Research Article

iMedPub Journals
www.imedpub.com

Journal of Medical Physics and Applied Sciences
ISSN 2574-285X

2024
Vol.9 No.3:73

Utilization of 3D Printing Technology to Improve Lead Shield Fabrication for Electron Therapy of the Face

Abstract

Purpose: Superficial lesions of the face are often treated with an electron beam and surface collimation utilizing a conformal lead shield with an opening around the Region Of Treatment (ROT). To fabricate the lead shield, an imprint of the patient face is needed. Historically, this was achieved by a laborious and time-consuming process which involved a Gypsum Imprinted Model (GIM) of the patient topography. We propose utilization of 3-Dimensional (3D) printing technology to create a 3-Dimensional Printed Custom Model (3D-PCM) of the patient facial topography as a more accurate and more efficient alternative to GIM.

Methods: GIM and 3D-PCM were generated for three patients requiring en face electron therapy of the nose. The models for both methods were then CT-scanned and fused rigidly to the CT of the patient. The accuracy of the models was compared to the patient CT by calculating Sørensen-Dice Similarity Coefficient (DSC). The two models were also visually inspected. Additionally, the efficiency of the two methods was evaluated by the average time needed to complete each process based on user-reported experience.

Results: The average DSC between the patient and GIM is 0.95336 (Standard Deviation (SD)=0.0099479), while the average DSC of the patient and 3D-PCM is 0.97886 (SD=0.0037441). With respect to efficiency, the average time to fabricate and dry GIM is 54.5 h with hands-on time of 2.5 h, while generation of 3D-PCM takes about 6.5 h, with hands on time of approximately 2.5 h.

Conclusion: 3D-PCMs based on CT are found to be an excellent substitute to GIMs by exhibiting higher degree of fidelity with patient's anatomy, requiring significantly less time to complete, are less labor intensive and allow for greater patient comfort. The disadvantage of exposing the patient to radiation associated with the CT acquisition for designing a 3D-PCM could be eliminated by employing 3D-camera scanning technology.

Keywords: 3D printing technology; En face electron therapy; Surface collimation; Lead shield; Skin cancer; Facial imprint; Gypsum; Plaster

Introduction

Skin cancers, mainly non-melanoma cancers including basal and squamous cell carcinomas, are the most common cancers in the Unites States, accounting for about 5.4 million diagnoses each year [1]. While surgery is the primary line of treatment, radiation is often used as an adjuvant therapy, or as the primary option for patients with large tumors or instances where surgery would otherwise not be viable.

With the evolution of superficial and orthovoltage therapy machines commonly replaced by megavoltage treatment linear accelerators in most radiation oncology departments, radiation therapy of the skin is now commonly achieved *via* electron beams. An en-face electron field allows for treatment of uniform dose at the desired depth, with sharp dose fall-off, offering dose sparing to underlying normal tissue anatomy as compared to photon radiation [2]. Collimation of an electron beam can be achieved by attaching cerrobend-filled custom insert to the primary cone collimator, or *via* surface collimation by placing lead on the patient's skin with an opening around the Region of Treatment (ROT). In comparison to custom cerrobend inserts attached at the end of the cone, surface collimation offers sharper penumbra and superior dose distribution for small electron fields. Furthermore, with the advent of multileaf collimators, some centers have retired their mouldrooms and cerrobend block manufacturing practices. Therefore, surface lead shield collimation may be especially advantageous for electron therapies of the face.

To collimate an electron beam at the level of the lesion, custom-fabricated lead sheets with an opening for ROT are used. To fabricate the lead mask, first an imprint of the patient facial topography is needed. Traditionally, a Gypsum Imprinted Model

(GIM) of the patient topography was developed. Generation of GIM is a multi-step process that is laborious, messy, time consuming, uncomfortable for the patient and often the transfer of the ROT markings onto the GIM can be inaccurate, requiring adjustments of the lead shield at the time of treatment. The advent of 3-Dimensional (3D) printing technology and its adaptation in healthcare offered a potentially streamlined alternative to the GIM. In this study, we explored utilization of 3D printing technology to generate a 3D Printed Custom Models (3D-PCM) based on Computed Tomography (CT) image as a better alternative to GIM.

