A dosimetric comparison of CT- and photogrammetry-generated 3D printed HDR brachytherapy surface applicators

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Abstract
In this study, we investigate whether an acceptable dosimetric plan can be obtained for a brachytherapy surface applicator designed using photogrammetry and compare the plan quality to a CT-derived applicator. The nose region of a RANDO anthropomorphic phantom was selected as the treatment site due to its high curvature. Photographs were captured using a Nikon D5600 DSLR camera and reconstructed using Agisoft Metashape while CT data was obtained using a Canon Aquilion scanner. Virtual surface applicators were designed in Blender and printed with PLA plastic. Treatment plans with a prescription dose of 3.85 Gy × 10 fractions with 100% dose to PTV on the bridge of the nose at 2 mm depth were generated separately using AcurosBV in the Varian BrachyVision TPS. PTV D98%, D90% and V100%, and OAR D0.1cc, D2cc and V50% dose metrics and dwell times were evaluated, with the applicator fit assessed by air-gap volume measurements. Both types of surface applicators were printed with minimal defects and visually fitted well to the target area. The measured air-gap volume between the photogrammetry applicator and phantom surface was 44% larger than the CT-designed applicator, with a mean air gap thickness of 3.24 and 2.88 mm, respectively. The largest difference in the dose metric observed for the PTV and OAR was the PTV V100% of −1.27% and skin D0.1cc of −0.28%. PTV D98% and D90% and OAR D2cc and V50% for the photogrammetry based plan were all within 0.5% of the CT based plan. Total dwell times were also within 5%. A 3D printed surface applicator for the nose was successfully constructed using photogrammetry techniques. Although it produced a larger air gap between the surface applicator and phantom surface, a clinically acceptable dose plan was created with similar PTV and OAR dose metrics to the CT-designed applicator. Additional future work is required to comprehensively evaluate its suitability in a clinically environment.

Keywords Photogrammetry · 3D printing · Brachytherapy · Surface moulds · Skin

Introduction
The benchmark for generating a virtual model necessary for 3D printing for radiation oncology applications involves imaging a patient or phantom using a CT scanner. The image data obtained can then be manipulated to create a 3D virtual model of the region scanned and converted into a format suitable for 3D printing. Research on using a CT scanner to generate 3D printable surface applicators and EBRT bolus has already been extensively studied [1–11].

Recent research has evaluated alternative imaging techniques for generating 3D printable patient-specific devices. These include using non-contact techniques such as 3D scanning technology [12–15] and optical photogrammetry [14, 16]. Photogrammetry is generally described as the science of making reliable measurements from photographs [16]. The basic workflow of photogrammetry involves capturing multiple images of an object at various angles and elevations to ensure adequate overlap of features in the photographs. Using these images, the photogrammetry software is able to reconstruct a 3D model of the object by locating and tracking the movement of key features present in the images. A 2D texture map is generated and each face of the 3D model is mapped to a group of pixels in the 2D texture map to overlay the texture onto the 3D model by a process of UV mapping.
The use of photogrammetry for reconstructing 3D models of objects is already well established in the literature and is commonly used for mapping terrain [17, 18] and modelling architecture [19, 20]. Several of these studies found that photogrammetry can be as accurate as conventional techniques such as laser scanning [18–20].

Photogrammetry has several advantages compared to using a CT scanner in generating virtual surface models. Since only a photographic camera is required for model generation, no ionising radiation is used and is therefore in line with the as low as reasonably achievable (ALARA) principle. This may also allow for fewer CT simulation appointments compared to model generation using a CT scanner as one session can be replaced with photography time. Photogrammetry technique additionally has no arbitrary skin surface definition as photographic images obtain direct information of an object’s surface (whereas CT requires a HU value to specify the skin surface) and is able to retain texture information of the object imaged, which may aid in the contouring of treatment targets.

At the Royal Adelaide Hospital, skin lesions located on the nose are commonly treated with brachytherapy using wax surface applicators. The purpose of the surface applicator is to fix catheter tubes in place so that a radioactive source can be reproducibly positioned in close proximity to the skin lesion. Due to the high curvature of the nose region, fabricating conventional wax surface applicators are challenging and time consuming. Designing a 3D printable surface applicator for this region has potential advantages.

The purpose of this study was to compare the geometric accuracy between a CT scan and photogrammetry based 3D printed surface applicator for a nose PTV, and to evaluate if an acceptable dosimetric plan could be created for a surface applicator designed using photogrammetry techniques.

