OneIso User Guide

An integrated quality assurance phantom for frameless single-isocenter multitarget stereotactic radiosurgery

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1 Introduction

Brain stereotactic-radiosurgery (SRS) treatments require multiple quality assurance (QA) procedures to ensure accurate and precise treatment delivery. As single-isocenter multitarget SRS treatments become more popular, the quantification of off-axis accuracy of the linear-accelerator is crucial. Consequently, the novel brain SRS integrated phantom was developed and validated to enable SRS QA with a single phantom to facilitate implementation of a frameless single-isocenter, multitarget SRS program. This phantom combines the independent verification of each positioning system, the Winston-Lutz, off-axis accuracy evaluation (i.e. off-axis Winston-Lutz), and the dosimetric accuracy utilizing both point-dose-measurements as well as film-measurement, without moving the phantom - coined *OneIso* [1]. The following document is a user guide for the phantom, shown in Figure 1, in an effort to translate this technology to multiple centers in a multi-institutional trial.

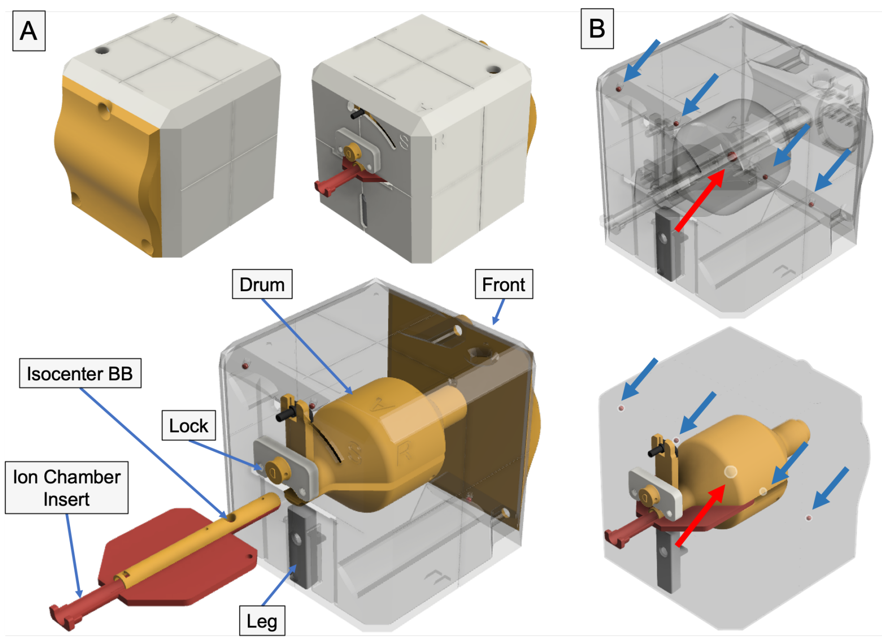

Figure 1: The OneIso. (A) The phantom is constructed of four major component groups and a total of twelve 3D printed parts. Notch-lock mechanisms were designed to lock the central ion chamber insert in-place. Inside there is a solid central drum. This drum contains one steel ball bearing to aid in determining the off-axis Winston-Lutz. Inside the drum, there are two independent inserts which contain the isocenter ball bearing as well as either an ion chamber (shown above) or film insert. (B) The phantom contains a row of off-axis ball-bearings designed to have no overlap with any ball-bearings in the anterior-posterior and lateral directions to quantify the spatial accuracy of a linear accelerator-based single-isocenter, multitarget cranial radiosurgery system.

2 CT Scan and Create QA Plan

Prior to performing dose or imaging measurements, the phantom needs to be scanned. In this section, we will outline the three minimum scans that needs to be perform - the "minimum" number of scans are for the following:

1. For ion chamber measurements;
2. For film measurements; and
3. For off-axis Winston Lutz measurements.

For film measurements, it is suggested to also scan the phantom with the inner drum rotated 45 degrees, so that one can capture multiple targets within one plane (Figure 2).

