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Off-Isocenter Winston-Lutz Test for Stereotactic Radiosurgery/Stereotactic Body Radiotherapy

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Abstract

The single-isocenter technique in linear accelerator-based stereotactic radiosurgery/stereotactic body radiotherapy (SRS/SBRT) has been broadly used to treat multiple lesions. However, quantitative study to verify that the mechanical field center coincides with the radiation field center when both are off from the isocenter has never been performed. We developed an innovative method to measure this accuracy, called the off-isocenter Winston-Lutz test, and here we provided a practical clinical guideline to implement this technique. We used ImagePro V.6 to analyze images of a Winston-Lutz phantom obtained using a Varian 21EX linear accelerator with an electronic portal imaging device, set up as for single-isocenter SRS/SBRT for multiple lesions. We investigated asymmetry field centers that were 3 cm and 5 cm away from the isocenter, as well as performing the standard Winston-Lutz test. We used a special beam configuration to acquire images while avoiding collision, and we investigated both jaw and multileaf collimation. For the jaw collimator setting, at 3 cm off-isocenter, the mechanical field deviated from the radiation field by about 2.5 mm; at 5 cm, the deviation was above 3 mm, up to 4.27 mm. For the multileaf collimator setting, at 3 cm off-isocenter, the deviation was below 1 mm; at 5 cm, the deviation was above 1 mm, up to 1.72 mm, which was 72% higher than the tolerance threshold. These results indicated that the further the asymmetry field center is from the machine isocenter, the larger the deviation of the mechanical field from the radiation field, and the distance between the center of the asymmetry field and the isocenter should not exceed 3 cm in our clinic. We recommend that every clinic that uses linear accelerator, multileaf collimator-based SRS/SBRT perform the off-isocenter Winston-Lutz test in addition to the standard Winston-Lutz test and use their own deviation data to create planning guideline.

Keywords

Off-Isocenter Winston-Lutz Test, SRS, SBRT

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1. Introduction

With the rapid development of highly accurate image guidance technology for both hardware and software and multiple published reports such as American Association of Physicists in Medicine Task Groups (AAPM TG) [1]-[3] and the American Society for Radiation Oncology (ASTRO) [4] [5] in the past decade, stereotactic radiosurgery/stereotactic body radiotherapy (SRS/SBRT) has advanced from a specialty procedure performed only at comprehensive university medical centers to a widely accepted treatment regimen adopted by most radiation oncology clinics worldwide. The delivery of SRS/SBRT has also diversified from dedicated machines such as the gamma knife or cyber knife units to all-purpose machines such as linear accelerators, tomotherapy units, or even proton therapy units. Patient immobilization is accomplished using methods ranging from invasive frame-based devices to frameless devices. Treatment sites that can be targeted by SRS/SBRT have also expanded from the cranium, spine, lung, and liver to the gastrointestinal tract and even the genitourinary tract (with hypofractionation). Every year, research relating to SRS/SBRT is the topic of hundreds of publications and dozens of national and international seminars and conferences.

Among all topics relating to SRS/SBRT, the precision of treatment delivery is always the most heavily discussed and researched. This precision depends on not only the treatment machine and image-guided radiotherapy tools used, but also the location and number of lesions. About half of patients who receive SRS/SBRT for metastatic brain lesions are being treated for more than one lesion [6]. This creates a big challenge for treatment delivered on isocentric units such as linear accelerators. It is unclear whether linear accelerator-based systems should deliver SRS/SBRT to multiple lesions using a single isocenter or multiple isocenters, and this has become an important topic of discussion in some publications and student theses [7] [8]. The arguments in favor of each technique are nearly equal. Recently, because of the associated ease in treatment planning and patient setup, reduced treatment times and availability of commercial planning system, many clinics have opted to use the single-isocenter technique to treat multiple lesions. However, so far no quantitative medical physics study has been performed to generate guidelines for the appropriate criteria to maintain the accuracy of this technique.

The Winston-Lutz test, originally proposed by Lutz, Winston, and Maleki at Harvard Medical School in 1988 [9], is a very popular and well-known test to verify that the radiation isocenter coincides with the mechanical isocenter in a linear accelerator-based SRS system. The test was originally developed to use very complicated film-based measurements that were dependent on the observer's measurement skill [1], but it later progressed to electronic portal imaging device (EPID)-based measurements that were easy to obtain using commercial software. This had become easy implemented after Rowshanfarzad *et al*. wrote a broad review of the test [10] and Childress *et al*. delineated a practical method to perform an EPID-based Winston-Lutz test in linear accelerator systems [11]. However, the standard Winston-Lutz test focuses only on the machine isocenter; it cannot accurately determine whether the center of the mechanical field (which is represented by the light field) and the center of the radiation field coincide when both are off from the isocenter (*i.e.*, an asymmetric field). The accuracy of this measurement is critical for the plan designer to decide whether the single-isocenter or multiple-isocenter technique should be used to treat multiple lesions.