### Methods

The head and neck section of a RANDO anthropomorphic phantom (Radiology Support Devices Inc., California, USA) was used in this work. The RANDO phantom was scanned on an Aquillion LB (Canon Medical Systems, Otawara, Japan) CT scanner with 1 mm slice thickness helical scan and 120 kVp tube voltage to generate the CT scan model. The resulting DICOM data was imported into the software 3D Slicer [21] (Version 4.10.2) where the RANDO skin surface definition was extracted using a HU threshold based segmentation. Photographic images were captured using a 24.2 MP (Megapixel) D5600 DSLR (Nikon© Tokyo, Japan) with an image resolution of 24.16 MP (6016×4016) fitted with a Nikon AF-P DX Nikkor 18–55 mm f/3.5–5.6G VR zoom lens. The camera settings selected, and other relevant parameters are summarized below in Table 1.

| Parameter                  | Value                      |
|----------------------------|----------------------------|
| **Camera specific**        |                            |
| F-stop                     | 5.6                        |
| Shutter speed              | 1/60 s                     |
| ISO                        | 1250                       |
| Focal length               | 55 mm                      |
| White balance              | Fluorescent                |
| **Other**                  |                            |
| Distance to phantom        | Phantom filled screen (approx. 600 mm) |
| Number of photos captured  | 160                        |
| Number of photos used in reconstruction | 100 |

This work focussed on the nose region of the RANDO phantom as it would challenge the accuracy of the photogrammetry software due to its high curvature. As the treatment target site selected included just the nose region, only photographic images of the anterior side of the RANDO phantom were taken. The photogrammetry workflow used is the same as that described by Bridger et al. [22]. To reduce the effect of non-uniform lighting on the phantom and improve the reconstruction quality, non-reflective micropore tape (3 M Company, NSW, Australia) was applied to the affected regions on the phantom prior to the image capturing stage. Different coloured markings were applied to each segment of micropore tape to aid the photogrammetry software in reconstructing the model.

![Fig. 1 Setup of RANDO phantom with non-reflective tape applied and an AR coded target for scaling. Coloured markers were used to aid the software in reconstructing the model](image-url)
Metashape (Agisoft LLC, St Petersburg, Russia) photogrammetry software was used to reconstruct the 3D models using the software’s default reconstruction settings. The 3D photogrammetry model of the RANDO phantom was exported in wavefront format (.OBJ) from Agisoft Metashape for applicator construction. For the 100 photo collection, the entire reconstruction workflow took approximately 35 min to process using a computer with an Intel® Core™ i7-4930 K CPU, 16 GB of RAM and a NVIDIA® GeForce® GTX 770 graphics card.

All post-processing was completed using the 3D modelling software Blender (Version 2.81, Blender Foundation, Amsterdam, Netherlands) [23]. The resulting model consisted only of vertices that formed the head surface of the RANDO phantom. A vertex (e.g., the corner points of a cube) is the intersection of two or more edges (e.g., the edges of a cube) where two vertices are required to construct an edge and three or four edges are required to construct a face (e.g., six faces of a cube). This was done to reduce the memory requirements (RAM) of the PC and the overall file size constraints during the surface applicator construction.

Both the CT scan and photogrammetry models were imported into the software CloudCompare (Version 2.11) [24] where they were aligned using the iterative closest point (ICP) algorithm [25] and exported in .STL format. Both models were aligned such that the virtual surface applicator could be constructed in approximately the same region, allowing for a reliable comparison of the two techniques. The aligned models were then imported into Blender where the design and construction stages of the surface applicators were performed. Hereafter, the CT scan based surface applicator is referred to as the reference surface applicator.

**Virtual surface applicator construction**

The surface applicators were designed to cover an area of approximately 10 × 10 cm² to treat the nose region and approximately 1 cm thick to achieve acceptable dose fall-off during treatment planning. The catheter tunnels were constructed such that their centres were located 5 mm from the treatment target surface and followed the contours of the RANDO phantom model. The inter-catheter spacing was 7 mm for both surface applicators.

