Simultaneous Optimization of Radiation-Imaging Coincidence for a Multi-Energy Linac

Cory Knill, Raminder Sandhu, Robert Halford, Michael Snyder[1], Danielle Lack[2]

Department of Radiation Oncology, Beaumont Health, Dearborn, [1]Department of Radiation Oncology, Beaumont Health, Royal Oak, [2]Department of Radiation Oncology, Beaumont Health, Troy, Michigan, USA

Abstract

Introduction: Medical physics guidelines stress the importance of radiation-imaging coincidence, especially for stereotactic treatments. However, multi-energy linear accelerators may only allow a single imaging isocenter. A procedure was developed to simultaneously optimize radiation-imaging isocenter coincidence for all linac photon energies on a Versa HD. **Materials and Methods:** First, the radiation beam center of each energy was adjusted to match the collimator rotation axis using a novel method that combined ion chamber measurements with a modified Winston-Lutz (WL) test using images only at gantry, couch, and collimator angles of 0°. With all energies properly steered, an 8-field WL test was performed to determine average linac isocenter position across all energies, gantry, and collimator angles. Lasers and the kV imaging isocenter were calibrated to the average linac isocenter of all photon energies. Finally, A 12-field WL test consisting of gantry, couch, and collimator rotations was used to adjust the couch rotation axis to the average linac isocenter, thereby minimizing overall radiation-imaging isocentricity of the system. **Results:** Using this method, the beam centers were calibrated within 0.10 mm of collimator rotation axis, and linac isocenter coincidence was within 0.20 mm for all energies. Couch isocenter coincidence was adjusted within 0.20 mm of average linac isocenter. Average radiation-imaging isocentricity for all energies was 0.89 mm (0.80–0.98 mm) for a single imaging isocenter. **Conclusion:** This work provides a method to adjust radiation-imaging coincidence within 1.0 mm for all energies on Elekta's Versa HD.

Keywords: Image-guided radiotherapy, isocentricity, linac, stereotactic body radiation therapy, stereotactic radiosurgery

INTRODUCTION

The utilization rate for linac-based stereotactic body radiation therapy (SBRT) and stereotactic radiosurgery (SRS) for cancer treatment has increased throughout the 21st century.[1-4] Characterized by conformal doses and small margins, SBRT/SRS treatments are able to deliver precise doses to targets in fewer fractions compared with conventional radiotherapy options.[5] Medical physics practice guidelines address the need for heightened precision by creating tighter tolerances for machines that are being used for SRS/SBRT.[6] One such tolerance is the requirement that the onboard imaging system, used to align the patient, coincides with the radiation isocenter within 1 mm. Borzov *et al.* have shown that the ± 1.0 mm tolerance is reasonable to preserve the dosimetric delivery accuracy of SRS/SBRT.[7]

Achieving coincidence of the radiation and imaging isocenter can be challenging on modern linear accelerators. This is due to the multiple photon energies available as well as the ability to use flattening filter-free beams which must all coincide with a single imaging isocenter. Cross-energy calibration on Elekta's Versa HD (Elekta AB, Stockholm, Sweden) is of particular importance due to its larger gantry sag of 1.0 mm compared with 0.5 mm on Varian's TrueBeam (Varian Medical Systems, Pal Alto, CA).[8-11] The isocenter movement of 1.0 mm on the Versa HD corresponds to a ± 0.5 mm drift in radiation isocenter, which amounts to half the 1.0 mm tolerance of the radiation-imaging isocenter coincidence for SRS/SBRT. Zhang *et al.* attempted to reduce the spread between the energies on an Elekta Versa HD using software included with the linac (Flexmap Wizard) to guide beam steering.[12] They were

Address for correspondence: Mr. Cory Knill,
Department of Radiation Oncology, Beaumont Health, 18101 Oakwood,
Dearborn, Michigan 48124, USA.
E-mail: knillcor@gmail.com

Access this article online

Quick Response Code:

Website:
www.jmp.org.in

DOI:
10.4103/jmp.JMP_7_21

---

able to achieve radiation-imaging coincidence of <1.5 mm for all energies, which was within their clinical tolerance.

