3D Printed Bolus for H&N Treatments

[1]Boutros M, [1]Woodward J, [2]Marsh D, [2]Quingua K, [3]Thompson A, [1]Hong L, [1]Matosinhos A
[1]Department of Radiotherapy Physics, University College London Hospitals NHS Foundation Trust
[2]Department of Radiotherapy, University College London Hospitals NHS Foundation Trust.
[3]Clinical Oncology, University College London Hospitals NHS Foundation Trust.

Background.
Implementing a streamlined process to produce 3D printed bolus to enhance accuracy in head and neck (H&N) treatments. The study aims to investigate whether 3D printed bolus, utilizing Adaptiiv software and RAISE3D Pro printer, offers superior conformity to patient contours and aligns more closely with dosimetric requirements compared to the conventional method involving shaping jelly bolus using a MLC projection on a thermoplastic mask. The previous approach at UCLH led to irregularities, particularly in curved surfaces, impacting bolus position and shape. This evaluation will assess the comparability of 3D printed bolus with TPS planned bolus, ensuring robust conformity and accurate dose distribution. Additionally, insights into lessons learned and established risk mitigation measures in the process will be presented.

Methods.
A patient pilot study was conducted to plan and produce 3D printed bolus for 10 H&N patients. The accuracy of produced bolus against planned bolus was verified using visual assessment of CBCT images. An additional CT scan of the shell and bolus (without patient) was acquired to confirm consistency of print density using Hounsfield unit comparison at the end of the treatment for each printed bolus. Metrics evaluated in this study included time to print, staff time required at each stage of the process, skin toxicity, bolus thickness, bolus length and shape, bolus Hounsfield units.

Results.
Results demonstrate excellent agreement in the dimensions and thickness of 3D printed bolus compared to TPS planned bolus, leading to enhanced adherence to originally planned TPS dose distributions and a reduction in systematic errors affecting dosimetry.

	Mean diff to planned	Max diff to planned	Median diff to planned
Thickness (cm)	0.04	0.30	0.01
Length (cm)	0.18	1.00	0.20
HU	-57.2	-92	-56.6

An HU assessment revealed that the initial estimation of 150HU, based on printer commissioning measurements, was higher than in study results. Skin toxicity, evaluated weekly by clinicians up to 6 weeks post-completion, showed results consistent with prior experiences, therefore there were no additional clinical concerns. Staff time was impacted throughout the bolus creation pathway at various stages including treatment planning, bolus creation, verification and adhesion to the shell. Although the process is slightly longer in the treatment planning stage, we saw that overall time was saved in the pathway in terms of staff hours.

Discussion.
Based on HU results, the bolus will be overridden to 100HU for clinical patients instead of 150HU as done in initial trial. In case of printer failure, our backup procedure is to revert to manually produced jelly bolus. In this instance, due to different electron density of the material, we evaluated the expected differences to planned dose distribution due to this change. We recalculated max difference (Gy) to PTV coverage, brainstem PRV and cord PRV if HU of the bolus was set to 0HU. Results indicate that this will likely have minimal clinical impact and will not likely result in needing a re-plan. This will be evaluated on a case-by-case basis with clinician input.

Conclusion.
In summary, the implementation of 3D printed bolus, guided by Adaptiiv software and RAISE3D Pro printer, has shown excellent alignment with TPS planned bolus, enhancing conformity to dose distributions and reducing systematic errors. Despite impacting staff time at treatment planning stage, the bolus creation pathway demonstrated overall efficiency gains. This study highlights the potential of 3D printed bolus in improving accuracy and streamlining processes in H&N treatments.

Key references. [1] Creation of 3D Printed Bolus for Complex Cases - Department of Medical Physics Saint Luke's Radiation Oncology Network, Dublin, Ireland.
[2] The use of 3D printing within radiation therapy to improve bolus conformity. Rebecca Pugh et-al, Wellington Blood and Cancer Centre 2016 (revised 2017)

Title of Presentation
"The Introduction of 3D Printing Technologies to a Radiotherapy Physics Service at Swansea"
Rhys Jenkins – *Advanced Radiotherapy Physics Technologist & 3D Printing Lead, Swansea Bay University Health Board*

Over the past three years, Radiotherapy Physics at Swansea has successfully transitioned from using wax bolus for H&N VMAT radiotherapy to 3D-printed PLA after acquiring an affordable FDM 3D printer, the ANYCUBIC Chiron. This transition aimed to enhance the accuracy and stability of the bolus, minimising air gaps and reducing staff time. The objective was to devise a straightforward solution by utilising the bolus model derived from DICOM data in the treatment planning system (TPS) and employing open-source software to convert and process into a printable bolus that fits onto the patient's thermoplastic shell. Following commissioning, during which we collected our own data to demonstrate quality improvement, all H&N VMAT radiotherapy boluses are now 3D-printed. In 2023, 73 boluses were printed for these patients, with clinicians and radiographers providing positive feedback.

