Utilizing a 3D Printed Nylon Filament Support Device For Enhanced Radiation Therapy Clamshell Set-up: A Pilot Project

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BACKGROUND

The treatment setup for external beam radiation therapy to the pelvis or inguinals may involve the use of clamshells, or testicular shielding to reduce radiation exposure. Low doses of radiation or scatter has the potential to cause sterility. Traditional methods of immobilization may result in variation in positioning, potentially compromising accuracy, outcomes, and may be uncomfortable for the patient[2]. The high attenuation of cast iron causes scatter on CT imaging, complicating differentiation between external contour and stand, and limits gantry angles during treatment. Researchers developed a 3D printed nylon fiber device to optimize patient immobilization. Nylon was used as literature shows the mass attenuation coefficients of Nylon-12 compare favorably with those of water within 3%[1].

The purpose of this study is to standardize clamshell placement while ensure consistent and reproducible patient position for accurate dose delivery.

METHODS

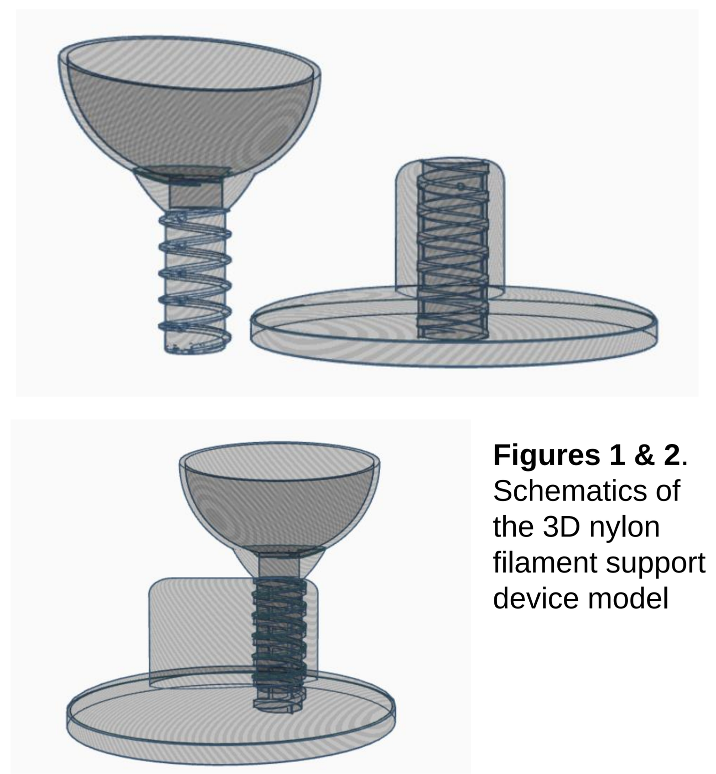
The Hounsfield Unit (HU) of the 3D printed nylon filament device was determined to assess its suitability for contouring purposes. This involved a systematic process wherein a CT scan of the nylon device, wrapped with 1 cm of bolus material to simulate clinical conditions, was acquired using a Philips CT machine. Subsequently, the CT images were uploaded to the Eclipse treatment planning system. Dosimetrists then conducted a thorough evaluation of the HU values at various points within the 3D printed structure using the Eclipse planning system's tools and functionalities. By analyzing the HU values obtained from the CT images, dosimetrists were able to assess the device's radiodensity and tissue equivalence, which are essential factors in accurately delineating anatomical structures during treatment planning.

A farmer chamber positioned at a source-to-surface distance (SSD) of 100 cm within 6 cm of solid water phantom material was utilized. This setup aimed to replicate clinical conditions encountered during radiation therapy treatments. A 21 EX Varian Linac equipped with open 20 by 20 fields emitting 100 monitor units (MU) was employed to subject the 3D printed nylon filament support device to attenuation testing. The output value was then measured in microcoulombs by an electrometer.

A retrospective analysis of previous clamshell placement variation was conducted to evaluate the accuracy and consistency of clamshell positioning in patients undergoing radiation therapy. Researchers identified and collected retrospective patient data from those treated with a lead clamshell over a ten-year period, spanning from 2014 to 2024. Within this timeframe, a total of 17 patients treated with lead testicular shielding "clamshell" were identified.