Materials and Methods

GIM and 3D-PCM were generated for three patients requiring en face electron therapy of the nose. Both models for each patient were then CT-scanned and fused rigidly with the original CT of the patient. The accuracy of the models was compared to the patient CT through Sørensen-Dice similarity Coefficients (DSC). The efficiency of the two methods was evaluated by the average time needed to complete each process based on user experience [3].

Lead shield fabrication using gim

The generation of GIM process, as depicted in **Figures 1** and **2**, involves the following steps:

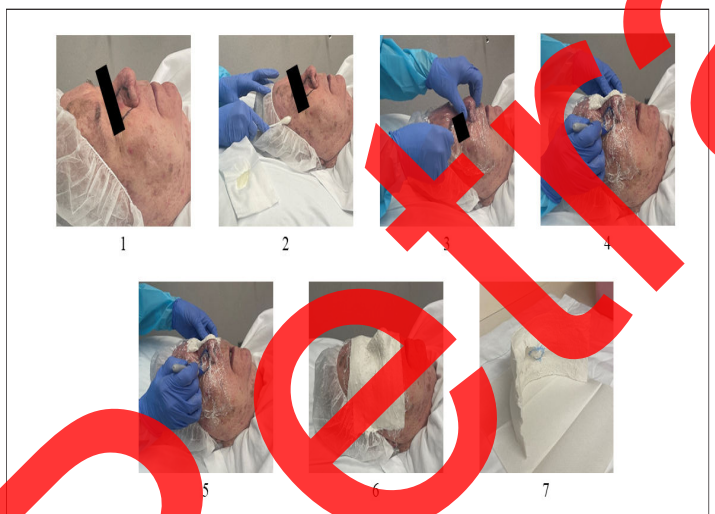

Figure 1: Steps for generation of GIM. **Note:** 1) Outlining the ROT on the skin; 2) Sinciput and buccal regions are coated with a thin layer of petroleum jelly-based product; 3) The face, including the superior labium, nose, buccal region and sinciput are covered with plastic wrap; 4) ROT markings are applied onto the plastic wrap; 5) Water-activated cut strips of plaster of Paris are applied over the plastic wrap; 6) Plaster remains on the patient's face until solid; 7) Plaster is removed from the patient and left to completely dry.

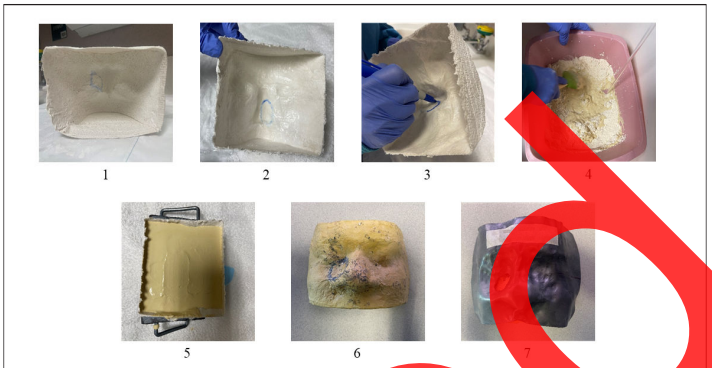

Figure 2: Steps for generation of GIM. **Note:** 1) The hard, negative plaster imprint of the face is enclosed by adding plaster of paris superiorly and inferiorly; 2) Insides of the negative plaster model are coated well with petroleum jelly; 3) Imprinted ROT markings are reinforced; 4) Plaster of Paris mixture is prepared by mixing water to a dry plaster of paris powder; 5) The plaster of Paris mixture is poured into the negative plaster imprint to rest until fully solid; 6) The the two plasters are separated; 7) Lead sheet is hammered out with an opening around the ROT onto the GIM. Materials used for GIM generation are specialist plaster bandage-extra fast setting by BSN medical Inc and buff stone type 3 gypsum by whip mix were used.