Building on this initiative, a stereolithography (SLA) printer, the Formlabs 3L, along with associated wash and cure machines, and a Peel2 optical 3D scanner were acquired to further streamline existing bolus and immobilisation procedures in the mould room. Three resins were explored for potential use in these tasks – 'Clear', 'Tough 1500', and 'Elastic 50A', each possessing unique properties. 'Clear' and 'Tough 1500' resins are suitable for replacing the traditional wet impression method of producing beam direction shells (BDS) for electron radiotherapy, with bolus integration into the shell print achieved by increasing thickness to 1cm where it is required. The anthropomorphic phantom underwent scanning, and a 2mm-thick immobilisation device was 3D-printed, as depicted in Figure 1, and subsequently compared to the existing method of producing BDS. 'Elastic 50A' is more flexible and holds promise for bolusing areas that are challenging to capture, such as breast contours and gynecological structures, particularly when combined with the Peel2 scanner to capture intricate anatomy. The aim was to reduce air gaps, as commercial gel bolus would have previously been used.

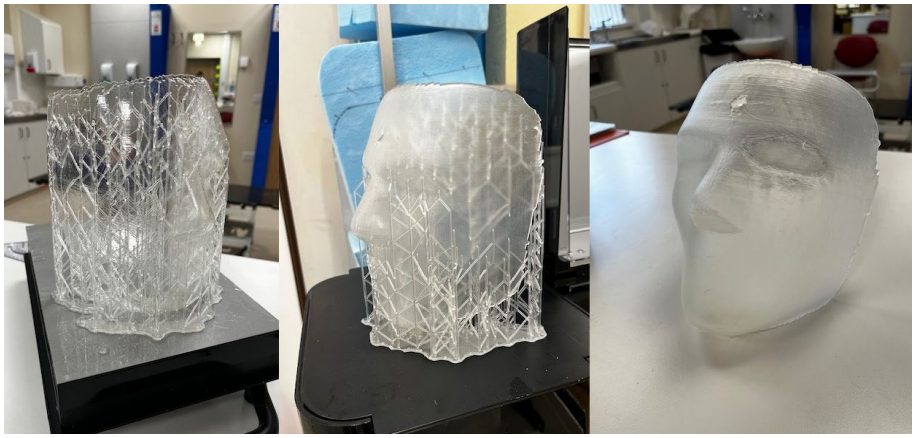


Figure 1: Shell after print (left), after washing/curing (middle) and after removal of supports (right).

Dosimetry work was conducted, which included testing the water-equivalence properties of each material using flat 1cm-thick sheets, as well as more conventional clinical shapes applied to an anthropomorphic phantom, yielding promising results. This involved gap measurements to analyse the 'fit' of the bolus to the phantom. EBT-3 film studies provided surface and depth dose measurements, while ionisation chamber measurements were also performed. The 'fit' of each print was found to be comparable or superior to wax/commercial gel bolus, and the electron density demonstrated close water-equivalence for each material, thus offering effective bolusing. Regarding immobilisation, the fit was on par with the existing wet impression method of producing electron beam direction shells. Prior to clinical implementation, ongoing efforts are focused on determining how to modify the print to ensure proper patient immobilisation, such as attaching the shell to the headrest or incorporating setting up plates for radiographers to align with the applicator.

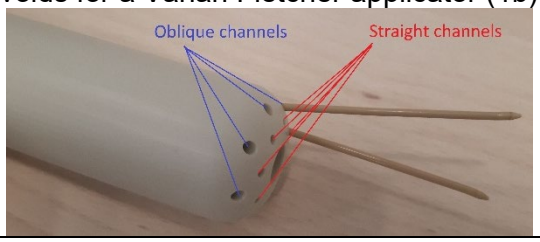
Optimisation of GYN brachytherapy by 3D printing of personalised applicators

Britt Haanen, Robert Voncken, Erik Roelofs, Celine van Beveren, Ludy Lutgens, Nienke Kuijsters, Gabriel Paiva Fonseca, Frank Verhaegen. *Department of Radiation Oncology (Maastro), GROW School for Oncology and Reproduction, Maastricht University Medical Centre+, Maastricht, The Netherlands.*

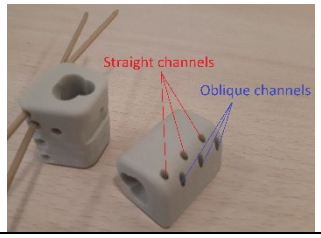
Background. Despite the long-established efficiency of combined intracavitary/interstitial technique for gynaecological brachytherapy[1,2,4,8], standard applicator needle configurations are experienced as dissatisfactory. Using 3D printing new clinical devices with optimised needle spacing can be created, either in the form of 'new standard' applicators[9], add-ons[7], or fully individualised applicators[3,5,6]. The aim is to set up a 3D printing workflow at our clinic to optimise treatment by (1) having a set of 3D printed 'standard' templates with optimised needle configurations, and (2) having a workflow for fully personalising applicators based on pre-plans.

Methods. Applicator designs are created in Fusion360. The designs for 'new standard' applicators were developed in an iterative process of proposed design, clinician feedback, design adaptation, and 3D printing. Full individualisation is based on a pre-plan treatment simulation with needles in the desired positions. A Matlab script converts the planned needle coordinates to input for Fusion360. By merging this input with the bare applicator design a personalised design is realised. Test models have been manufactured in several ways (SLS, SLA) to evaluate biocompatibility and applicability in a clinical setting.

Results. Following the iterative process, prototypes of a new type of cylinder (1a) and a new set of ovoids for a Varian Fletcher applicator (1b) have been created.