Of the 17 patients identified, three underwent simulation with a clamshell, and merely two patients had kilovoltage (kV) imaging beams that allowed for visualization of the clamshell's placement. Subsequently, utilizing the image registration functionality within the Mosaiq EMR software, researchers compared and measured the offset in clamshell position between the simulation and the kV imaging at the time of treatment delivery.

MODEL



Figures 1 & 2. Schematics of the 3D nylon filament support device model

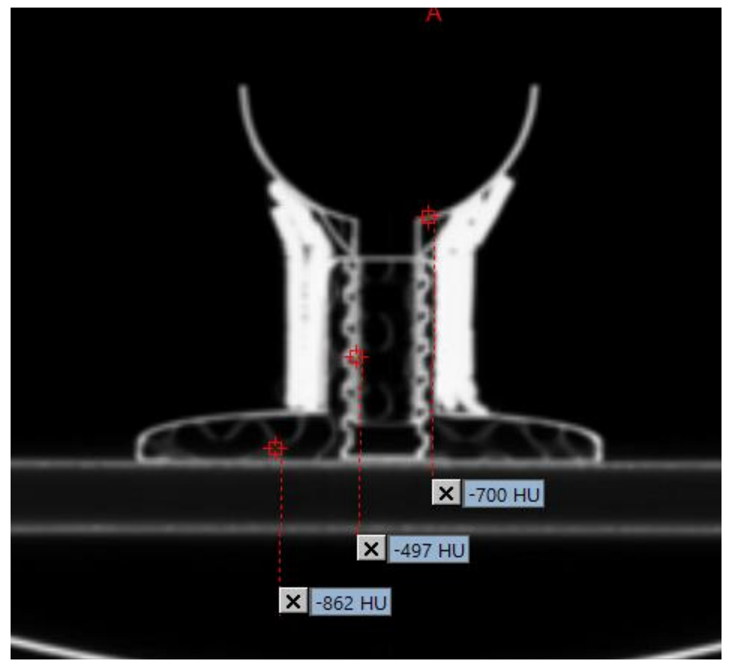


Figure 3. CT scan of support device used to determine Hounsfield units

Figure 4. 3D printed nylon filament support device on LINAC

RESULTS

Utilizing a Farmer chamber and an electrometer, researchers positioned the 3D nylon model enface with the screw, at a 45-degree angle offset, and on its side, comparing it with a control scenario devoid of any device. The data analysis revealed an attenuation ranging between 3% to 7%. Researchers compared the simulated lead clamshell position with actual kilovoltage (kV) imaging during 10 treatment fractions, noting shifts in 3 directions, longitudinal, lateral, and vertical. The registered values of these measured shifts where then plotted on a line graph and an average for each direction was calculated.

