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Original scientific paper

DESIGN AND MANUFACTURING OF 3D PRINTED PARTS FOR RADIOTHERAPY APPLICATION

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A b s t r a c t: The purpose of this study was to apply an additive manufacturing method to create the bolus, which was estimated to increase the homogeneity and absorbed dose of the planning target volume when they are located on superficial region and be treated with high-energy photons beams. For this reason a patient with diagnosis: "*Ca. Cutis exulcerans region frontalis lat. sin.*" was simulated on computer tomography (CT), then a personal bolus was designed and printed with thermoplastic material, polylactic acid (PLA). For quality comparison purposes an identical treatment plan was prepared with and without printed bolus. The dosimetric evaluation shows that 4% of the delivered dose will be higher when printed bolus was applied. This additional dose made a big difference in favor of quality treatment of the patient and operational costs for bolus printing and application are negligible related to treatment benefits.

Key words: 3D printing; radiotherapy; bolus; thermoplastic; PLA

ДИЗАЈН И ИЗРАБОТКА НА 3D ПЕЧАТЕНИ ДЕЛОВИ ЗА ПРИМЕНА ВО РАДИОТЕРАПИЈА

А п с т р а к т: Целта на оваа студија беше со примена на адитивен метод на изработка да се создаде болус за кој се претпоставува дека ќе ги зголеми хомогеноста и апсорбираната доза на планираниот целен волумен кога тие се наоѓаат на површинскиот регион и се третираат со високоенергетски фотонски зраци. Поради оваа причина пациент со дијагноза: „*Ca. Cutis exulcerans region frontalis lat. sin.*" беше симулиран на компјутерска томографија, потоа беше дизајниран личен болус и испечатен со термопластичен материјал, полилактична киселина (polylactic acid – PLA). Заради споредба на квалитетот, беше подготвен идентичен план за третман со и без печатен болус. Дозиметриската евалуација покажа дека испорачаната доза е за 4% поголема кога ќе се примени печатениот болус. Оваа дополнителна доза направи голема разлика во корист на квалитетот на третманот на пациентот, а оперативните трошоци за печатењето и апликацијата на болусот се занемарливи во однос на придобивките од третманот.

Клучни зборови: 3D-печатење; радиотерапија; болус; термопластика; PLA

1. INTRODUCTION

At the radiotherapy departments, to increase skin dose for treating superficial tumors the bolus has to be applied to the skin. The task of the radiotherapist is to prepare a bolus for a specific treatment and region of the patient. The bolus will apply directly in contact with the patient skin. It will have an important effect on shifting the maximum radiation dose (D_{max}) closer to patent skin. The maximum percentage of depth dose for high-energy external photons can be reached on a certain depth of patient tissue, this is known as maximum depth dose (d_{max}) and it happens due to the build-up effect [1]. In a study realized by Shiau et al [2], they recommended using a bolus if the tumor does invade the superficial region. The same justification was argued, also by other authors [3, 4, 5].

The bolus should perfectly match with the external contour patient; no air should be allowed between the bolus and the patient skin, otherwise, the absorbed dose and its homogeneity in the interested region of the patient will not increase. Therefore, the staff is committed to achieving desirable shapes of the bolus. Thermoplastic bolus used as a sheet or pellets and place on water bath at minimum temperature 60 °C. The thickness of the bolus can be adjusted depending on the patient's skin, the tumor position, and photon energy.

The manufacturing process of three-dimensional (3D) printing is based on the additive manufacturing (AM) process, where layers are placed one after the other and, finally, a physical very complex product is produced. This technology has widespread application in most of the fields, because of its low-cost, diverse production, reduced processing time, and ease of use. Nowadays, there are available many different materials to be used for 3D printing; the most common materials are metals, ceramics, plastics, carbon fiber, etc. [6].