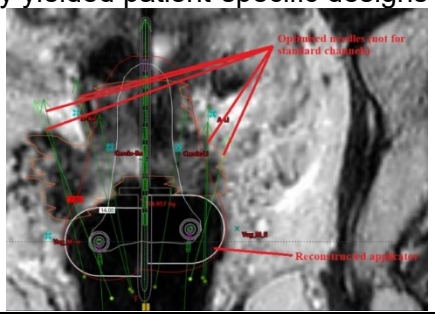


1a.) New cylinder with combined straight and oblique channels (old standard: only oblique)

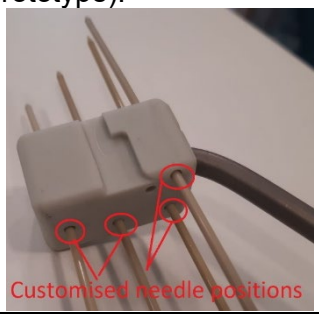


1b.) New ovoids with combined straight and oblique channels (old standard: only straight)

A proof-of-concept of the individualisation workflow included two pre-plans (2a) which successfully yielded patient-specific designs of ovoids (2b, prototype).



2a.) Pre-plan 1



2b.) Resulting patient-specific ovoid

Reconstruction of the novel applicator designs in the Eclipse (Varian) treatment planning system has been achieved using scripting in Fusion360 and in Eclipse itself. A biocompatible manufacturing method was selected for creating clinical products (keeping in mind MDR compliancy) and further clinical implementation has been initiated.

Discussion. Clinical implementation involves further sophistication of the software steps by testing and integration into our clinical systems. In addition, the individualisation workflow could be improved by automating the merger of the Fusion input from Matlab with the applicator (which is currently done manually). From a software architecture perspective, reduction of the number of components is pursued by transforming Matlab scripts into the Eclipse scripting environment. Lastly, the selected manufacturing method will be set up by acquisition of the selected equipment, followed by validation and training of staff. The in-house development process is currently undergoing a rigorous MDR compliancy procedure.

Conclusion. A full procedure from the design to manufacturing of patient-specific 3D-printed applicators has been achieved in this work. This is now in the process of being translated 'from bench to bedside' through assession of MDR compliancy and ensuing improvement of the developed methods. It is anticipated that this will soon result in the treatment of GYN brachy patients with personalised 3D printed applicators.

Key references.

In alphabetical order, numbered (acc. to CSE Citation-Name convention)

[1] Fokdal L et. al. 2013. Clinical feasibility of combined intracavitary/interstitial brachytherapy in locally advanced cervical cancer employing MRI with a tandem/ring applicator in situ and virtual preplanning of the interstitial component. Radiotherapy and Oncology. 107(1): 63-8. https://doi.org/10.1016/j.radonc.2013.01.010.

[2] Jürgenliemk-Schulz IM et. al. 2009. MRI-guided treatment-planning optimisation in intracavitary or combined intracavitary/interstitial PDR brachytherapy using tandem ovoid applicators in locally advanced cervical cancer. Radiotherapy and Oncology. 93(2): 322-30. https://doi.org/10.1016/j.radonc.2009.08.014.

[3] Kamio Y et. al. 2023. The Montreal split ring applicator: Towards highly adaptive gynecological brachytherapy using 3D-printed biocompatible patient-specific interstitial caps. Journal of Contemporary Brachytherapy. 15(6): 453-64. https://doi.org/10.5114/jcb.2023.133676.

[4] Kirisits C et. al. 2006. The Vienna applicator for combined intracavitary and interstitial brachytherapy of cervical cancer: Design, application, treatment planning, and dosimetric results. International Journal of Radiation Oncology*Biology*Physics. 65(2): 624-30. https://doi.org/10.1016/j.ijrobp.2006.01.036.

[5] Lindegaard JC et. al. 2016. Individualised 3D printed vaginal template for MRI guided brachytherapy in locally advanced cervical cancer. Radiotherapy and Oncology. 188(1): 173-75. https://doi.org/10.1016/j.radonc.2015.12.012.

[6] Logar HBZ, Hudej R, Segedin B. 2019. Development and assessment of 3D-printed individual applicators in gynecological MRI-guided brachytherapy. Journal of Contemporary Brachytherapy. 11(2): 128-36. https://doi.org/10.5114/jcb.2019.84741.

[7] Marar M et. al. 2022. Applying 3D-Printed Templates in High-Dose-Rate Brachytherapy for Cervix Cancer: Simplified Needle Insertion for Optimized Dosimetry. International Journal of Radiation Oncology*Biology*Physics. 114(1): 111-19. https://doi.org/10.1016/j.ijrobp.2022.05.027.

[8] Nomden CN et. al. 2012. Clinical Use of the Utrecht Applicator for Combined Intracavitary/ Interstitial Brachytherapy Treatment in Locally Advanced Cervical Cancer. International Journal of Radiation Oncology*Biology*Physics. 82(4): 1424-30. https://doi.org/10.1016/j.ijrobp.2011.04.044.

[9] Serban M et. al. 2021. Characterization of combined intracavitary/interstitial brachytherapy including oblique needles in locally advanced cervix cancer. Brachytherapy. 20(4): 796-806. https://doi.org/10.1016/j.brachy.2021.03.019.