Lead shield fabrication using 3D-PCM

The generation of 3D-PCM process involves the following steps: (1) Outlining of the ROT with a radiopaque wire on the skin, (2) Patient's head is CT-scanned and imported into to the Treatment Planning System (TPS), (3) External body contour is generated, air cavities in nose and mouth are filled in and the radiopaque wire is accentuated, (4) Contour of the anterior part of the patient's face is generated and Digital Imaging and Communications in Medicine (DICOM) file is exported to a directory on the local drive, (5) The structure is converted to Stereolithography (STL) file using adopted open source script and the STL file is processed within the 3D-printer software and G-code file for 3D printer is generated, (6) 3D print is executed using G-code file to generate 3D-PCM, (7) lead sheet with an opening around the ROT is hammered out onto the 3D-PCM [4].

Patients were CT-scanned on a somatom sensation open CT scanner (Siemens Medical Solutions USA, Inc.) using 1 mm thick slices. Contouring was performed in Raystation v10A TPS (Ray Search Laboratories) and the DICOM in radiotherapy (DICOM-RT) contour sequence was converted to STL file using an adopted python script written by Nowak et al. [4]. The STL file was processed into G-code file in UltiMaker Cura 5.4.0 Software and it was printed on CreatBot F430 3D Printer (Henan CreatBot Technology Limited) using high speed 1.75 mm Polylactic Acid (PLA) filament (Elegoo). Printing speed of 40 mm/s and infill density of 15% was used.

Accuracy and efficiency evaluation

To assess the spatial accuracy of GIM and 3D-PCM, each model was visually inspected, CT-scanned and rigidly fused to the patient CT. DSC values were obtained using facial topo-graphy contours generated in RayStation TPS [5]. The DSC is calculated by dividing twice of the intersection volume between the model and patient CT contour with the sum of the two volumes, expressed in the following manner:

$$DSC = \frac{2[(Model\ CT\ Volume) \cap (Patient\ Volume)]}{(Model\ CT\ Volume) + (Patient\ Volume)}$$

The efficiency of the two methods was evaluated by the average time required to complete each process and hands-on time required as reported based on user experience.

Results

The 3D-PCM as stept 5 shown in **Figure 3**, visually has a higher degree of anatomical facial details in comparison to GIM step 1 **(Figure 3)**. Greater similarity of the 3D-PCM with the actual anatomical contour of the face in comparison to GIM is also visually observable upon inspection of the CT registrations between each of the models with the patient's CT.

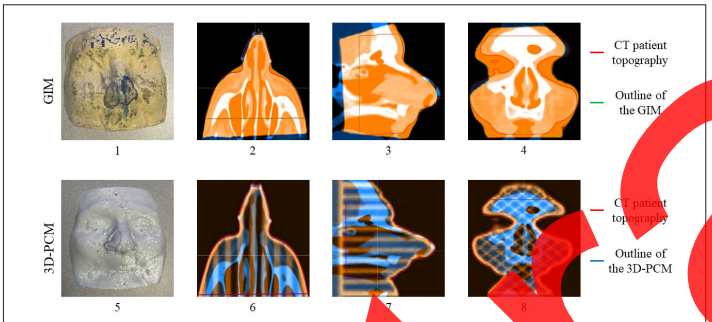

Figure 3: Rigid CT fusions and outline of the contours used for DSC calculations. **Note:** 1) GIM with imprinted and reinforced ROT contours; 2) Transverse view of fused patient CT and GIM; 3) Sagittal view of fused patient CT and GIM; 4) Coronal view of fused patient CT and GIM; 5) 3D-PCM; 6) Transverse view of fused patient CT and 3D-PCM; 7) Sagittal view of fused patient CT and 3D-PCM; 8) Coronal view of fused patient CT and 3D-PMC.