Part of the difficulty in achieving a < 1.0 mm radiation-imaging isocenter coincidence across all energies is that this specification is not guaranteed by the linac manufacturers, and as such, there is no formal calibration procedure. With no direction from the vendors, it is left to physicists to develop a procedure. In clinical practice, this calibration is best implemented with the installation engineer, prior to acceptance. However, there can often be hesitation from the installation engineer when asked to perform a calibration outside their agreed-upon scope of work. Furthermore, if the physicist is unfamiliar with the procedure and its associated limitations, it may result in the physicist asking the engineer to achieve unrealistic tolerances. Therefore, in this work, a formal procedure was developed to perform cross-energy isocenter calibrations during Versa HD installations. The cross-energy calibrations were performed along with couch and imaging calibrations to reduce the overall radiation-imaging isocentricity of the Versa HD and this procedure along with its limitations is discussed.

MATERIALS AND METHODS

Calibration of the total radiation-imaging isocentricity of a machine is done by calibrating individual components. The following terms will be used to describe these individual components throughout this procedure:
1. Radiation beam center: Center of the radiation beam that is dictated by where the electron source beam strikes the photon-generating target
2. Collimator rotation axis: Mechanical center of the collimator rotation
3. Linac isocenter: Average radiation center of a beam over all gantry and collimator rotations
4. Couch rotation axis: Mechanical center of the couch rotation
5. Imaging isocenter: Location of imaging system center or isocenter calibration and laser calibration.

In this procedure, the radiation beam centers were adjusted to match the collimator rotation axis, followed by a calibration of the imaging isocenter to match the linac isocenter, and finally, the couch rotation axis was adjusted to match the linac isocenter.

Prior to adjusting the radiation beam centers to match the collimator rotation axis, the linac was calibrated closely to its final geometric and beam settings during initial customer acceptance testing. Briefly, this included: adjusting percent depth doses, profiles, collimator runout, and calibrating the multi-leaf collimators (MLCs) and jaws to within the installation customer acceptance specifications. Importantly, the collimator mechanical isocentricity was tested and the collimating head was adjusted to be within installation tolerances. With the linac close to clinical settings, the beam centers of each energy were steered to match the collimator rotation axis.

Steering radiation beam centers to match collimator rotation axis

At this point in a traditional linac calibration, beam center steering would be performed with a half-beam block (HBB) test. The HBB setup would consist of taping a cylindrical ion chamber (e.g., Farmer-type ion chamber) in the gun-target (GT) direction to a block tray at the central axis of collimator rotation [Figure 1a] for an off-center 10 cm × 10 cm field. The central axis of the farmer chamber is placed on the light-field crosshairs; small misalignments of the farmer chamber will not affect the overall result. One jaw is closed to the central axis to cover half of the field in either the gun or target direction and the opposing jaw remains open [Figure 1b]. A voltage is applied to the farmer chamber, 100MU is delivered with the collimator at 0°, and the resulting charge reading is recorded. The collimator is rotated 180° and the measurement is repeated. If the radiation beam center was perfectly aligned with the collimator rotation axis then, these two measurements would be the same.

If the two measurements were different, an adjustment would be needed to the beam center to align it with the collimator rotation axis. This would typically be done by changing the current in the steering coils (adjusting bending fine [BF] on a Versa HD), which moves the location where the electron beam strikes the target and consequently the center of the resulting photon beam. After adjustments, the HBB test would be repeated until the two measurements agree within some threshold (<0.5% is often used). Some drawbacks to the HBB measurements are that these adjustments can be time-consuming and will not give quantitative information of the distance between the beam centers and collimator axis. These drawbacks will become exacerbated when performing the HBB test for the five photon energies on the Versa HD.

In the proposed linac calibration, to reduce the beam steering time and provide quantitative information regarding the
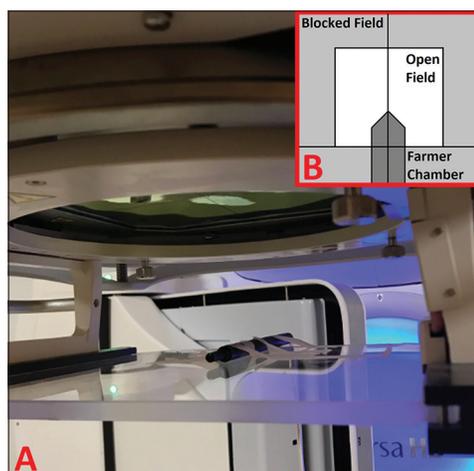