Key words: *Brachytherapy, cervical cancer, gynaecological applicator, 3D printing, individualised treatment*

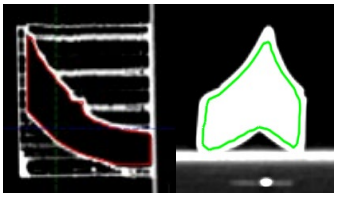
Clinical experience of the first 120 patients treated with 3D printing-enabled bolus at Northampton General Hospital

Steven Stibbs, Principal Radiotherapy Physicist, Northampton General Hospital

Background

Since 2021, challenging rectal and H&N bolus has been produced by 3D printing from TPU (n=35) or by pouring silicone into 3D printed moulds (n=85). Following substantial improvement in hardware, software and workflow, silicone bolus has become routine practise. This work evaluates the clinical effectiveness of 3D bolus and shares key learning from experience of 120 patients.

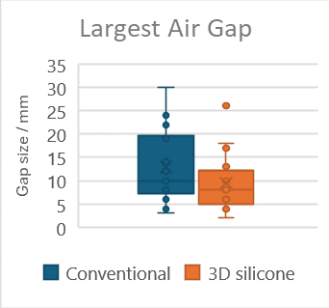
Methods



An intrapatient study of 25 recent rectal patients compared silicone with conventional paraffin bolus. The homogeneity, incidence of significant air gaps (>5mm)[1] and largest gap dimension were measured for paraffin on planning CT scans and silicone on first fraction CBCTs.

Patient-specific QA of 20 TPU and 35 silicone boluses evaluated radiological density, homogeneity and geometric accuracy versus TPS structures through CT scanning. An audit of the first 20 and latest 20 silicone moulds quantified improvements in print time and failure rates necessitating user intervention.

Results



25/35 and 84/85 patients were successfully treated with TPU and silicone respectively. The incidence of significant air gaps under rectal bolus reduced from 88% to 64% with 3D silicone whilst mean largest gap dimension reduced significantly from 13 to 9.6 mm ($p<0.05$).

33/35 silicone and 20/20 TPU boluses passed QA with geometric deviation <0.5mm and density within 30HU of baseline. Silicone failures arose from air bubbles causing shape changes and inhomogeneity, but neither deviation significantly altered planned dose distributions.

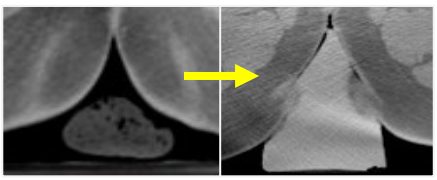
Mean print time for rectal moulds fell from 13.2 to 5.5 hours and failure rates from 25% to 5%.

Discussion

Our results show that 3D printing moulds or bolus itself offers accuracy superior to conventional techniques and consistency sufficient to make routine patient-specific QA unnecessary. However, directly printed TPU bolus (now discontinued) was found to be unsuitable for rectal and H&N applications due to poor tolerability and sensitivity to contouring accuracy. In contrast, flexible silicone offers clinically significant improvement with none of the drawbacks. These results add to the emerging picture in literature that the suitability of directly printed bolus is highly site-dependent[2,3] and recommend moulded silicone as an effective solution.

The substantial workflow improvements achieved were essential to allow moulded silicone to enter routine practise for these sites and enable subsequent expansion to additional use cases.

Conclusion



Silicone bolus produced from 3D printed moulds significantly improves conformity and homogeneity for rectal patients. Furthermore, silicone's flexibility makes it effective for treatment sites where directly printed bolus is unsuitable.

Three years of improvement have resulted in a high-capacity service requiring minimal user input.

References

1: Chung, J. et al. *JKPS* **61**, 1143–1147 (2012). DOI: 10.3938/jkps.61.1143
2: McCallum, S. et al., *Curr Med Imaging* **17**(7), 820-831 (2021). DOI: 10.2174/1573405617666210202114336
3: Malone, C. et al. *J Appl Clin Med Phys* **23**(3):e13490 (2022). DOI: 10.1002/acm2.13490

Advanced 3D-printing of static and dynamic phantoms applied in radiotherapy

Didier Lustermans[1], Roua Abdulrahim[1,2], Britt Haanen[1], Teun van Wagenberg[1], Robert Voncken[1] ,Brigitte Reniers[2], Frank Verhaegen[1] and Gabriel Paiva Fonseca[1]

[1]Department of Radiation Oncology (Maastro), GROW School for Oncology and Reproduction, Maastricht University Medical Centre+, Maastricht, The Netherlands

[2] Research group NuTeC, Centre for Environmental Sciences, Hasselt University, Diepenbeek, Belgium

Background: Recently, 3D-printing technology has been introduced into radiotherapy, resulting in multiple applications. The increased customization that 3D-printing offers allows for the generation of multiple applications such as anthropomorphic phantoms. This abstract describes the 3D-printed applications in the physics research division, focusing on static and dynamical phantoms and how to address the patient complexities and motion.