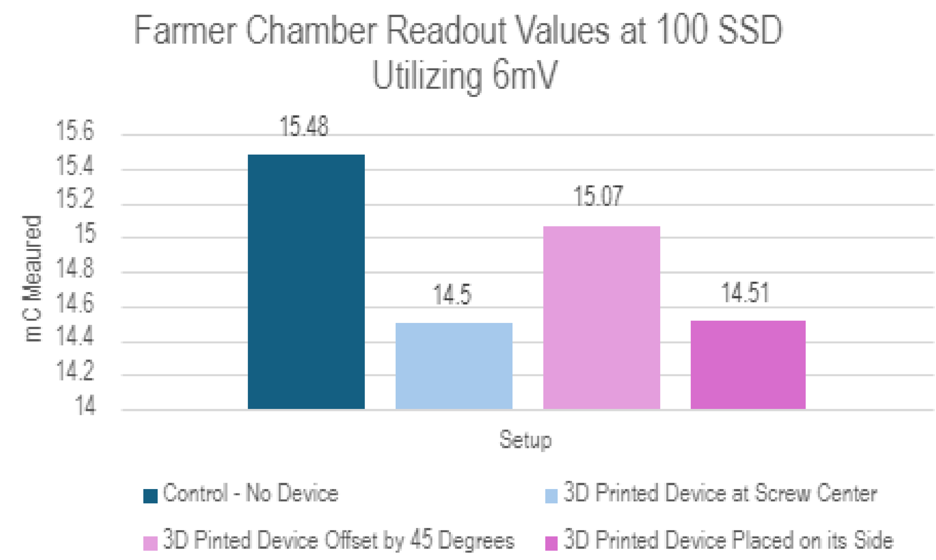


Figure 5. Graph showing the attenuation test with farmer chamber

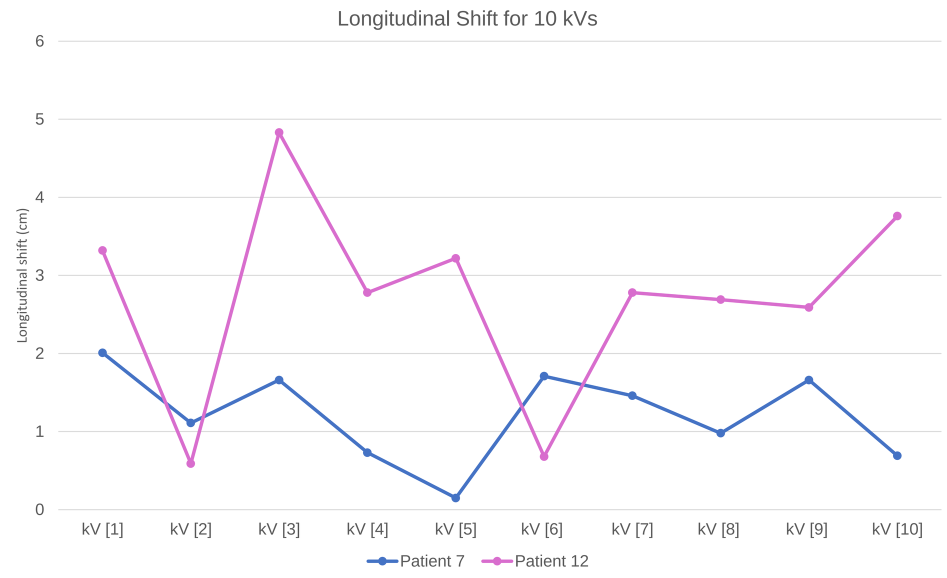


Figure 7. Graph showing the longitudinal shift of the clamshell position for 10 kV portal images

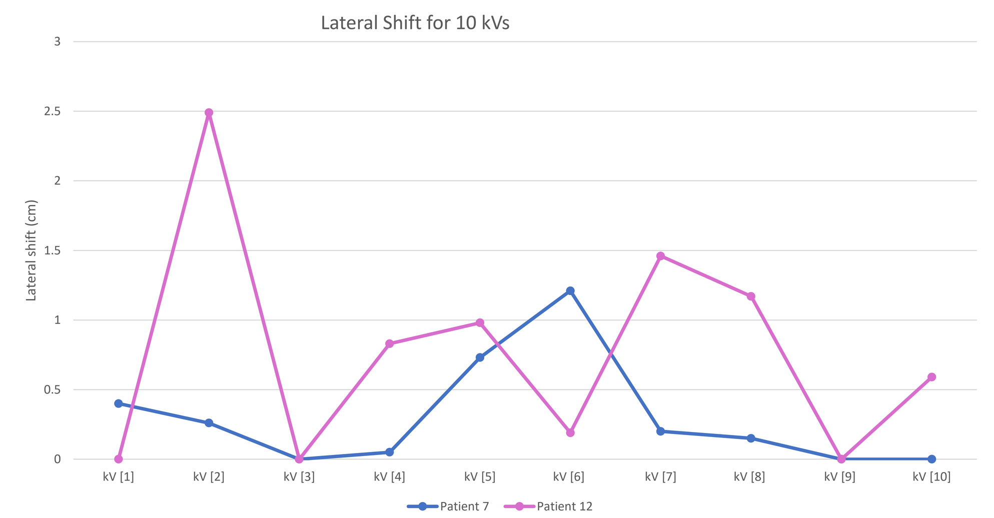


Figure 6. Graph showing the lateral shift of the clamshell position for 10 kV portal images