To quantify the degree of similarity of each model against the patient CT, DSC were obtained. DSC coefficients of spatial overlap based on rigid fusions between the two models (GIM and 3D-PCM) and patient CT for three patients were calculated. The average DSC between patient-CT and GIM-CT is 0.95336 (SD=0.0099479), while the average DSC of patient-CT and 3D-PCM is 0.97886 (SD=0.0037441), as shown in **Table 1**.

Table 1: Average Sørensen-Dice similarity coefficient of spatial overlap based on rigid fusions between the two models (GIM and 3D-PCM) and patient CT for three patients.

	Average SÃ¸rensen-Dice similarity coefficient	Standard deviation
GIM and patient CT	0.953	0.01
3D-PCM and patient CT	0.979	0.004

The efficiency of each process was assessed through users' experience. The time from start to finish to create the GIM plaster is 54.5 h, with approximately 2.5 h of active hands-on duty time and about 52 h of drying time. The intermittent drying time requires multiple instances of work including: 0.5 h to line the negative plaster imprint with petroleum jelly, prepare and the plaster of paris mix into the negative plaster imprint, about 48 h are needed for the plaster of paris mix to fully dry and harden and finally, it takes about 1 h to fabricate a lead.

Generation of 3D-PCM is a considerably quicker process which could be completed in approximately 6.5 h, however the hands-on time is similar to the GIM process at 2.5 h. The CT scan acquisition, inclusive of positioning of the patient takes about 0.5 h. Approximately 0.5 h are needed to contour and generate the STL file and an additional 0.5 h are needed to generate the G-code file and prepare the 3D-printer. The actual printing time takes approximately 4 h to complete. Lead fabrication time is similar to GIM, *i.e.* 1 h.

Discussion

Since the advent of 3D-printing in the 1980's, the 3D printing technology has been increasingly incorporated into many medical practices, from orthopedic applications to complicated 3D functional tissue constructs [6]. To better support the rapid expansion of 3D printing in medicine, The Radiological Society of North America (RSNA) in 2016 published guidelines for medical 3D printing and appropriateness for clinical scenarios [7]. The main aspects of 3D printing in radiation oncology involve bolus fabrication, brachytherapy applicators and other patient-specific models. In this work, we explored the utilization of 3D printing technology to generate facial imprint models using CT as a surrogate to fabricate surface lead shield collimator for electron beam radiation therapy.

In the past, plaster of paris was used to generate GIM to fabricate facial lead shield collimators for electron therapy of the face. This is a very laborious and time-consuming process that requires great attention and skills to achieve good results. The generation of the negative plaster imprint of the face using strips of plaster bandages often can be uncomfortable as the nasal passages are covered and the patient is asked to breathe through the mouth. Furthermore, having the lesion covered with plastic wrap and plaster can also be painful for the patient. Lastly, the transfer of the ROT markings from the skin to the plastic wrap, to the negative plaster imprint and ultimate to the GIM introduces opportunities for inaccuracies, often requiring adjustments of the lead shield at the time of treatment. The variability of the finished result may require longer setup time on the first day of treatment, which in turn may impact the throughput of the clinic. Implementation of 3D-printing to generate 3D-PCM for lead mask fabrication eliminates most of these challenges.

Generation of 3D-PCM for lead shield fabrication is a simple, straightforward, quicker process that is more accurate and allows for improved patient comfort as they are not subject to the uncomfortable procedure required to develop the negative

plaster. While the hands-on time to generate 3D-PCM is comparable to GIM, the overall time needed to complete 3D-PCM is shorter than GIM. Additionally, the contouring component of the 3D-PCM process can be completed “remotely” from any location and does not require physical presence, in contrast to all aspects of the GIM hands-on workflow. In our single institution experience, the responsibilities for individuals executing the "hands on" portion of the process shifted from radiation therapists to dosimetry and physics staff due to the nature of the work and migration from plaster to utilization of technology. This split of labor may vary depending on personnel and experience. In additional, it should be noted that we have spent significant amount of time troubleshooting, repairing and optimizing the 3D printer, choosing suitable filament material, as well as apt printing speed and infill density for appropriate 3D-PCM sturdiness. These may create additional burden to the duties of the medical physicists, so staffing assessment is recommended prior to starting 3D printing program.