Methods: The physics research division introduced commercial and in-house developed 3D-printers in 2018 and upgraded them throughout the years, varying from single-extruder, double-extruder, large printing bed and multi-color prints. These printers were used to generate in-house static phantoms for pelvic and head dosimetry in brachytherapy and a large breast phantom for evaluation of extended field-of-view (eFoV) CT algorithms. This has been expanded to dynamical phantoms, consisting of a motion platform and a novel thorax phantom, containing tissue-equivalent soft tissue, bone-equivalent material and a compressible lung-equivalent with realistic structures such as bronchi and tumors. It allowed to simulate accurate breathing phases by a lung compression system (LCS) and chest movement system (CMS). For quantitative imaging and dosimetry, material composition in the phantom is important. Therefore, dual-energy CT (DECT) was used to identify the physical properties of multiple materials (e.g. PC, PLA, PP and TPU) to eventually select filaments that resemble tissue-equivalency, including a custom filament mimicking bone.

Results: The head and pelvic phantoms (Figure 1A) are used for developing treatment verification methods. Evaluating the CT eFoV algorithms was done by the large breast phantom (Figure 1B) and demonstrated more accurate geometry outcomes in a deep learning eFoV algorithm. These static phantoms can be placed on a 3D motion platform to simulate more complex patient motion. Furthermore, an anthropomorphic thorax phantom (Figure 1C) including a compressible lung is manufactured to simulate realistic patient breathing and evaluate image quality and tumor tracking in 4DCT applications. The tumor size and location can be changed, therefore making it applicable for multiple treatments.

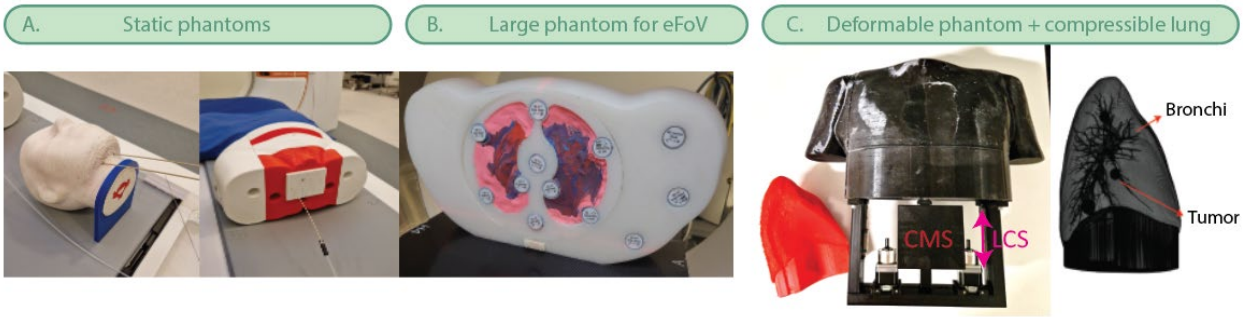


Figure 1: An overview of the manufactered phantoms in the physics research division for brachytheraphy dosimetry verification (A), a large breast phantom used in eFoV evaluation (B) and dynamic phantom, containing a motion platform (A) and a deformable thorax phantom (C) to simulate patient breathing

Discussion: The 3D-printing technology is used in multiple areas in the division (QA, brachytherapy applicators, phantoms), and research has been performed for selecting accurate tissue-equivalent materials, which is important for dosimetry. More phantom complexities should be explored to insert more heterogeneity and motion in various directions.

Conclusion: 3D-printing in radiotherapy offers various possibilities for an increased phantom complexity mimicking multiple patient applications, leading to more tools to improve the radiotherapy workflow and image quality.

Keywords: 3D-printing, Static phantoms, Dynamic phantoms, Phantom application

"Characterization of Flexible Materials for Dynamic Phantoms in Radiotherapy"

Roua Abdulrahim[1,2], Didier Lustermans[1], Britt Haanen[1], Murillo Bellezzo[1], Tommaso Siligardi[1], Brigitte Reniers[2], Frank Verhaegen[1], Gabriel Paiva Fonseca[1]

[1] Department of Radiation Oncology (Maastro), GROW School for Oncology and Reproduction, Maastricht University Medical Centre+, Maastricht, The Netherlands. [2] Research group NuTeC, Centre for Environmental Sciences, Hasselt University, Diepenbeek, Belgium.

Keywords: 3D-Printing, Dynamic Phantoms, Flexible Materials, Radiation Therapy

Background: The integration of 3D-printing technology into radiotherapy has opened new avenues for manufacturing phantoms for treatment verification. However, a significant challenge within the field has been the scarcity of dynamic phantoms that are both anthropomorphic and can replicate the motion of human tissues. This study investigates thermoplastic polyurethane (TPU) as a flexible 3D-printing material, aimed at simulating both the motion characteristics of lung tissue and its CT numbers.

Methods: An iterative experimental approach was employed to find 3D-print parameters that achieve the functional features of a dynamic lung phantom. Initially, cubes with varying infill densities were produced to assess mechanical flexibility. Miniature lung models were also produced, to assess the combination of high and low infill densities that may resemble the densities of lung and tumor tissue. Systematic variations in key print parameters, such as line width and layer height were explored [Table 1]. The miniature lung prototypes are shown in Figure 1a. A compression device utilizing motors, a microcontroller, and a pressure and distance sensor has been developed for conducting comprehensive compression tests.

Sample ID	Color	Shore Hardness	Infill Density (%)	Line Width (mm)	Print Speed (mm/s)	Layer Height (mm)	Nozzle Diameter (mm)	Flow Rate (%)	Print Temperature (°C)
1	White	62A	34	0.24	10	0.18	0.25	125	230
2	White	62A	24	0.24	10	0.18	0.25	125	240
3	Red	82A	24	0.19	22.5	0.12	0.2	138	240

Table 1. Printing parameters to characterize the miniature lungs.