Figure 1: Half beam block setup for steering beam centers. (a) Farmer chamber is taped on a block tray at the central axis in the gun-target direction, (b) the collimator is closed to the central axis to block half the field

distance from the beam centers to the collimator axis, a second test, a modified version of the Winston-Lutz (WL) test using only images at gantry, couch, and collimator angles of 0°, was introduced into the calibration procedure.[13-15] By analyzing the WL images, the deviation between a BB, placed in the field, and the radiation beam centers could be determined (henceforth known as the BB-beam center deviation). The goal was to collect HBB measurements and BB-beam center deviations for various values of BF and correlate the results of the two tests to find the ideal BF settings needed for the BB-beam center deviation to match the HBB measurements. Adjustments could then be made to BF and the BB-beam center deviation could quickly be re-measured to providing quantitative information of the radiation-collimator alignment.

First, a HBB measurement was performed, using a Standard Imaging (Middleton, WI) Exradin A12 Farmer-Type Ion Chamber, for all five photon energies at collimator angle 0° without performing any beam adjustments. Next, four additional measurements were acquired for each energy with the BF parameter adjusted ± 0.1 and ± 0.2 around the starting value. To quickly change BF, without effecting the stored clinical beam, a 100MU beam should be started and quickly interrupted during the initial ~1 s warm-up period prior to any delivery of radiation. Then the BF parameter can be changed on the steering page, and the beam will deliver with the new BF parameter. After delivery, the beam will revert to its original stored value for BF. After acquiring 5 HBB measurements at collimator 0° for each photon energy, the collimator was rotated 180° and the measurements were repeated. Finally, the HBB percent differences between 0° and 180° were calculated for each energy and BF setting for a total of twenty-five results for the five photon energies.

Next, the HBB setup was completely removed, and a BB was placed close to collimator axis using the light-field crosshairs as a guide. A square field was used to acquire portal images of the BB on the Versa HDs onboard MV imaging system (iView) at gantry and collimator angles of 0°. Twenty-five portal images were acquired with various energies and BF parameters to match the HBB measurements. After each portal image, the beams revert to their original stored value for BF as described in the previous paragraph. The portal images were exported to Sun Nuclear's SNC machine v1.3 (Sun Nuclear Corporation, Melbourne, FL) software as DICOM files, which processed the portal images to determine the BB-beam center deviation for each image.

The deviations in the GT direction were plotted against the results of the HBB test for the five energies and modeled with a linear regression [Figure 2]. From the definition of the HBB test, if the difference between the two HBB measurements (for collimator 0° and 180°) is zero percent, the beam is perfectly aligned with the collimator axis. Therefore, the linear regression can be solved to determine the desired BB-beam center deviation needed to achieve perfect alignment between the beam centers and collimator rotation axis. It is important
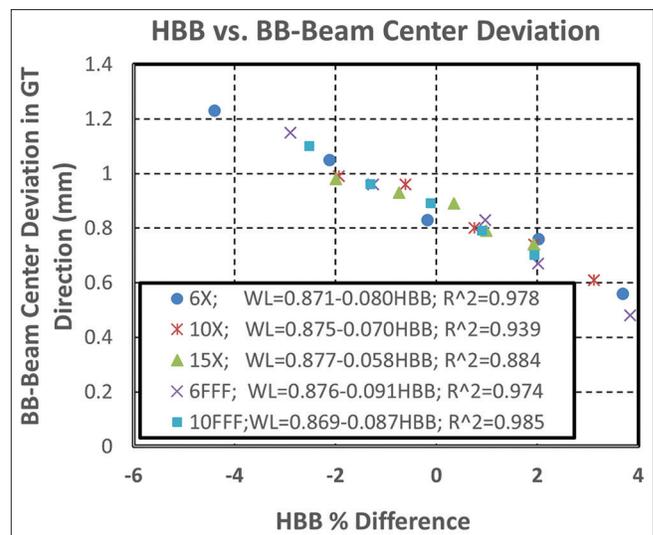

Figure 2: Correlating half beam block measurements with BB-beam center deviation results in the gun-target direction for Versa HD photon energies (6X, 10X, 15X, 6FFF, and 10FFF). The 0.0% half beam block result corresponding to 0.87 mm is the desired beam block-beam center gun-target deviation

to note that if the BB was perfectly placed at the collimator rotation axis, the desired BB-beam center deviation would be a distance of 0.0 mm. However, since the Beam block was placed close to the collimator rotation axis using the light field, the desired BB-beam center deviation to achieve perfect radiation-collimator alignment will likely be non-zero. As the BB will likely not be placed perfectly at the collimator rotation axis, no adjustment should be made to the collimating jaws to match the BB position. In this instance, the average desired BB-beam center deviation over all energies, corresponding to a HBB measurement of zero percent, was 0.87 mm [Figure 2].