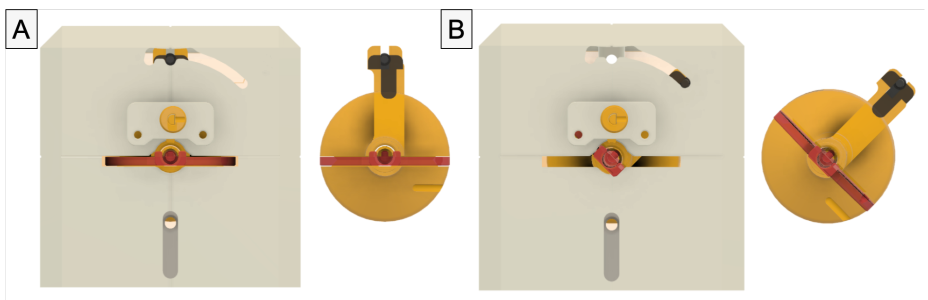

Figure 2: Rotating the inner drum of the OneIso for multiple film planes. (A) The central drum at 0 degrees. (B) The central drum at 45 degrees.

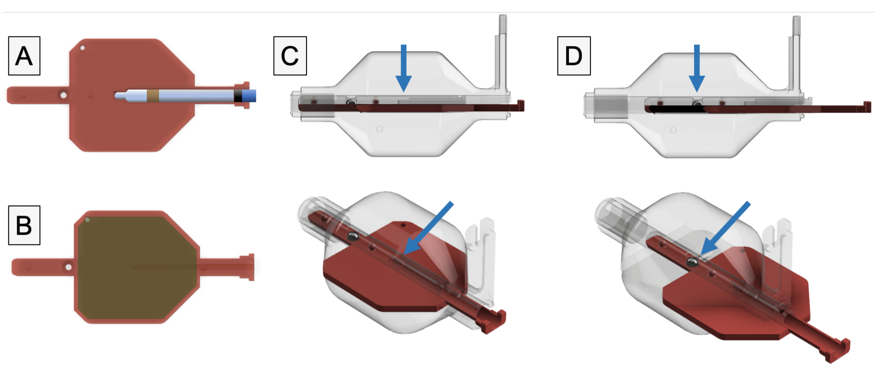

Figure 3: Inside the drum, there are two independent inserts which contain the isocenter ball bearing as well as either an ion chamber (A) or film (B) insert. The insert is printed in two parts that mate together; and slides between two positions: (C) fully inserted for either the film or the ion chamber at isocenter, and a second position, (D) that can be locked in-place, where the ball bearing is at isocenter.

To ensure the phantom remains stationary, a couch index bar mount was designed, and 3D printed. It slides over the two 9” spaced ½” diameter pins on the Varian Exact bar (Varian Medical Systems, Palo Alto, CA) and is compatible with several indexing bars designs, such as the iBEAM indexing bar (Elekta, Stockholm, Sweden).

The phantom was scanned in the appropriate orientation, as indicated by the “A, S, R” illustrated in Figure 1 (A), on the CT couch using the index bar mount and Varian Exact or iBEAM indexing bar. For film and ion chamber measurements, the inserts, as shown in Figure 3, was fully inserted into the central drum of the phantom to the first locked position. For the off-axis Winston Lutz measurement, the insert was moved to the second position, that can be locked in-place, where the ball bearing is at isocenter.

The phantom was CT scanned with the finest slice thickness and 120 kVp and scans were imported into the treatment planning system (TPS). Once scanned and imported into the TPS, a QA plan was created with the CT image of the OneIso phantom and dose was calculated with the Acuros® XB algorithm version 15.6 (AXB, Varian Medical Systems) and 1 mm calculation grid. The dose deposition calculation was set to water. For the off-axis Winston-Lutz test, the plan will be imported (available for download from authors).

For the ionization measurement, the material for the ionization chamber contour was overridden to 0 HU and the dose was calculated to water. The phantom material was not assigned since the plastic of the central buildup drum (radius of 3 cm) is printed with PLA plastic; a bulk average density of 1.00 ± 0.02 g/cc. By default, dose transport is calculated through skeletal muscle at this density [2]. Though skeletal muscle and polylactic acid are not an exact match, inspection of the United States National Institute of Standards and Technologies (NIST) mass attenuation reference data indicates the error in attenuation through 3 cm of material is less than 0.5 %. The mean dose calculated by the TPS was the mean value within a contour centered at the ion chamber with radius 1 mm and length 5 mm. For plans with multiple targets, the couch was used to shift the OneIso phantom based on the locations of the targets in the TPS.

3 Ion Chamber Measurement

The following section outlines the procedure to perform ion chamber point measurements.