Results: Mechanical tests reveal greater flexibility along the X and Y printing axes compared to the Z axis, and further compression ranges of the samples are being tested. The potential for simulating human lung tissue is showcased by the range of CT numbers achieved with soft material. Samples were scanned in a CT (at 140kV), where samples 1 and 3 resulted in the following CT numbers of lung and tumor models (Sample 1: -640 ± 7, 45 ± 22) (Sample 3: -720 ± 15, 20 ± 16). CT numbers for Sample 2 are in [Figure 1b]; these values closely represent CT numbers of human tissues.

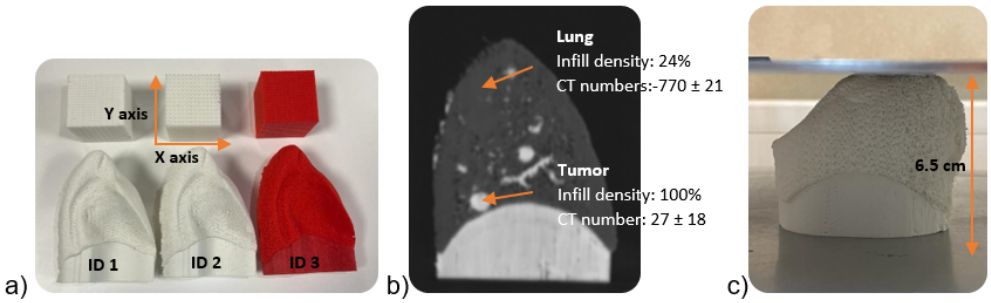


Figure 1. a) 3D-Printed cubes & miniature lungs. b) CT slice of a sample 2 and c) a demonstration of the compression range of sample 2, the original height at 11 cm and compressed height at 6.5 cm.

Discussion and Conclusion: An initial phase of this characterization study was done. Challenges were found in pushing the print parameters beyond the manufacturer recommendations for flexible material, aiming to achieve the desired mechanical flexibility and homogeneity of CT numbers. An additional lung model in a realistic patient geometry was produced using flexible material, and was tested by simulating breathing motion using motors. This characterization study informs the continued search for the optimal material and settings to create dynamic, anthropomorphic phantoms for radiation therapy research.

Improving patient experience with surface scanning for a printed mould

John Mills[1], Ellen Dear[2], Susan Barley[2]
[1] Print Easy Acrylic Shells (PEAS), Hickley, Leicestershire, LE10 0DL
[2] GenesisCare, 69 Alma Road, Windsor, SL4 3HD

Background. Patient plaster casts are still required when a lead mask is used for electron and kV treatment. The long-standing method of alginate and plaster bandage impression can be an uncomfortable experience and, in some cases, prohibitive due to the age or apprehension of the patient. The aim was to determine if an inexpensive and simple process could be devised to produce a plaster mould using 3D printing.

Methods. A low-cost surface scanner was evaluated for producing accurate scans, including comparison with high resolution, expensive surface scanners. This identified a systematic method for patient scanning and development of an attachment to enhance the use of the scanner. A process for expediently deriving a mould print file was developed in both industrial and free software. An optimum method of printing the mould was determined to minimise print time and material and maximise reliability.

Results. Clinical implementation of the method was rolled out over six years. Scanning experience of trained operators has resulted in consistently improving scan files. The number of scans has increased from 1 in 2017 to 30 in 2022. Only two scans in that five-year period have been rejected for processing which highlighted a need for additional training with regard to scanning ears. Scans take typically between 2 and 4 minutes. Patient experience has been good and enabled elderly and frail patients to benefit from electron treatment with masks. By changes to the Mould design and printing methods, print times have been reduced from 11 to 4 hours.

Discussion. Careful assessment and development of the entire process has led to a reliable and simple method to print moulds. The surface scanning has been found to be straight forward and reliably undertaken by technical, radiographic and scientific staff. The scan is well tolerated by patients and clinical staff have easily accommodated the technique into the treatment process.

Conclusion. The production of 3D printed Moulds is simple and affordable. It can be easily implemented and enhances and improves patient treatment when a Mould is required.

Producing Low Melting Point Alloy Masks with 3D Printing

John Mills, Print Easy Acrylic Shells

Aims and Background

Lead masks are still used by some radiotherapy providers for electron and kV treatment. The lead masks are produced by beating sheet lead onto a plaster cast of the patient. The digital information contained in a surface scan of the patient provides the basic information about the shape and profile of the shielding mask. The aim of this work was to devise an inexpensive and simple process to utilise surface scan information to produce masks with low melting point alloy.

Methods

An established surface scanner was used to obtain the profile of the region for which a mask was required. Two major file processing challenges were to determine the size and shape of the required treatment area as well as the beam alignment to the treatment area. It was recognised that the most cost effective way to utilise 3D printing was to process the data to print a mould which could receive molten LMP alloy. The thickness of the mask, chosen to suit clinical and physics requirements was accommodated easily in the processing software.