The aim of this study is to create a 3D specific bolus of the patient diagnosed with "Ca. Cutis exulcerans region frontalis lat. sin", from the standard protocol for the management and transmission of medical images, known as DICOM (Digital Imaging and Communications in Medicine). A computerized tomography scan (CT) of the patient will be processed on open source software, named '3D Slicer', to create a segmentation of bolus on 'Standard Triangle Language', known as STL file. In addition, polymer gel bolus, which ordinarily and clinically is used for daily patient treatment is analyzed for the same patient for comparisons reasons. Verification of the dose at a specific depth was done with the Monte Carlo calculation algorithm.

2. MATERIAL AND METHODS

For this research, a real DICOM patent file was taken from the Clinic of Oncology database at the University Clinical Centre of Kosovo, in Prishtina. The patient was 81 years old with a clinical diagnose "Ca. Cutis exulcerans region frontalis lat. sin" and he was treated months before with standard procedure. Therefore, for our research, we did not have any impact on patient health.

A DICOM file of the simulated patient by CT simulator was opened on 3D Slicer software [7]. 3D Slicer is a well-known open-source software package used widely for medicine and related imaging research [7, 8]. The segmentation editor module of 3D Slicer software gives the possibility to delineate a structure of interest; it can be a specific organ or additional part of the patient, as a bolus.

The thickness slides of CT simulations is an important parameter on the reconstruction of 3D image and it should be set as lower as it can be, in our case it was set 5 mm. With the reduction of the thickness of the slide, the smoother 3D surfaces of the patient will be reconstructed from 2D scanned images. It has greater importance, as parallel as the patient's surface is to the slice orientation. This effect is visualized in the upper part of the patient's head.

The region of interest of our case study is around the left eyebrow of the patient. Therefore, the effect of the slide thickness does not have a great impact. The Figure 1 is a picture of the patient before treatment has started and in Figure 2 is segmentation of patient skin on 3D Slicer.

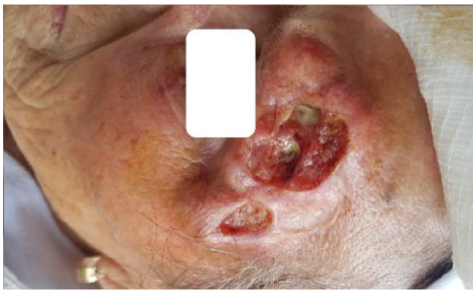


Fig. 1. Picture of the real patient

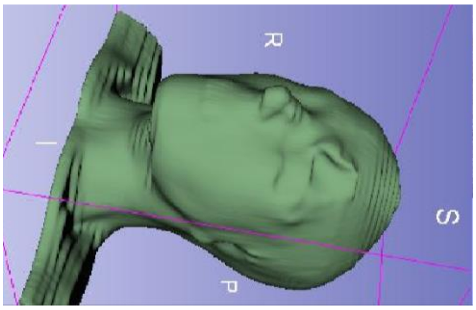


Fig. 2. 3D patient skin segmentation

2.1. *Segmentation process of patient's head and bolus*

The segmentation process has two steps: contouring of the patient skin and the bolus. With the Level Tracer button, from the Segment Editor Module of 3D Slicer was added the uniform intensity region of each 2D slice. The background voxel was used to find the closed path that follows the same intensity value back to the starting point within the current slice. Then the Gaussian smoothing tool was applied with a deviation standard of 3 mm to all segments for removing extrusions and filling small holes. After that, the file was exported as a '3D_head.stl' file.

The designed bolus consists of two main surfaces, the inner side surface of the bolus surface, which should perfectly match the patient skin, and the outer side surface of the bolus, which should give a better possibility for homogenous dose distribution on the patient tissue. By Margin Tool was designed the bolus with 1 cm growth, based on the '3D_head' file. After that, Scissor Tools was used to cut unnecessary parts. The designed bolus is presented in Figure 3.