The construction of the virtual surface applicators were completed in three major stages. First, a 15 × 15 cm² region enclosing the nose was selected as the initial applicator size. This surface region was extruded by 10 mm normal to the surface to create a uniform thickness applicator. Using Blender’s non-uniform rational basis spline (NURBS) path function, 3 mm diameter catheter tunnels were created 5 mm from the skin surface. To ensure the tunnels followed the contours of the surface applicator, Blender’s built-in “shrinkwrap” modifier was applied to all paths. The “shrinkwrap” modifier shrinks an object onto the surface of a target object by moving each of its vertices to the closest position on the target’s surface [26]. The method by which the selected object shrinks to the target’s surface depends on the mode selected. The ‘project’ mode was used as it projects vertices from the selected object onto the target’s surface along a specific axis. To ensure the catheters tunnels were all placed 5 mm above the treatment target surface, a second applicator was constructed from the previous 15 × 15 cm² mesh segment and extruded to 5 mm instead. The purpose of this structure was to act as the target surface for the “shrinkwrap” modifier so that all tunnels were positioned exactly 5 mm from the treatment surface. All paths were extruded to have diameters of 3 mm and the tunnels were created by a Boolean Difference operation of the paths with the applicator. A small margin was added to account for the finite resolution of the 3D printer, warping of the material and small pieces of filament in the tunnel. The applicators were then resized approximately to the desired dimensions of 10 × 10 cm² by another Boolean Difference operation. This operation also smoothed the edges of the surface applicators which meant they would lie flat on the print bed while printing. The general workflow of surface applicator design in Blender is shown in Fig. 2.

**3D printing of the surface applicators**

Once the surface applicator construction in Blender was complete, the models were exported in .STL format for 3D printing. The surface applicators were printed with Polylactic Acid (PLA) filament at 90% infill using a Zortrax M200 desktop printer (Zortrax, Olsztyn, Poland). An infill of 90% was selected to avoid material warping that can occur at 100% infill [27] and still obtain near water equivalence [28, 29].

**Surface applicator evaluation**

To quantitatively evaluate the surface applicators, a geometric accuracy and dosimetry plan comparison was performed. The geometric accuracy of the two surface applicators was evaluated by the following metrics: air gap volume and mean air gap thickness between the surface applicator and RANDO phantom surface, and virtual surface applicator similarity.

**Air gap volume and virtual model similarity**

The 3D printed surface applicators were placed onto the RANDO phantom and scanned using an Aquillion LB CT scanner with 1 mm slice thickness helical scan and 120 kV_p tube voltage. The resulting DICOM data was imported into 3D Slicer where the air gap volume was automatically
contoured using the threshold segmentation tool. Any air
gaps between the surface applicator and RANDO phantom
were detected by applying a HU window of intensity range
-2000 to -280 HU. Detected air gaps outside the region of
interest were manually removed from the segmentation.
The volume of the resulting air gap segmentations were
then computed using 3D Slicer’s segmentation statistics
tool.

To measure the mean thickness of the air gap vol-
ume between the surface applicators and surface of the
RANDO phantom, the segmented air gap volumes were
imported into Blender as .STL format. The air gap vol-
ume segmentations consist of two separate surfaces, the
front and back, joined together to create a 3D solid model.
Using Blender, the centre of mass point of each surface
was determined. The front and back surfaces contain the
same distribution of vertices and therefore their centre
of mass points are approximately separated only by the
distance between the two surfaces. The distance between
these two points was used as a metric for the mean thick-
ness of the air gap volume.

The virtual surface applicators with catheter tunnels
were compared by importing into CloudCompare software
and aligned using the ICP algorithm. The distance between
all vertices in the photogrammetry model and the reference
model was computed and the percentage of vertices within
1 mm was determined.

**Dosimetry comparison**

The CT scan data of each virtual surface applicator was
imported into Varian (Palo Alto, USA) BrachyVision© (Ver-
sion no. 13.7) treatment planning system (TPS) to evaluate
their dosimetric properties. Both datasets were manually co-
registered to the bony anatomy of RANDO and skin. The
anatomy of the RANDO phantom is the same between each
CT scan. By co-registering both CT scans to the anatomy of
the RANDO phantom, any differences observed between the
scans is due to differences in the surface applicator’s position
and shape. This allows for easy visualisation of any differ-
ences in air-gaps between the two co-registered CT scans.

Treatment plans were created using AcurosBV (Version
no. 1.7.0.37099) TG-186 algorithm [30] and volume opti-
mized for a hypothetical planning treatment volume (PTV)
contoured on the bridge of the nose at 2 mm depth using
the same planning constraints and objectives for both treat-
ment plans. Catheter reconstruction was performed sepa-
rately on each plan and loading volumes were generated to
activate dwells within the two PTVs. A clinical prescription
dose of 3.85 Gy×10 fractions with 100% dose to the PTV
was applied, whilst keeping the skin dose to a maximum
of 115%. The two plans were compared visually based on
isodoses and quantitatively using suitable dose metrics.
These dose metrics were the PTV D_{98%}, D_{90%} and V_{100%},
skin D_{0.1cc} and D_{2cc} and body V_{50%}. Summarised in Table 2
are the basic calculation parameters used in BrachyVision for the treatment plans.