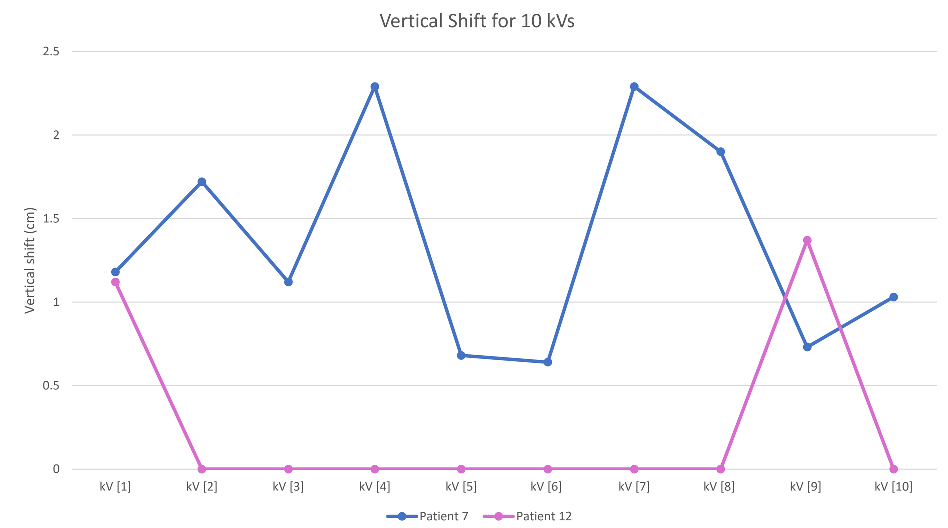


Figure 8. Graph showing the vertical shift of the clamshell position for 10 kV portal images

DISCUSSION

The Hounsfield Unit of the 3D printed nylon filament device is between -900 HU to -490 HU. Through testing and evaluation, it has been demonstrated that this innovative support system exhibits low attenuation of 7%, highlighting its potential to enhance treatment accuracy by minimizing the interference caused by traditional support materials.

Of the 3 patients that underwent simulation with a clamshell, only 2 patients have the clamshell device visible on the kV images. The average offset in clamshell position between simulation and the kV image is 1.97 cm longitudinally, 0.54 cm laterally, and 0.81 cm vertically. This demonstrates variation in clinical setup, potentially impacting treatment outcome due to a less accurate calculation in dose delivery.

CONCLUSIONS

Incorporating the support device into the treatment planning process enables dosimetrists to optimize treatment plans based on the device's physical characteristics and its impact on radiation attenuation and scatter. This level of integration allows for more accurate dose calculations and ensures that treatment plans are tailored to each patient's specific anatomy and support device configuration.

The utilization of the clamshell support device offers a notable improvement in the consistency of clinical setups. By providing a standardized and reproducible support platform, it empowers radiation therapists to achieve more precise and reliable patient positioning during the simulation process.

One notable limitation of our retrospective analysis is the small sample size, with only 17 patients treated over the span of the last ten years (2014-2024). While this sample size allowed for preliminary evaluation of the device's efficacy and feasibility, it may not fully capture the breadth of potential outcomes and nuances associated with its clinical implementation. In conducting further exploration researchers may consider conducting clinical trials to assess the device's ability to reduce wide shifts and strengthen the treatment planning integrity while maximize treatment outcome and minimizing potential side effects. Additionally, longer-term follow-up studies are warranted to evaluate the durability and long-term effects of using the 3D printed support device in clinical practice.

Overall, the integration of the 3D printed nylon filament support device represents a significant step forward in advancing the field of radiation therapy. Its ability to minimize attenuation, provide consistent clinical setups, and facilitate personalized treatment approaches underscores its potential to revolutionize patient care and treatment outcomes in the years to come. As such, further research and implementation of this technology hold promise for continued advancements in the field and ultimately, for the benefit of patients worldwide.

REFERENCES

1. Ade, N., van Eeden, D., & du Plessis, F. C. P. (2019). Characterization of nylon-12 as a water-equivalent solid phantom material for dosimetric measurements in therapeutic photon and electron beams. Applied Radiation and Isotopes, 155, 108919. https://doi.org/10.1016/j.apradiso.2019.108919

2. Sweigart, K. D., Richter, M. P., Horvick, D., & Kirsner, S. (1992). Immobilization and stabilization of testicular clamshell shields in seminoma patients. Medical Dosimetry, 17(3), 157–159. https://doi.org/10.1016/0958-3947(92)90034-d

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