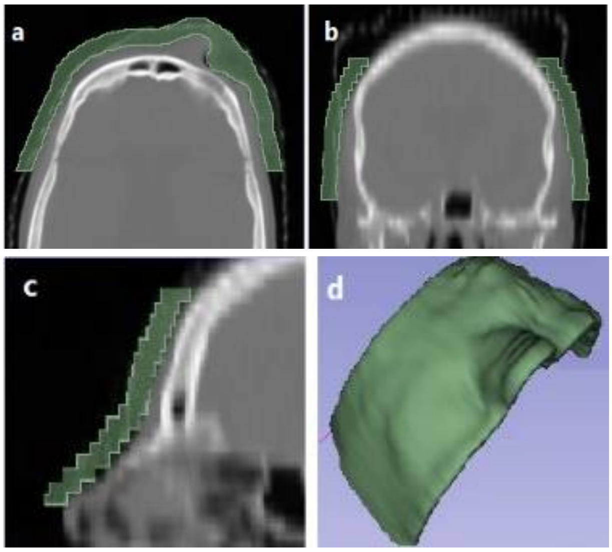


Fig. 3. Segmentation of bolus by 3D slicer with planes: a) Transverse, b) Frontal, c) Sagittal, and d) 3D view of bolus

2.2. *The printing parameters*

Both designed STL files were imported at PrusaSlicer software, ver.2.4.0 [9]. The layer high was set at 0.1 mm, with 90% in filling for bolus. When all parameters were set correctly, a G-code file was generated and transferred to the 3D printer for printing.

The calibrated 3D printer, named Prusa Research, model i3MKS+, with extruder nozzle diameter 0.4 mm, was used for printing. The filament was polylactic acid (PLA) with 210 °C and 60 °C, for nozzle and bed temperature, respectively.

2.3. *Dosimetric experiment for bolus evaluation*

To evaluate the effect on the quality treatment of patients with the printed bolus, a CT-simulation of bolus filled with water inside was performed, because the water has a similar density to human tissue. The treatment plan was prepared for this case as it was prepared for the standard procedure of treating. On the Treatment Planning System (TPS), Monaco was applied a Monte Carlo calculation algorithm to find the absorbed dose and homogeneity of target volume for identical beam parameters as they were used on the standard treating process of the patient.

The treatment planning of the patient with bolus was prepared identically as treatment planning without bolus application. So, all irradiation parameters (beam energy, monitoring units, angle of the gentry, MLC positions, collimator angle, couch coordinates, etc.), were as on real case were used as standard procedure. In Figure 4 is presented the CT simulation process of printed bolus sandwiched with two transparent PMMA parallel plates and filled with water.

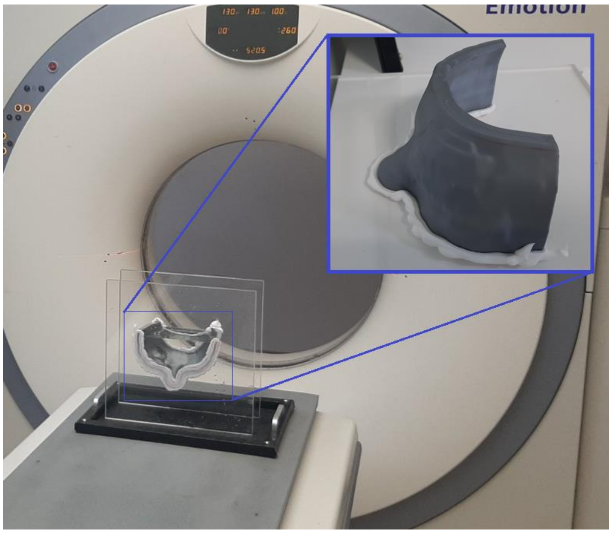
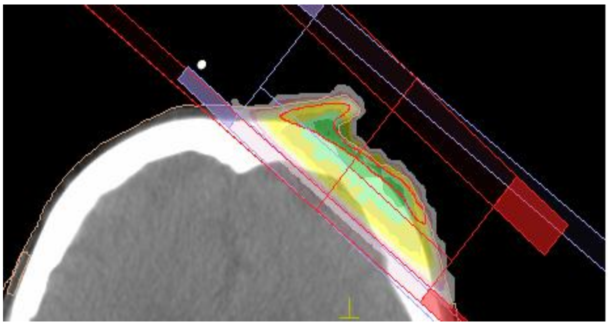