To adjust the beam centers to match the collimator rotation axis, the bending magnets were adjusted by the service engineer using the "BF" setting on the linac, and another portal image was acquired and processed using SNC Machine. This procedure was repeated until the SNC Machine reported BB-beam center deviation in the GT direction was sufficiently close to the ideal value determined from the linear regression (0.87 mm for this calibration). After BF adjustments, the BB was removed and the symmetry of the beam was checked using Sun Nuclear's IC Profiler (Sun Nuclear Corporation, Melbourne, FL). If large adjustments in BF are made for a given energy, a corresponding symmetry adjustment may be necessary.

Calibrating imaging isocenter to match linac isocenter

Following the profile symmetry checks, the BB was placed back near isocenter using the light field and a 3-dimensional WL test was performed for all energies to determine their respective linac isocenters. This test utilized the Elekta provided Flexmap Wizard beam sequence, which included portal images at the four cardinal gantry angles with two collimator angles, 180° apart, for a total of 8 portal images. The different gantry angles were needed to account for gantry

sag, while the collimator angles were needed to nullify the effects of collimator misalignment. All portal images were acquired using iView and processed through SNC Machine, which computed the offset between the BB and linac isocenter for each energy.

With the linac isocenter position for each photon energy determined, it was decided to calibrate the lasers and kV imaging system to the average of all the energies. Some other possible options include calibrating to the average of the energies used for SRS/SBRT or the most commonly used energies. In this work, the average position was selected to determine the overall radiation-imaging isocentricity achievable across all energies simultaneously.

Once the selection was made, micrometers on the Elekta provided BB jig were used to move the BB to the average linac isocenter position using the shifts derived from SNC Machine. Additional 8-field WL portal images were acquired and processed through SNC Machine to ensure the BB was moved correctly relative to its original location. After verifying the BB was in the correct location, the Elekta Flexmap Wizard was run to calibrate the imaging isocenter to the BB location, which corresponds to the average linac isocenter location for all photon energies.

After imaging calibration, the lasers were adjusted to match the external lines on the BB jig. It should be noted that the lines on the BB jig may not be perfectly aligned to the BB. When the BB jig is initially delivered to the facility, it is recommended to place small copper wires on the external lines and acquire kV images using either the kV imager on the Versa HD or topograms from a department CT. The wires and BBs will both be visible on the planar images and the wire overlap at the centroid of the BB can be evaluated.

Adjusting couch rotation axis to match linac isocenter

The last step in the procedure was to adjust the couch rotation axis to match the linac isocenter. The location of the current couch rotation axis relative to the radiation-gantry isocenter was determined by performing a specialized Hancock WL test that is included in SNC Machine. The Hancock WL test involved acquiring twelve WL images with a specific combination of gantry, collimator, and couch rotations (5 couch angles were used: 270°, 315°, 0°, 45°, 90°). SNC Machine was used to analyze these portal images and it returned a report that states the offset between the couch rotation axis and linac isocenter. The reader is referred to the Sun Nuclear manuals for full details on how the software uses the portal images to calculate couch offset.

Alternatively, a couch runout test could have been performed by projecting the lasers (now calibrated to linac isocenter) onto a piece of paper on the couch and marking the laser position at various couch angles. If there is a deviation between the couch rotation axis and linac isocenter, the laser will trace a semicircle about the couch rotation axis.

The couch rotation axis was matched to the linac isocenter position by adjusting the couch support system. The couch sits on top of a tripod support system shown in Figure 3. The couch rotation axis was adjusted by turning the two bolts closest to the gantry according to Equations 1a and 1b. Similar equations for other couch types can be derived through theoretical calculations or empirical testing. After the couch was adjusted, the BB was repositioned at the linac isocenter using an 8-field WL test, and the Hancock WL test was re-run until the coincidence between the couch rotation axis and linac isocenter was satisfactory.