1. Creating verification plan for delivery.
   (a) Select Structure Set that contains the contours of the OneIso. Specifically, select the phantom with the appropriate rotation of the central drum (as described in the scanning procedure).
      i. Body Structure
      ii. Pinpoint Structure (overridden to 0 HU)
      iii. Couch Structure
      iv. High Density Structure (overridden to appropriate HU)
   (b) Calculate the dose to the phantom using Acuros® XB.
   (c) Record Mean Dose [cGy] of pinpoint contour structure.

2. Performing measurements.

    (a) For daily output correction factor, perform the following steps. Note: if daily output correction factor is already performed, skip to step (b).

        i. Solid water with pinpoint chamber and electrometer.
        ii. Put solid water phantom on couch - 10 cm back scatter with 2.4 cm buildup for 10 FFF.
        iii. Prescribe a field - size 10×10 cm^2 and 100 cm SSD.
        iv. Set up electrometer.
        v. Go to Service Mode.
        vi. Deliver a 10×10 cm^2 field with the appropriate energy and dose rate (ie. if you are expecting 2400 cGy, then deliver 2400 cGy in the solid water).
        vii. Perform this three times.
        viii. Pack-up solid water.

    (b) Calculate constant conversion factor (C) - the measured dose from the ratio of delivered dose under reference conditions (D_{ref}) to the collected charge (M): $C = D_{ref} / M$.
    (c) Set up OneIso.
    (d) Line up use exact bar holder and insert pinpoint chamber.
    (e) Line up with lasers and light fields.
    (f) Load patient QA.
    (g) Add CBCT by adding imaging and CBCT before field.
    (h) Perform auto-matching with ROI of the drum.
    (i) Move phantom.
    (j) Reacquire CBCT and evaluate displacement to see if realignment is required.
    (k) Reset electrometer and deliver all the fields.
    (l) Repeat measurement if necessary.
    (m) Calculate dose to ion chamber - the collected charge to chamber ($M_{patient}$) with correction factor (C) applied: $D_{patient} = M_{patient} \times C$.

4 Film Measurement

The following section outlines how to perform film measurements.

1. Creating verification plan for delivery.

    (a) Select Structure Set that contains the contours of the OneIso.

        i. Body Structure

        ii. Couch Structure
        iii. High Density Structure (overridden to appropriate HU)
    (b) Calculate the dose to the phantom using Acuros® XB.
    (c) Export dose plane by selecting correct dose plan (in correct orientation).

2. Performing measurements.
    (a) For daily output, perform the following steps. Note: this is performed for FilmQA Pro (Gafchromic EBT-XD film (Ashland Advanced material, Bridgewater, NJ).
        i. Solid water with film.
        ii. Put solid water phantom on couch - 10 cm back scatter with 2.4 cm buildup for 10 FFF.
        iii. Prescribe a field - size 10×10 cm^2 and 100 cm SSD.
        iv. Go to Service Mode.
        v. Deliver a 10×10 cm^2 field with the appropriate energy and dose rate (ie. if you are expecting 2400 cGy, then deliver 2400 cGy in the solid water).
        vi. Pack-up solid water.
    (b) Set up OneIso.
    (c) Line up use exact bar holder and insert film insert - do not include film.
    (d) Line up with lasers and light fields.
    (e) Load patient QA.
    (f) Add CBCT by adding imaging and CBCT before field.
    (g) Perform auto-matching with ROI of the drum.
    (h) Move phantom.
    (i) Reacquire CBCT and evaluate displacement to see if realignment is required.
    (j) Remove film insert and place film in cutout,shown in Figure 3 (B).
    (k) Reinsert film insert.
    (l) Deliver all the fields.
    (m) Scan film and perform Gamma Analysis based on the procedure used at your institute.

5 Off-axis Winston Lutz Test

The following section outlines how to perform off-axis Winston Lutz measurements.

1. Import the plan from the following link.

(a) Ensure Import/Export Configuration is set up to map a Machine ID of HD_TrueBeam (case sensitive) onto a local machine with an HD MLC with the appropriate energy.

(b) Open the patient and series that contain your scanned OneIso Phantom in the Off-Axis Winston Lutz configuration.

(c) Under File → Import, import the downloaded Winston Lutz Plan by selecting the appropriate Import Filter and following the Import Wizard prompts. Be sure to import the plan into the patient which contains your scanned OneIso Phantom.

(d) The plan will be in 3rd Party Approval Status, which needs to be changed to Unapproved.

(e) Assign the OneIso Phantom Structure Set to this plan by Right Clicking on the plan → Assign Structure Set.