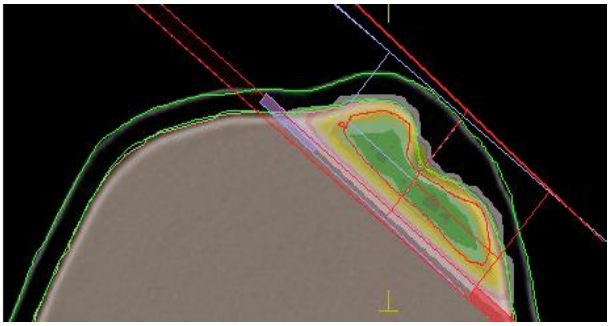
Fig. 4. CT simulation set up of printed bolus 'filed' with water

3. RESULTS AND DISCUSSIONS

A treatment plan was prepared for patients diagnosed with "*Ca. Cutis exulcerans region frontalis lat. sin.*" with a three-dimensional conformal radiotherapy technique (3DCRT). Radiation Physician contoured the Organ at Risks (OR) and Planning Target Volume (PTV), which was located close to the patient skin and has to receive 40 Gy in total by 20 fractions, with 2 Gy each. So, Medical Physicist decide to use the 6MV photon beams energy produced by the Medical Linear Accelerator (LINAC) to prepare the treatment plan of the patient. The same parameters were applied on CT simulation with a 3D printed bolus. The homogeneity of the treatment plan is presented in Figure 5 for both cases.



a)



b)

Fig. 5. Treatment field orientation and dose distribution: a) standard procedure, b) with 3D printed bolus

The dosimetric evaluation is done by Report 50 of International Commission on Radiation Units and Measurements (ICRU), for modality technique three-dimensional conformal radiotherapy (3DCRT) which describe that the target volume dose variation should be within +7% and –5% of the value prescribed at the reference point in the tumor volume with the determined absorbed dose value [10].

Table 1

Dosimetric comparisons between treatment plan when printed bolus is and is not applied

The treatment dose [Gy]	Maximum		Mean	
	PTV	< 107% of target	PTV	> 95% of target
1. Standard PTV	42.78	42.8	38.23	38
2. PTV with 3D bolus	42.75	42.8	39.64	38

Therefore, the target dose for both cases is 40 Gy. So, the maximum limit of the delivered dose is 107%, for a target dose of 40 Gy it is 42.8 Gy. At the same time, the mean delivered dose to PTV should be more than 95% of the target dose, which response to 38 Gy for our case.

The maximum planed after calculations of the dose to the patient has shown similarities for both methods. The mean dose of planned treatment dose with 3D printed bolus shows 4% more dose than the traditional treatment process. So, the application of bolus has a positive impact on shifting the dose closer to the patient skin and this will bring better homogeneity of dose distribution to the PTV. The bolus can reduce the hotspot at the same time.

4. CONCLUSION

An extra-personalized device, called a bolus, for external radiotherapy treatment of the patient was designed by 3D Slicer software and produced by additive manufacturing technology. The bolus was printed from PLA thermoplastic material with 90% infilling.

Two treatment plans with identical irradiations parameters were prepared; the first one was prepared with standard procedure and criteria, this was selected for patient treatment. The second treatment plan was prepared with a 3D-printed bolus. The Monte Carlo calculation was used to find the homogeneity and total dose. The homogeneity and absorbed dose values were increased when bolus was applied to the patient simulations. So, the bolus application has an effect to shift the maximum depth dose closer to the skin of the patient. For the case study subject of this study, the patient will get at least 4% more dose if bolus was applied. This dose is very valuable for increasing the quality of the patient treated versus the time and operational cost when the bolus is applied.

Therefore, we are proposing to use additive manufacturing as part of the routine treatment process for a superficial lesion on external radiotherapy treatments.

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