A bolt turns = (10.88 Table X – 10.48 Table Y) flats/cm (1a)

B bolt turns = −(10.88 Table X – 10.48 Table Y) flats/cm (1b)

Measuring radiation-imaging isocentricity

Finally, the radiation-imaging isocentricity of the system was characterized by analyzing WL portal images acquired at a subset of combinations of gantry, couch, collimator, and photon energies that were to be used for SRS/SBRT treatments with the BB located at imaging isocenter. In total, 18 combinations of gantry, collimator, and table (GCT) positions were performed: G180C270T0, G180C0T0, G180C90T0, G270C270T0, G270C0T0, G270C90T0, G0C270T0, G0C0T0, G0C45T0, G0C90T0, G0C315T0, G90C270T0, G90C0T0, G90C90T0, G0C0T45, G0C0T90C0, G0C0T315, G0C0T270. Additionally, the isocentricity was calculated for the following combinations of GCT positions: G180C0T45, G180C0T90, G180C0T315, G180C0T270. Since the number of permutations that need to be tested can become large, a smaller subset can be chosen for analysis according to clinical requirements. All WL portal images were acquired using iView and processed through SNC Machine to determine the deviation between the center of the BB and the center of the radiation field. The deviations in both directions of the image were combined to determine the Euclidian distance between the BB and the radiation field. The overall radiation-imaging isocentricity was specified as the largest Euclidian distance in any image for a given energy.

RESULTS

The results of the BF adjustment along with corresponding changes to the beam center position are shown in Figure 4. The ideal location for the BB, obtained from Figure 1, was 0.87 mm. All beams were calibrated within 0.10 mm of the collimator rotation axis.

For future measurements, the slopes of the correlations in Figure 4 can be used to estimate the necessary change in BF needed to adjust the beam center for each photon energy: 6X: 0.55 BF/mm, 6FFF: 0.50 BF/mm, 10FFF: 0.58 BF/mm, 15X: 0.75 BF/mm. BF adjustment was not performed for 10X during this initial testing, however, it was performed at a later date and found to be 0.67 BF/mm. The radiation-collimator isocentricity in the GT direction of all energies was calibrated within 0.10 mm.
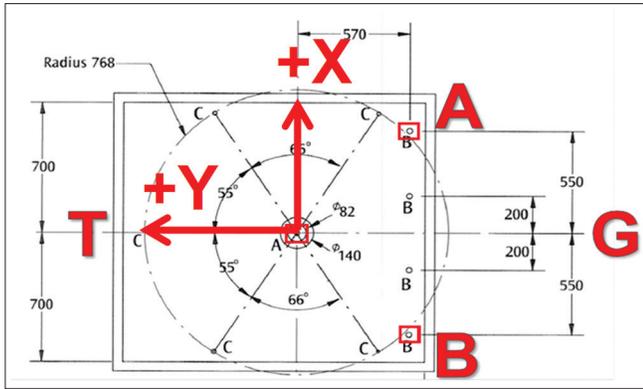
Figure 3: Versa HD couch schematic showing the location of adjustment bolts A and B. The gun (G) and target (T) directions are also labeled, while the up (U) and down (D) directions are not shown

The postbeam-adjustment three-dimensional linac isocenter locations, as determined by the 8-field WL tests, are shown in Table 1. The maximum Euclidian distance between any two isocenters was 0.20 mm (6FFF and 15X). The largest spread in the GT direction was 0.10 mm, which matches the 0.10 mm deviation that was measured during the aforementioned calibration.

The posttable-adjustment coincidence between the couch rotation axis and the linac isocenter position for each photon energy is shown in Table 1. The overall radiation-imaging isocentricity for all gantry, collimator, and couch angles of all energies was <1.0 mm.

DISCUSSION

Following this procedure, the beam centers were matched to within 0.10 mm in the GT direction. A similar procedure can be repeated to match the energy isocenters in the AB (left-right) direction. However, there is no easily adjustable parameter, like bending magnet current, which can steer the beam in the AB direction. Rather, if a discrepancy is found, the symmetry should be checked, followed by an examination of the beam startup.

