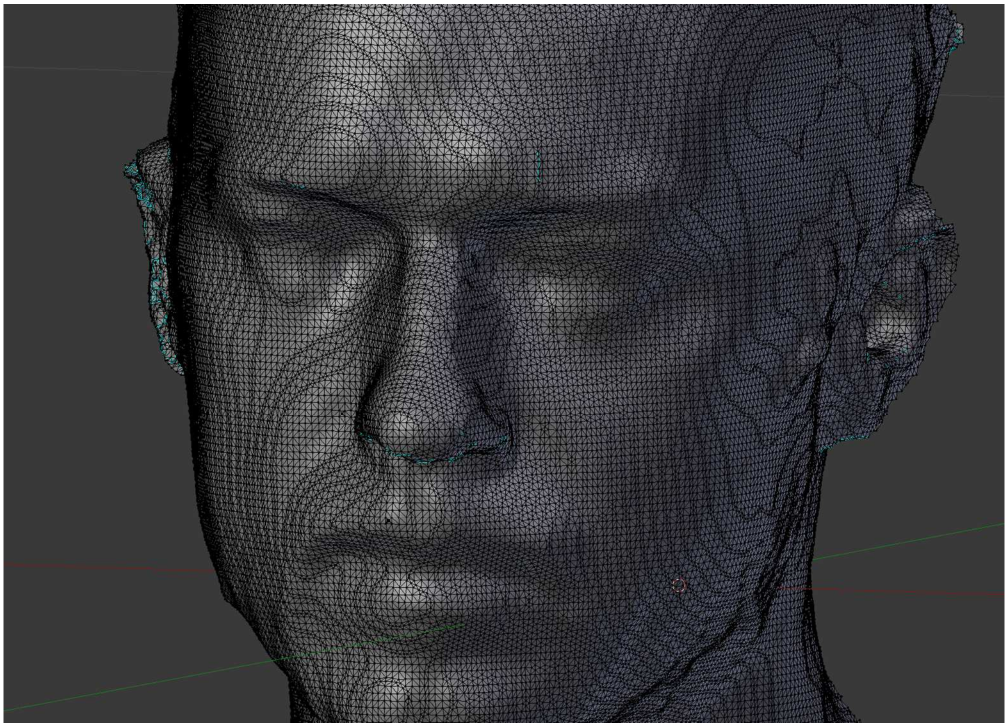

Figure 6: The model in edit mode revealing the unorganised geometry unsuitable for 3D printing.

571x409mm (72 x 72 DPI)