Results

Virtual surface applicator construction

Figure 3 shows the final design of the virtual surface applicators. The total time taken from acquiring the photographs to designing the virtual surface applicator using the photogrammetry approach was 95 min. In contrast, the reference virtual surface applicator was designed in 70 min from acquiring the CT scan of the RANDO phantom. The largest difference in process time was the generation of the 3D virtual model from the image data, which took 10 min for the reference method and 35 min for photogrammetry.

3D printing of the surface applicators

Both surface applicators were successfully 3D printed with only minor defects and replicated the region of interest with the expected dimensions. The total print time was approximately 13 h each and the completed surface applicators are shown in Fig. 4. No issues were found when positioning the surface applicators onto the nose region of the RANDO phantom.

Surface applicator evaluation

Air gap volume and virtual model similarity

The measured air gap volume for both surface applicators are shown in Table 3 along with the percentage of vertices in the photogrammetry virtual surface applicator that are within 1 mm of the reference virtual surface applicator.

Using 3D Slicer, air gaps between the RANDO phantom and the surface applicator designed from both approaches were identified and are shown in Fig. 4. The total volume of all air gaps measured for the reference surface applicator was 18,685 mm$^3$ compared to 26,859.5 mm$^3$ for the photogrammetry surface applicator, an increase of 44%. Based on the two air gap volumes shown in Fig. 5, there is a larger air gap generated by the photogrammetry surface applicator than the reference surface applicator.

The mean air gap thickness between each surface applicator and the surface of the RANDO phantom are also summarised in Table 3. It was found that the photogrammetry surface applicator generated an air gap volume with a mean thickness of 3.24 mm compared to 2.88 mm for the reference surface applicator.

Although the two surface applicators generated different air gap volumes, 93.6% of all vertices in the photogrammetry virtual surface applicator were within 1 mm of the reference virtual surface applicator, see Table 3.

| Table 2 Calculation parameters used for treatment plan generation |
| Calculation parameter | Selection |
|-----------------------|-----------|
| Source model          | GammaMedPlus [31] |
| Nominal source strength | 40,823 U (10 Ci) |
| Source geometry       | Linear    |
| Dose grid resolution  | 0.1 × 0.1 × 0.1 cm$^3$ |
| Dose calculation      | Dose to medium |
| Dose reporting        | Dose to water |
| Dwell Spacing         | 0.5 cm    |

Fig. 3  a Anterior and b superior view of computer generated rendering of the CT scan based surface applicator. c Anterior and d superior view of computer generated rendering of the photogrammetry based virtual surface applicator
Fig. 4  a Lateral and b anterior view of the 3D printed surface applicator generated by a CT scan. c Lateral and d anterior view of the 3D printed surface applicator generated using photogrammetry techniques.

Table 3  Comparison of the virtual surface applicator volume, measured air gap volume, average air gap thickness and the distance to agreement between the photogrammetry and reference virtual surface applicators.

| Surface applicator approach | Volume of virtual surface applicator (mm³) | Air gap volume (mm³) | Mean air gap thickness (mm) | % of vertices within 1 mm of Reference model |
|-----------------------------|-------------------------------------------|----------------------|-----------------------------|---------------------------------------------|
| Reference                   | 129,547.7                                 | 18,685.0             | 2.88                        | –                                           |
| Photogrammetry              | 126,320.8                                 | 26,859.5             | 3.24                        | 93.6                                        |

Fig. 5  a Anterior and b superior view of computer generated rendering of the air gap volume measured between the surface of the RANDO phantom and the CT scan based surface applicator. c Anterior and d superior view of computer generated rendering of the air gap volume measured between the surface of the RANDO phantom and photogrammetry based surface applicator.
Dosimetry comparison

A 3D surface render of RANDO’s head plus photogrammetry-generated surface applicator with source dwell positions in the catheters is shown in Fig. 6.

Figure 7 shows the isodoses corresponding to the plans with the reference and photogrammetry surface applicators.