Many of these measurements can be performed using the stored beam option in the Versa HD service mode. However, caution should be used when switching between energies in stored beams as there can be a hysteresis effect where the previously selected energy affects the current measurement. In the context of this procedure, this is particularly problematic when switching from a higher energy to a lower energy. Instead of starting from a low bending magnet current (bending magnet coarse parameter in service mode) and increasing the current to the appropriate value for the beam energy, as is done in clinical mode, the linac will drop the bending magnet current when switching from a higher energy to a lower energy in stored beams. Approaching the desired bending magnet current from a different direction can cause the beam center to shift. To prevent this issue, it is recommended to first load a field of the desired energy using the quick beam service page,
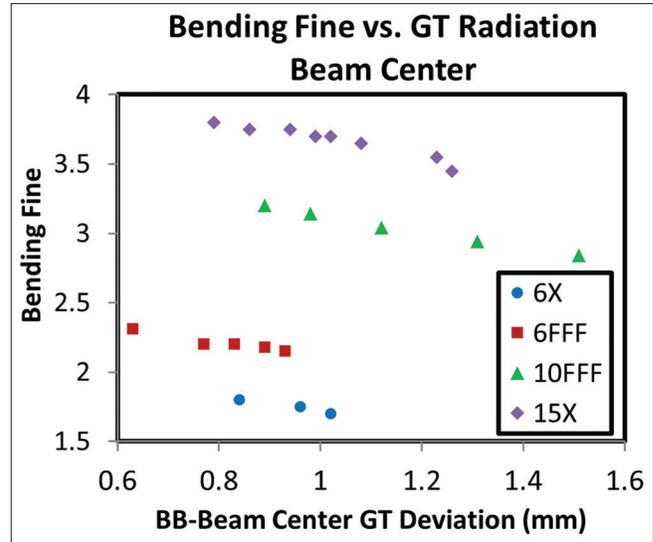

Figure 4: Iterative adjustment of bending fine to achieve the ideal BB-beam center gun-target deviation (0.87 mm). The 10X energy did not require adjustment

Table 1: Versa HD multi-energy isocentricity

	Linac (mm)			Couch (mm)		Overall radius (mm)
	AB	**GT**	**UD**	**Table X**	**Table Y**	
6X	0.04	0.00	0.08	0.15	−0.08	0.8
10X	0.02	−0.06	−0.01	0.1	0.12	0.88
15X	0.02	−0.01	−0.11	0.04	0.20	0.91
6FFF	−0.06	0.04	0.07	−0.15	−0.08	0.98
10FFF	−0.03	0.01	−0.01	−0.18	−0.06	0.87
Average	0.00	0.00	0.00	−0.01	0.02	0.89

WL results showing the linac isocenter coincidence across all energies, coincidence between the couch rotation axis and linac isocenter, and overall radiation-imaging coincidence for all gantry, collimator, and couch angles. AB: couch left-right, GT: linac gun-target, UD: couch up-down

prior to switching energies in the stored beams service page, particularly when switching from high to low energies. Loading a field of the desired energy in the quick beams service page, will mimic the bending magnet behavior of clinical mode and prevent the hysteresis behavior when switching back to stored beams.

The ideal location for the cross-energy isocenter calibrations was determined by correlating the results of the HBB test with the BB-beam center deviations for all energies. However, the main reason for performing the HBB measurements is to correlate the results with the BB-beam center deviations to find the GT deviation in the images that correspond to the collimator rotation axis. The collimator rotation axis is a mechanical property of the machine that should not change between energies. From Figure 2, the maximum difference in ideal BB deviation, corresponding to the collimator rotation axis, between energies was

Table 2: Versa HD isocentricity tolerances

Versa HD isocentricity tolerances		
	Tolerance A (mm)	Tolerance B (mm)
Beam center versus collimator rotation axis coincidence	0.20	0.1
Cross-energy linac isocenter coincidence	0.50	0.20
Linac isocenter versus couch rotation axis coincidence	0.50	0.25

Tolerance A: Easily achievable on all Versa HDs. Tolerance B: lower expected limit of what is achievable

0.008 mm. Therefore, to reduce calibration time, the HBB and BB-beam center deviation measurements can be performed for a subset of energies.

Various vendors manufacture BB jigs that attach to the couch and allow micrometer adjustments of the BB position in a specified direction. In practice, shifting the BB along one direction often leads to unwanted small changes in orthogonal directions. For example, moving the BB in the GT direction may inadvertently cause a shift in the AB direction. Alternatively, the six degrees-of-freedom Hexapod couch can be used to move the BB. It was found that the Hexapod couch can reproducibly move a BB within 0.10 mm of isocenter in all directions. Regardless of the movement method, care should be taken to level the couch and align it as close to angle 0° as possible to ensure translational couch movements correlate with the gantry coordinate system.

For the Versa HD tested in this study, it was possible to achieve <1 mm radiation-imaging coincidence for all energies. In practice, SRS/SBRT tolerances may only be maintained for selected energies on the treatment machine. Table 2 shows two tolerance levels for the individual steps of the described procedure. It is recommended that Tolerance A values be met for all energies that will be used for SRS/SBRT. Tolerance B values, which were achieved during commissioning, are the limits at which it is expected that any additional work may result in diminishing returns.