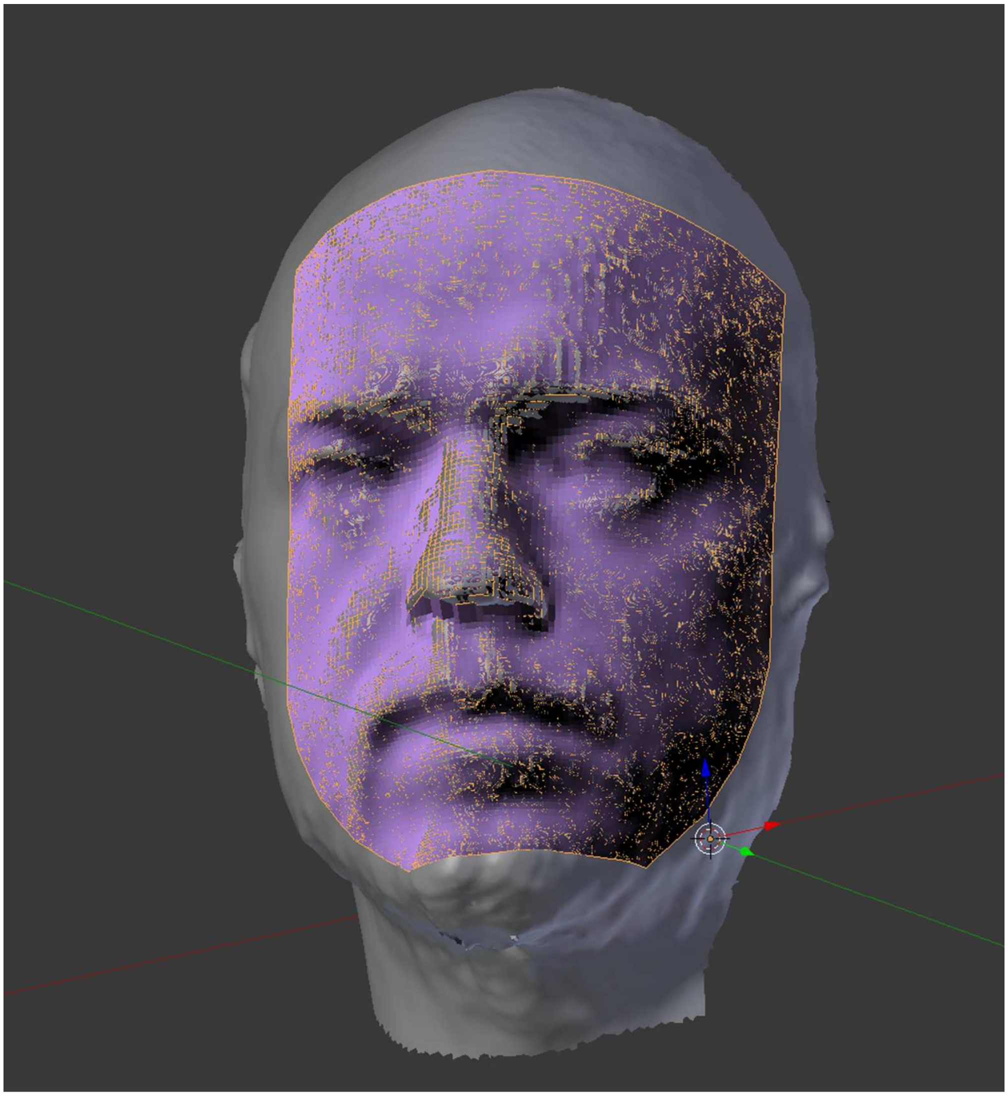

Figure 7: The purple model with clean well organised geometry created by 'snapping' to the surface of the original model.

351x381mm (72 x 72 DPI)

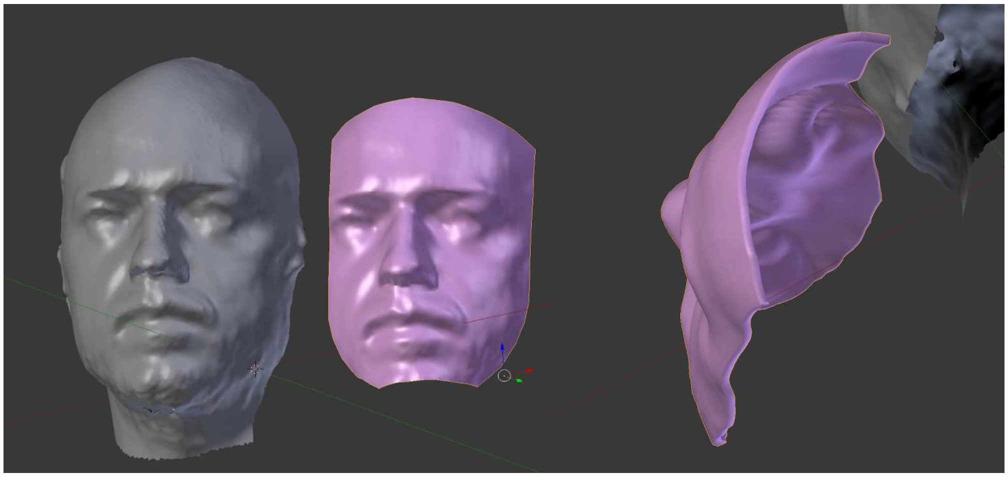

Figure 8: A solidify modifier applied to the purple model in order to define a thickness of 10mm.