Although the 3D-PCM process is advantageous in terms of construction time efficiency and patient comfort, the need for a CT scan and radiation dose associated with it can be viewed as a disadvantage compared to the GIM process which does not involve any ionizing radiation. Topographical mapping of the patient face may be obtained using a 3D-optical camera which eliminates the need for a CT and radiation exposure. This technology has become affordable in recent years and is able to provide acceptable degree of accuracy to generate 3D-PCM [8].

The topographical contour of the patient may be obtained by a 3D optical camera with a patient sitting which may be advantageous for patients unable to lay in supine position for a long period of time [8]. 3D-optical imaging is a potential substitute to CT to generate 3D-PCMs.

Conclusion

In this study, we have shown that utilizing 3D-printing technology to generate a 3D-PCMs based on CT images is a better alternative to GIM in terms of accuracy, efficiency and patient comfort. The 3D-PCMs exhibit higher degree of facial topographical details depicted both visually and through higher DSC value in comparison to GIMs. We recognize that larger patient sample size is needed to establish clinical significance of the DSC scores. We found that the overall process to generate 3D-PCM is more efficient requiring less time to complete in comparison to the GIM method. While the hands-on time to generate 3D-PCM is comparable to GIM, the overall time needed to complete 3D-PCM is shorter than GIM. Furthermore, the 3D-PCM workflow is more patient-centric where the patient is not subjected to what could be uncomfortable or painful procedure required to develop the negative plaster for the GIM where the lesion and the nasal passages of the patient are covered. Even more, the transfer of the ROT markings from the skin to the plastic wrap, to the negative plaster imprint and ultimate to the GIM introduces opportunities for inaccuracies, often requiring adjustments of the lead shield at the time of treatment which could lead to machine schedule delays. One drawback of our current 3D-PCM workflow is the need of a CT, where the GIM workflow does not require ionizing radiation. The need for a CT and expositing the patient to ionizing radiation can be eliminated with implementation of a 3D-optical scanner to obtain facial topography in the future.

References

1. Facts and Figures (2024). American Cancer Society, Atlanta, Georgia.
2. Hogstrom KR, Almond PR (2006) Review of electron beam therapy physics. Phys Med Biol 51: 455-489.
3. Mouldroom techniques for teletherapy. International Atomic Energy Agency (IAEA) (2024), Vienna, Austria.
4. Nowak LJ, Pawlowska E (2019) Technical note: An algorithm and software for conversion of radiotherapy contour-sequence data to ready-to-print 3D structures. Med Phys 46: 1829-1832.
5. Sørensen T (1948) A method of establishing groups of equal amplitude in plant sociology based on similarity of species and its application to analyses of the vegetation on Danish commons. Biol Skr K Danske Vidensk Selsk 5: 1-34.
6. Chia HN, Wu BM (2015) Recent advances in 3D printing of biomaterials. J Biol Eng 9: 1-4.
7. Chepelev L, Wake N, Ryan J, Althobaity W, Gupta A, et al. (2018) Radiological Society of North America (RSNA) 3D printing Special Interest Group (SIG): Guidelines for medical 3D printing and appropriateness for clinical scenarios. 3D Print Med 4: 11.
8. Sharma A, Sasaki D, Rickey DW, Leylek A, Harris C, et al. (2018) Low-cost optical scanner and 3-dimensional printing technology to create lead shielding for radiation therapy of facial skin cancer: First clinical case series. Adv Radiat Oncol 3: 288-296.