Furthermore, the shape and magnitude of inherent couch-wobble will vary between Hexapod couches. This may affect the achievable imaging-couch isocenter coincidence for a given linac. If an inherent couch wobble is large enough to prevent the calibration of all energies within the 1.0 mm SBRT/SRS tolerances, it is recommended that a subset of the energies be calibrated for SRS/SBRT or the couch be replaced.

Conclusion

A procedure was developed to calibrate the cross-energy radiation isocenter locations for all photon energies on multi-energy linac. It was implemented during commissioning of a Versa HD, where it was able to achieve the radiation-imaging coincidence tolerance of <1.0 mm for all energies. This work provides a framework to help physicists achieve SRS/SBRT tolerances in a simple and precise manner, eliminating much of the tediousness usually encountered when optimizing machine isocentricity.

Conflicts of interest
There are no conflicts of interest.

References

1. McClelland S 3rd, Degnin C, Chen Y, Watson GA, Jaboin JJ. Impact of the American Tax Payer Relief Act on stereotactic radiosurgery utilization in the United States. J Neurooncol 2019;145:159-65.
2. Sidiqi B, Sheth N, Lee A, Safdieh J, Schreiber D. Patterns of stereotactic radiotherapy utilization and fractionation for acoustic neuroma in the United States. J Radiosurg SBRT 2018;5:201-7.
3. Park HS, Wang EH, Rutter CE, Corso CD, Chiang VL, Yu JB. Shifts in Stereotactic Radiosurgery Platform Utilization for Brain Metastases in the United States. Int J Radiat Oncol Biol Phys 2015;93:E62.
4. Corso CD, Park HS, Moreno AC, Kim AW, Yu JB, Husain ZA, *et al.* Stage I lung SBRT clinical practice patterns. Am J Clin Oncol 2017;40:358-61.
5. Benedict SH, Yenice KM, Followill D, Galvin JM, Hinson W, Kavanagh B, *et al.* Stereotactic body radiation therapy: The report of AAPM Task Group 101. Med Phys 2010;37:4078-101.
6. Klein EE, Hanley J, Bayouth J, Yin FF, Simon W, Dresser S, *et al.* Task Group 142 report: Quality assurance of medical accelerators. Med Phys 2009;36:4197-212.
7. Borzov E, Nevelsky A, Bar-Deroma R, Orion I. Dosimetric evaluation of the gantry sag effect in clinical SRS plans. BJR Open 2019;1:20180026.
8. Rowshanfarzad P, Riis HL, Zimmermann SJ, Ebert MA. A comprehensive study of the mechanical performance of gantry, EPID and the MLC assembly in Elekta linacs during gantry rotation. Br J Radiol 2015;88:20140581.
9. Clivio A, Vanetti E, Rose S, Nicolini G, Belosi MF, Cozzi L, *et al.* Evaluation of the machine performance check application for TrueBeam Linac. Radiat Oncol 2015;10:97.
10. Du W, Gao S, Wang X, Kudchadker RJ. Quantifying the gantry sag on linear accelerators and introducing an MLC-based compensation strategy. Med Phys 2012;39:2156-62.
11. Rowshanfarzad P, McGarry CK, Barnes MP, Sabet M, Ebert MA. An EPID-based method for comprehensive verification of gantry, EPID and the MLC carriage positional accuracy in Varian linacs during arc treatments. Radiat Oncol 2014;9:249.
12. Zhang Y, Ding K, Cowan G, Tryggestad E, Armour E, Wang KK. Alignment of multiradiation isocenters for megavoltage photon beam. J Appl Clin Med Phys 2015;16:314-24.
13. Lutz W, Winston KR, Maleki N. A system for stereotactic radiosurgery with a linear accelerator. Int J Radiat Oncol Biol Phys 1988;14:373-81.
14. Wootton P, Almond PR, Holt JG, Hughes DB, Jones D, *et al.* Code of practice for x-ray therapy linear accelerators. Medical Physics, 1975;2: 110-21.
15. Narayanasamy G, Saenz D, Cruz W, Ha CS, Papanikolaou N, Stathakis S. Commissioning an Elekta Versa HD linear accelerator. J Appl Clin Med Phys 2016;17:179-91.