Results

A double scanning technique was devised to enable localisation of the treatment area and this enabled the size, shape and location of the treatment aperture in the mask mould to be accommodated. An alignment jig was devised which enabled the apposition to the treatment area to be determined along with a vector indicating the beam direction. Any clinical considerations such as directing the beam away from critical tissue could be accommodated by fine tuning of the alignment jig. Using this vector the aperture in the mask mould was aligned correctly. Having established these two techniques, it was possible to generate two files to be printed. The prints were undertaken in ABS filament enabling the completed mould to be easily fabricated by joining them together with acetone. Processing of the files were initially of the order of two hours and each print took less than 4 hours for a typical mask to be used with a 10x10 electron applicator. The thickness of a cast LMP mask was measured over a number of positions with calipers. The extrusion distance for the surface scan was set at 5mm to create the top part of the mould and the mean thickness over ten sample measurements was 5.89 ±0.33mm. Pouring and stripping the mould from the mask took less than 30 minutes depending upon cooling time for the alloy.

Discussion

A scanning and processing technique has been devised which demonstrates that 3D printing can be used to produce a mould and a shielding mask in LMP alloy. The technique can be further extended to the printing of the bolus associated with using a mask in electron treatment.

Conclusion

3D printing can be used to cost effectively to produce shielding masks which have consistent thickness across the mask and accurate alignment to the treatment area.

A 3D-printed adaptable anatomical phantom for end-to-end testing of online adaptive radiotherapy for cervical cancer based on clinical patient geometry

Matt Jones – Radiotherapy Physics, The Royal Surrey NHS Foundation Trust

Background:

Adaptive radiotherapy for cervical cancer has the potential to improve local control, but the technique lacks site-specific test objects. Commercial solutions are scarce and may prove to be prohibitively expensive. This study presents the development of the Adaptable System for Testing End-to-end Radiotherapy (ASTER); a 3D-printed, adaptable cervix phantom based on clinical anatomical deformations.

Methods:

Imaging data from ten cervix patients were used to quantify target volume deformation, and exported structures displaying the most significant change were used to design the 3D-printed phantom. Target Inserts representing clinical anatomy were designed to be exchangeable and facilitate both point dose and 2D film dosimetry measurement. Achievable accuracy was determined using unadapted cervix plans on TrueBeam linear accelerators. The physical similarity to the source anatomy and the time and material costs of the phantom production are also assessed.

Results:

Printed volume differences compared to the source anatomy ranged from -3.3 to 6.6 % with mean 1.7 ± 2.9% (mean ± s.d.). Dice similarity coefficients between the printed and clinical structures ranged from 0.81 – 0.98 with mean 0.93 ± 0.05 (mean ± s.d.). Differences in CT imaged density range from -54 to 22 HU with a mean of -16 ± 22 HU (mean ± s.d.), all of which agreed with clinical density to within 1 s.d. Fabrication used <6kg of PLA, costing <£109, but taking >51 days to print. Dosimetric trial runs returned measured point doses within ≤1.3% of those calculated by the treatment planning system. Non-uniformity in calibrated EBT3 dose distributions limited analysis to 8 x 20 cm Ant-Post and Sup-Inf strips, in which gamma scores of 95.8 – 99.9% at 5%/2mm were achievable, compared to planned distributions.

Conclusion:

A 3D printed, cost-effective, adaptable cervix phantom has been developed that models clinical anatomical changes and can be used for end-to-end audit of cervical ART workflows. Continuing work includes an end-to-end audit of adaptive cervical radiotherapy techniques using the Varian Ethos ART system, and a multi-centre 3D printing audit to investigate consistency of printed densities and attenuation characteristics thereof.

Key words: 3D printed, adaptive radiotherapy, audit, cervix, phantom

The production of a bespoke 3D printed HDR skin brachytherapy applicator for the treatment of skin lesions - A case study

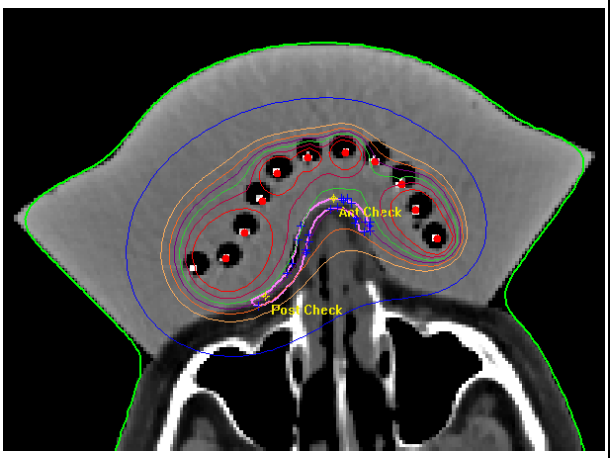
Ahmar Yaseen, Stuart Duggleby, Stuart Tomlinson, Bansi Mulji-Shah, Northampton General Hospital

Background

In 2023 our department chose to decommission our orthovoltage kV unit due to it being economically unviable to operate. Instead, we sought to convert our experience of 3D printing for photon treatments, to print bespoke HDR skin surface applicators for the treatment of skin lesions. This case study is of a 76 year old patient who presented with infiltrating BCC of the right nasal ala arching over the nasal bridge. The patient opted against surgical intervention in favour of radiotherapy. The use of high energy electrons was not favoured due to concerns over exit dose and overlap with previous treatment. Brachytherapy using the Freiburg flap applicator (Elekta, Stockholm, Sweden) was also not ideal as applicator fitting in pleated regions resulted in problems with placement, positioning reproducibility and achieving good skin contact. Instead, a 3D printed applicator conforming to the patients' skin surface was proposed.