845x396mm (72 x 72 DPI)

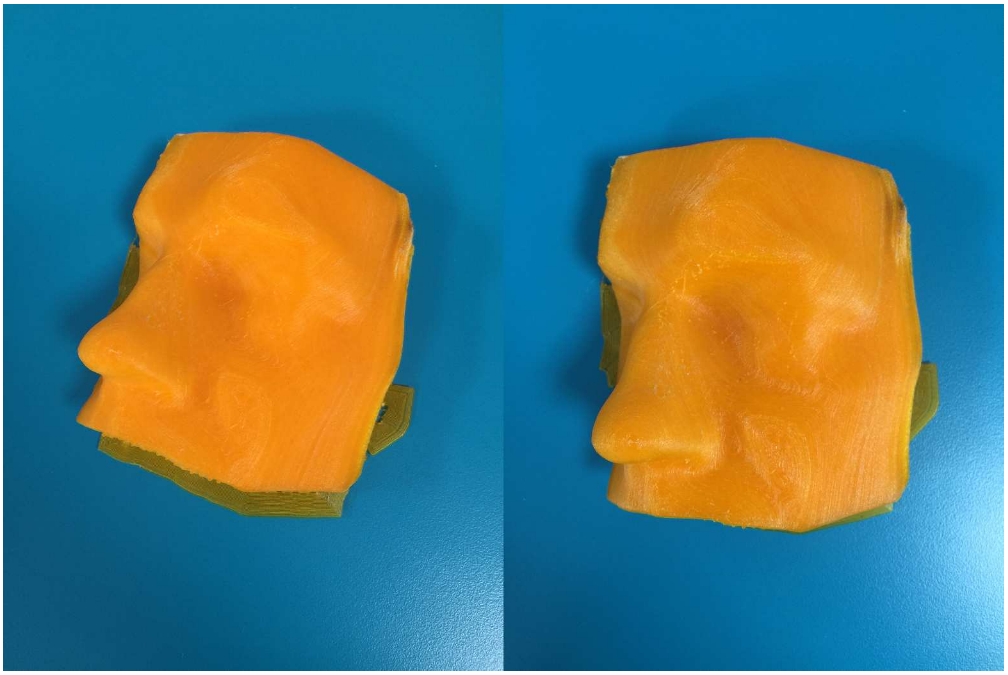

Figure 9: Prototype model 1, 3D print

1727x1151mm (72 x 72 DPI)

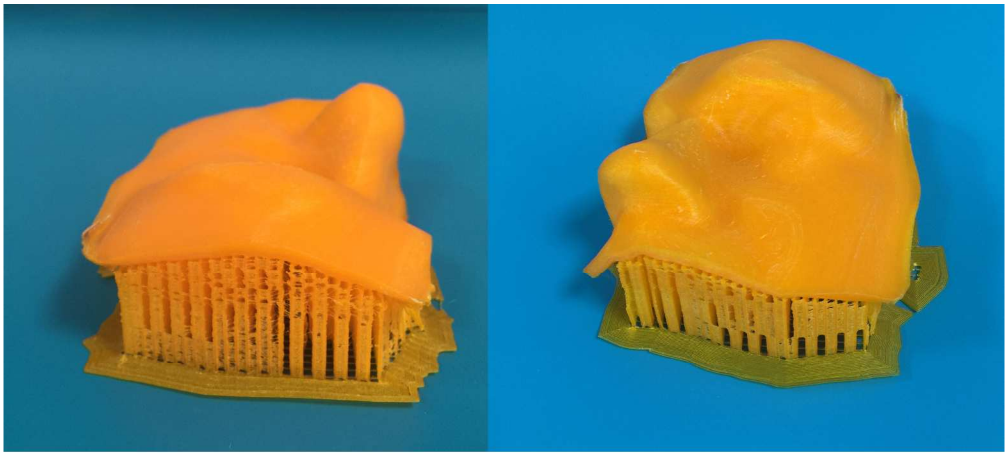

Figure 10: The underlying supporting material

1561x700mm (72 x 72 DPI)

Figure 11: The lead mask along side the first 3D print

300x179mm (300 x 300 DPI)

Figure 12: The lead mask fitted onto the 3D print

260x177mm (300 x 300 DPI)