(f) Align the isocenter of the plan to the central BB as accurately as possible. This can be achieved in various ways.

   i. Navigate your viewing planes to the central BB.

   ii. Window and level the display to show only the high HU of the central BB.

   iii. Zoom in and refine alignment of the viewing planes to the central BB in all 3 dimensions.

   iv. Once aligned, Right Click on the User Origin → Set Origin → Set to Predefined Target → Viewing Plane Intersection.

   v. Manually type in 0, 0, 0 cm into the x, y, z field positions to align the isocenter to the central BB.

(g) By linking the imported plan to the new OneIso CT/Reference set, the MUs will need to be repopulated. Simply, calculate the Plan with Preset MUs (SHIFT + F5). As a check, the MUs for static fields should be 50, dynamic fields 250.

2. Create DRRs from your CT scan.

   (a) Right Click on any Field → New DRR. For optimal software analysis, manually adjust the Parameters for the DRR to:

      i. CT Window from 500HU to 4000HU;

      ii. Uncheck Clipping; and

      iii. Check Apply to all Fields.

   Depending on scan acquisition and image quality, these parameters might need to be adjusted. Ensure that DRRs show only the BBs and BBs are smooth and round.

3. Deliver the plan.

   (a) Add an appropriate Tolerance Table and Treatment Time for each field and Plan Approve the plan (easiest to do in the Treatment Preparation Workspace).

(b) Schedule the appropriate imaging templates in the Plan Scheduling Workspace; namely Dosimetry or Integrated Mode imaging for treatment fields and MV/kV/CBCT imaging fields for the set up fields.

(c) Export the plan for delivery in File Mode to a desired location. File → Export and select the appropriate Export Filter. Be sure to include the reference images for IGRT at treatment and to be used in the analysis.

> **NOTE**: *Delivery in Clinical QA Mode is also possible, but captured EPID images would need to be manually exported after delivery. With File Mode, captured images are stored in a timestamped folder for ease of access.*

(d) Mode up the plan on the appropriate machine in either File Mode or QA Mode.

(e) Position OneIso as per the previous instructions and initiate IGRT with kV/kV matched set-up fields and CBCT. Once the central BB is aligned, confirm with a matched MV/MV pair using the treatment energy to verify central BB is still well centered.

(f) Deliver the full plan capturing EPID dosimtery or integrated mode images for each field.

4. Use software to analyze the delivered fields.

6 Optical Surface Mapping Measurement

In this section of the users guide, we will outline the procedure to perform the optical surface mapping measurements.

1. Contour the body of the OneIso and carefully review in the treatment planning system.

2. Export plan to the optical surface mapping system.

3. Performing the measurements.

4. Setup the OneIso with onboard imaging (Ground Truth).

5. Determine the deviation between the DICOM reference surface and the OneIso surface on the couch using your optical surface mapping system.

6. After the deviation between two isocenters is recorded, tilt the legs which extends out from the back of the phantom (shown in Figure 1) to verify the pitch angle for the optical surface mapping system.

7 Summary

In this user guide, we have outlined the many QA tasks OneIso can facilitate in an *"all-in-one"* QA phantom for a linear accelerator-based single-isocenter, multitarget cranial radiosurgery system.

The OneIso provides improved positioning verification and accurate dosimetry suitable for SRS QA measurements critically needed to commission a frameless SIMT cranial SRS program. This phantom and associated image analysis software will facilitate the commissioning and periodic QA of a multitarget frameless VMAT radiosurgery program, where specific metrics can be reliably reproduced enabling clinical translation of this highly sought-after workflow solution.

For more information, please feel free to contract Amy Yu (amysyu@stanford.edu). Publications based off this work, describing the methods and development of the OneIso, are described previously in the following studies [1, 3].

References

[1] DPI Capaldi, LB Skinner, P Dubrowski, and AS Yu. An integrated quality assurance phantom for frameless single-isocenter multitarget stereotactic radiosurgery. *Physics in Medicine & Biology*, 2020.

[2] K Bush, IM Gagne, S Zavgorodni, W Ansbacher, and W Beckham. Dosimetric validation of acuros® xb with monte carlo methods for photon dose calculations. *Medical physics*, 38(4):2208–2221, 2011.

[3] AS Yu, TL Fowler, and P Dubrowski. A novel-integrated quality assurance phantom for radiographic and nonradiographic radiotherapy localization and positioning systems. *Medical physics*, 45(7):2857–2863, 2018.