Method

The patient was initially CT scanned with fiducial markers used to mark the PTV. An applicator structure conforming to the skin surface was then generated in the Eclipse TPS. Using the Adaptiiv 3DBolus software a mould of the applicator was designed accounting for the number of catheter tunnels, curvature of paths and distance from skin surface. The mould was printed using PLA and later filled with silicon. Quality checks were carried out before the patient underwent a fitting session to assess comfort followed by a planning scan with the applicator and catheters insitu. A plan was generated on the Oncentra TPS, peer reviewed followed by QA and treatment.



Results:

Good contact between the applicator and skin surface was achieved.
Reported setup was easy with accurate reproducibility for every fraction and was well tolerated by the patient.
Dose conformity and better underlying tissue sparing.

Discussion:

Software limitations
Production time
Trade-off between backscatter material and weight reduction
Consideration of better anchoring catheters or reducing tunnel radius
Treatment planning challenges

Conclusion:

Without the use of a 3D printed applicator for brachytherapy, the patient would have had to choose a treatment that would likely resulted in significant cosmetic morbidity to achieve the same radical intent. A 3D printer can reliably be used to produce bespoke 3D printed applicators that provide consistent contact with the skin for treatment of complex sites and can be used as an alternative to traditional methods.

Point-of-care 3D printing at the Royal Brisbane & Women's Hospital

Scott Crowe, Tania Poroa, Rachael Wilks, Tanya Kairn

Background. The Royal Brisbane & Women's Hospital is a tertiary hospital in Brisbane, Australia. It features a large Radiation Oncology department with 5 linear accelerators, 2 brachytherapy afterloaders, and kilovoltage and intraoperative therapy. The department has a mold room with 3 FDM printers and is co-located with a biofabrication and 3D printing research institute, providing access to photopolymerisation, powder fusion, and jetting systems.

New Technology or Processes. The department routinely 3D prints patient-matched bolus, support, and positioning devices, and since 2020, has printed devices for over 275 patients. In addition to these devices, the department also prints modular positioning devices for clinical use, educational models and quality assurance devices tools for applications ranging from intraoperative brachytherapy to real-time MLC tracking of lung tumours, and have completed development work on higher risk intra-oral positioning devices and intracavitary brachytherapy applicators. Some of these devices are shown in the figure below. This has been done under an ISO-style quality management system, with point-of-care production of medical devices registered with the Australian regulator, the TGA.

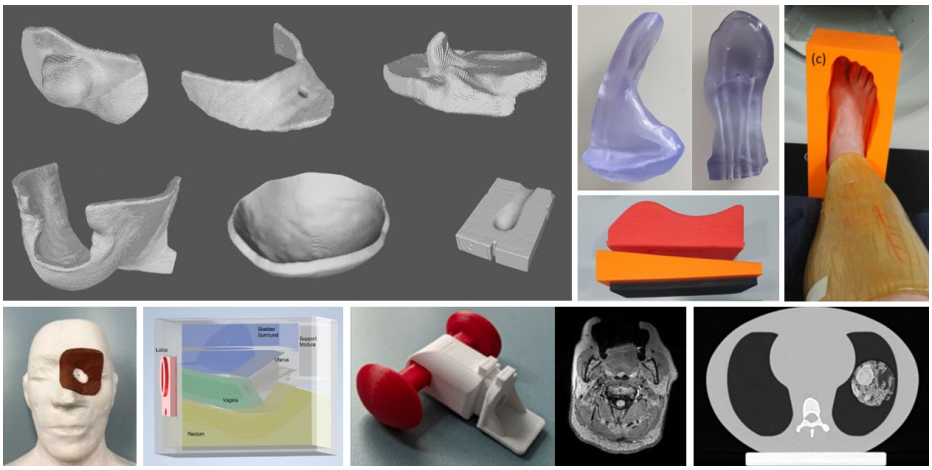


Figure 1, clockwise from top left: patient matched bolus and positioning devices, gynacological applicator, wedged head rest spacer, foot positioning device, lung phantom with realistic insert, mouth-piece, gynaecological brachytherapy educational model, Copper-PLA shielding.

Lessons Learned. Clinically, 3D printing has allowed the preparation of devices difficult with conventional techniques, e.g., devices shaped to fit a rhinectomy cavity. Optimising the use 3D printing requires consideration of patient characteristics and other techniques (such as wax or thermoplastics), as printing may not be worthwhile for patients where anatomy may change. The printing of higher risk devices, such as gynaecological applicators with additional biocompatibility and sterilisation requirements has been challenging – as the validation and certification of materials used in other applications (e.g., dental) don't necessarily apply to different designs.

Best Practice. Understanding and implementing ISO-compliant quality management systems is made easier through collaboration, within multidisciplinary teams, with biomedical engineers, peers in other departments, and engagement with regulatory agencies. Until recently, the Australian regulators did not necessarily appreciate the breadth of medical devices being manufactured at point-of-care, and health professionals did not appreciate regulatory obligations, but this has been improved through open communication.

Conclusion. 3D printing has improved radiation therapy practices at the Royal Brisbane & Women's Hospital, and has provided devices that could not have been easily manufactured using other techniques, satisfying design requirements in a safe, cost-effective way.