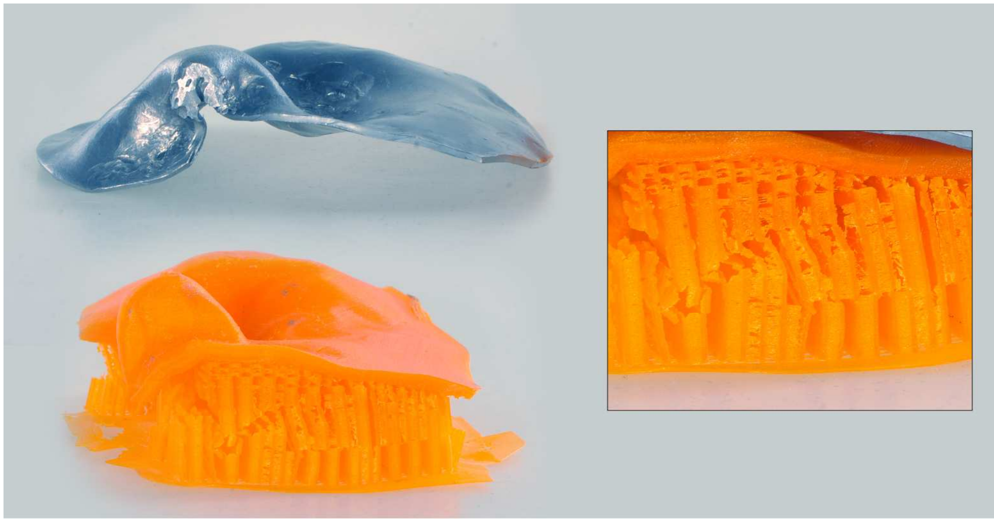

Figure 13: Fractured support structures

279x143mm (300 x 300 DPI)

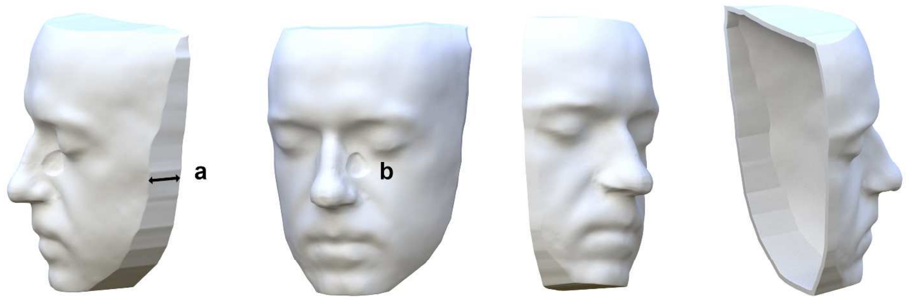

Figure 14: Prototype model 2 - The outer rim of the model was extruded to create a flat surface and for added structural strength (a). An indented area (b) was added to indicate where the exposed treatment area will be on the lead mask.

1182x461mm (72 x 72 DPI)

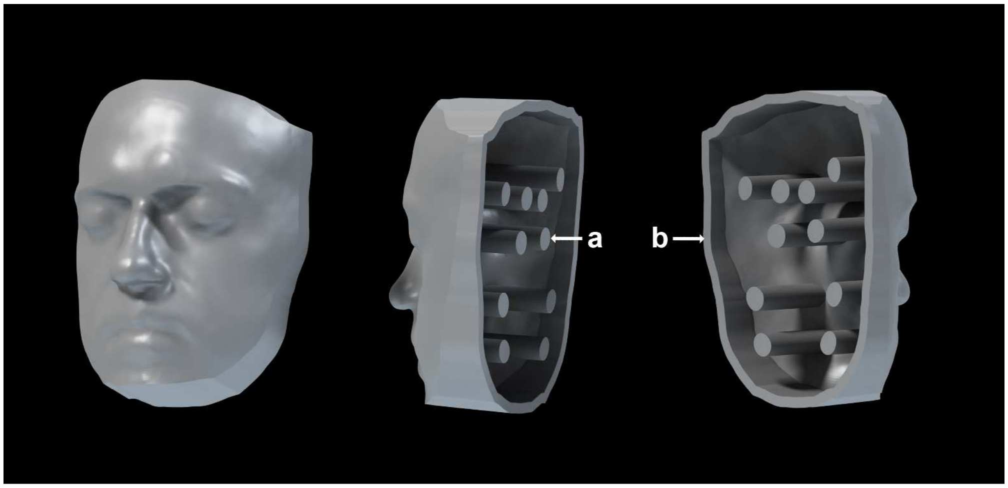

Figure 15: Prototype model 3 - The wall thickness was doubled to 1cm(a) and thick cylindrical columns were added for additional strength (b)

988x475mm (72 x 72 DPI)

Figure 16: Prototype model 3 - 3D print used to create a successful radiotherapy treament mask.

619x234mm (300 x 300 DPI)