The PTV $D_{98\%}$, $D_{90\%}$ and $V_{100\%}$ and the OAR $D_{0.1cc}$, $D_{2cc}$ and $V_{50\%}$ dose metrics obtained for both plans and percentage difference relative to the reference surface applicator values are summarized in Table 4.

From Table 4, the dose coverage of the PTV ($D_{98\%}$ and $D_{90\%}$) for the photogrammetry approach was within 0.2% of the reference plan. The PTV $V_{100\%}$ showed the largest difference between the two plans with the photogrammetry approach 1.27% lower than the reference plan. OAR dose metrics for the skin ($D_{0.1cc}$ and $D_{2cc}$) and body ($V_{50\%}$) for the photogrammetry approach were also within 0.5% of the reference plan. The total treatment time calculated for the reference plan was 171.5 s, compared to 179.7 s for the photogrammetry approach.

Discussion

Virtual surface applicator construction

The photogrammetry software required an additional 15 min to generate a 3D model of the RANDO phantom surface compared to the reference approach. Photogrammetry processing time could be reduced by approximately 75% by reducing the number of images used by half. If texture information is not required for generating the 3D model of the treatment site, this part of the workflow could be removed from the process and further reduce the photogrammetry reconstruction time. For a reconstruction consisting of 100 photos, removing the texturing stage from the process was found to reduce the total processing time by approximately 8%. However, this may be of use in contouring surface lesions. The photogrammetry model also required more post-processing than the reference model. Alternatively, if a department were to adopt this approach instead of CT based surface applicators, GPU acceleration could be used to speed up the process.

3D printing surface applicators

Patient-specific surface applicators with ten catheter tunnels were successfully printed using CT and photogrammetry image data. 3D printing the surface applicator took the longest time to complete in the workflow (780 min), but since this process is automated with minimal human intervention, it may not present a significant issue. The operator is only required to import the 3D print file to the printer and start the printing process, which would take less than 5 min out of the total workflow. The surface applicators could also be left to print overnight and be ready the next day for use.

Surface applicator evaluation

Air gap volume and virtual model similarity

Fabricating a surface applicator that produces the smallest air gap volume can be beneficial on the planned dosimetry. Large air gap volumes increase the separation between the surface applicator and the skin which reduces the steepness of the dose fall-off due to the inverse square effect. This results in a higher dose to the underlying healthy tissue beyond the PTV if the air gap volume is taken into account in the treatment plan and present during treatment. If a large air gap volume is present during treatment but not taken into account in the treatment plan, a large air gap volume can significantly reduce the dose delivered to the PTV in high dose rate (HDR) brachytherapy treatments [32]. Any air gap volume...
volume will however introduce a potential source of uncertainty regarding reproducibility in positioning the surface applicator on the patient’s skin. They should therefore be minimised in the fabrication process where possible.

Air gap volumes for a nose surface applicator generated from a CT image dataset are typically less than 3 mm as reported by Zhao et al. [11] and Jones et al. [8]. The photogrammetry surface applicator contained a significantly larger air gap volume than the reference surface applicator and the average thickness of the air gap was 13% larger. This indicates that the reference surface applicator has a superior fit compared to the photogrammetry based applicator. The lack of conformity alone in the end product of the photogrammetry based applicator does not necessarily rule out this technique for manufacturing surface applicators, but rather highlights the need for further improvements. Although the photogrammetry workflow is in-line with the ALARA principle, the additional dose received by a patient from a CT scan (about 2–10 mSv for head and thorax, respectively) using the CT scanner method is small compared to the typical prescription dose (about 38.5 Gy). A Radiation Oncologist is unlikely to sacrifice precision for an additional CT scan.

The difference in the air gap volume between the two surface applicators could be attributed to several factors including: scaling uncertainties in the photogrammetry reconstruction, reduction in the size of the 3D printed surface applicator post-printing due to thermal shrinkage and, PLA print material is rigid. Since the reduction in size of the 3D prints would affect both surface applicators equally, it does not necessarily explain the discrepancy in air gap volume. Similarly, the rigidity of the PLA material would affect both applicators equally. Only the photogrammetry based surface applicator would be affected by the scaling of the reconstruction from the photogrammetry software and

| Structure | Index | Reference applicator (%) | Photogrammetry based applicator (%) | % Difference |
|-----------|-------|---------------------------|-------------------------------------|-------------|
| PTV       | D98%  | 92.95                     | 93.11                               | 0.16        |
| PTV       | D90%  | 98.05                     | 97.98                               | −0.07       |
| PTV       | V100% | 74.80                     | 73.53                               | −1.27       |
| Skin      | D0.1cc| 115.23                    | 114.97                              | −0.28       |
| Skin      | D2cc  | 102.86                    | 102.63                              | −0.23       |
| Body      | V50%  | 2.77                      | 2.92                                | 0.15        |

Fig. 7  a Sagittal and b axial CT scan view of the reference surface applicator placed on the RANDO phantom. c Sagittal and d axial CT scan view of the photogrammetry-based surface applicator placed on the RANDO phantom. Respective isodose lines are overlaid on the CT scan images. Red arrows highlight regions with large air gap volumes (low conformity) whereas white arrows highlight regions with small air gap volumes (high conformity).
is the most plausible factor. Absolute scaling of a 3D reconstruction is a limitation of photogrammetry since accurate measurements of an object’s known dimensions is required. The impact of scaling on photogrammetry reconstruction accuracy has previously been mentioned in other studies [14, 16] and possible future work will look at improving the scaling accuracy.

**Dosimetry comparison**

All PTV and OAR dosimetric parameters computed using Acuros BrachyVision dose calculation algorithm for the photogrammetry approach were within 1.5% of those computed for the reference plan. The largest discrepancy being the PTV V100% with a difference of -1.27%, indicating that the photogrammetry based surface applicator had reduced PTV coverage. This suggests that the extra air gap volume between the photogrammetry applicator and RANDO phantom surface had minor effects on the dose distribution. The small reduction in conformity of the photogrammetry applicator caused by the larger air gaps can be, at least partially, but mostly compensated by the optimiser in the TPS by adjusting dwell times. Since catheter reconstruction was performed manually and separately in each plan, small variations in the final source positions may also contribute to differences in the two dose distributions. The authors performed catheter reconstruction and optimisation separately in each treatment plan. This particular approach was taken since the purpose of this work was to determine whether a clinically acceptable treatment plan could be created from the photogrammetry based applicator. Optimising each treatment plan separately is more realistic and in line with a true clinical workflow.

**Limitations**

The study presented here has several limitations in its methodology. Firstly, this was a theoretical study to demonstrate the differences between a 3D printed surface applicator designed from a CT image dataset and using photogrammetry techniques for a single treatment site. No other treatment sites were examined and only two surface applicators were fabricated.

The photogrammetry based surface applicator was fabricated from photographs of a motionless humanoid phantom. In a clinical environment, the patient has multiple degrees of freedom which may negatively affect the reconstruction process and degrade the 3D model quality. Additionally, the texture of the RANDO phantom is not skin-like and therefore may not accurately represent the quality of the photogrammetry models of people. Future work involving human volunteers would need to be investigated to assess the capability of the photogrammetry technique in more realistic scenarios. This study did not evaluate the overall effect of the 3D printer’s accuracy on the accuracy of the dwell positions. Several printer parameters including the minimum resolution, print speed, infill percentage and reproducibility will directly influence the accuracy of the printed product. The effect of these parameters on the print quality have already been addressed in the literature [7] and an in-depth evaluation is outside the scope of this article.

The results from this study highlighted some of the limitations with the photogrammetry technique, which identified further issues for improvement before routine use in the clinical environment. However, the aim of this work was to investigate whether photogrammetry can be used as an alternative technique for surface applicator fabrication to that using a CT scanner, rather than as a replacement.

**Conclusion**

CT and photogrammetry imaging techniques were used to produce 3D printed surface applicators for HDR brachytherapy and compared using volumetric and dosimetric parameters. The reference surface applicator designed from a CT scan produced a superior fit compared to the photogrammetry applicator as shown by a 44% smaller air gap volume. Using the same planning constraints and objectives, the photogrammetry based surface applicator enabled a HDR surface plan with similar dose metrics to the reference surface applicator for a highly irregular treatment site to be generated. Implementing its use in a clinical environment may reduce the number of CTs required and is in-line with the ALARA principle. This new workflow using photogrammetry techniques for surface applicator construction or bolus for use in external beam radiotherapy is promising but significant future work is required to determine its suitability in a clinical environment.

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**Data availability** All data will be made available on request.

**Code availability** All codes used will be made available on request.

**Declarations**

**Conflict of interest** The authors have no conflicts of interest to declare that are relevant to the content of this article.
Ethical approval  This study used anthropomorphic phantoms and no human participants. No ethics approval was required.

Informed consent  This study used anthropomorphic phantoms and no human participants. No informed consent was required.

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