The purpose of the current study was to perform a quantitative investigation of the accuracy of the single-isocenter treatment technique which is the off-isocenter Winston-Lutz test. To develop this technique, we measured the offset between the center of the mechanical field and the center of the radiation field when both were away from the isocenter of the linear accelerator when multiple lesions were being treated (single-isocenter SRS/SBRT treatment technique). This off-isocenter Winston-Lutz test, to the best of our knowledge, is the first time developed to measure this offset. The Linac in our clinic was calibrated follow TG-142 and Practical Radaiton Oncology (PRO) guideline. The detection accuracy of EPID image system is less than 1 mm; the frameless SRS head set (from Civco company) accuracy is within submillimeter. The overall accuracy of current method is still within submillimeter. Therefore the off-isocenter Winston-Lutz test is highly reliable method to measure the offset. The findings from the current study provide very practical clinical guidelines for the SRS/SBRT procedure. These guidelines directly impact radiation oncologists, physicists, and dosimetrists involved in the plan design and beam selection for SRS/SBRT for multiple lesions. Given the clinical significance and easy implementation of the off-isocenter Winston-Lutz test, we recommend that all medical physicists who perform linear accelerator-based SRS/SBRT implement this test in addition to the standard Winston-Lutz test during periodic machine quality assurance routines and before each procedure. This will help physicists provide solid data to help radiation oncologists and dosimetrists with the plan design. We also recommend that the off-isocenter Winston-Lutz test be included as a supplement to the current standard Winston-Lutz test in future updates of the AAPM TG-142 and TG-101 reports and the ASTRO SRS/SBRT report.

2. Materials and Methods

The off-isocenter Winston-Lutz test was developed as sketched in **Figure 1**. Targets 1, 2, and 3 represent three lesions under the beam. C1 is the mechanical field center of target 1 and could be the center of the lesion. d_1 is the distance from the machine isocenter to the center of the mechanical field shown in target 1. The solid lines represent the radiation field boundary. We performed the off-isocenter Winston-Lutz test on a Varian 21EX linear accelerator with an EPID and BrainLab ExacTrac image guidance system. The specification meet TG-142 SRS/SBRT requirement. The light field and radiation field consistency for asymmetric field is 1 mm. The couch position indicator is 1 mm. The Off ISO Winston-Lutz test is designed as **Figure 2**. The machine systemic and random setup error in the off-isocenter geometry (b) and (c) can be eliminated when we compare results from (b) and (c) to resuts from isocenter geometry (a) which is for standard Winston-Lutz test. Our SRS/SBRT final beam shaper was a 120-leaf Millennium multileaf collimator (MLC). In our clinical practice, a jaw collimator and an MLC are the primary and secondary collimators used in SRS/SBRT procedures; we do not use cone. The Winston-Lutz phantom, obtained from Sun Nuclear Corporation, had 8-mm steel spheres embedded at the center of a 6-cm plastic cube (to avoid computed tomography artifacts), as well as crosshairs and setup markers on all sides to allow quick alignment with the mechanical isocenter. We used the Varian ARIA V.11 planning system and ImagePro V.6 image analysis tool (Sun Nuclear Corporation).

The Winston-Lutz phantom was scanned using GE 16 slices CT and imported into Varian Eclipse. Owing to high monitor units per fraction during the patient treatment, both jaw collimator and MLC mechanical accuracy are very important. For our jaw collimator, the in-house criterion for passing the Winston-Lutz test is 2.5 mm.

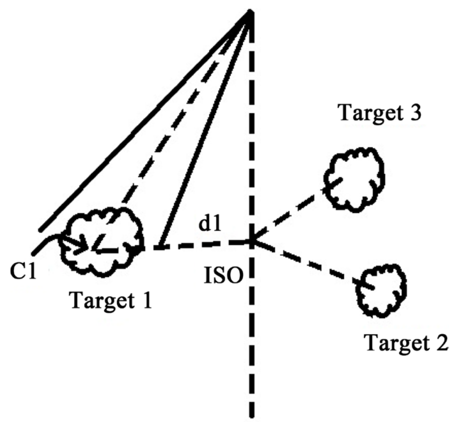

Figure 1. Sketch of the off-isocenter Winston-Lutz test for treating multiple lesions in a setup with a single isocenter.

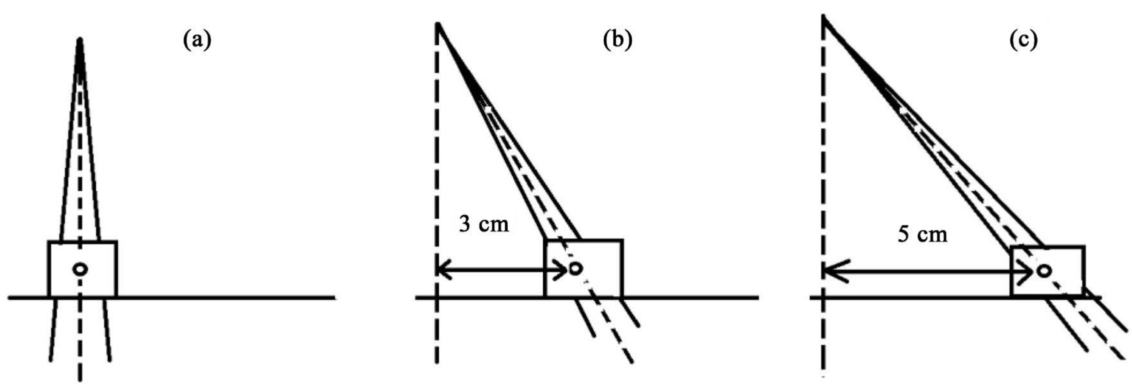

Figure 2. Sketches of the three types of plans used for the jaw and multileaf collimators for the off-isocenter Winston-Lutz test, in which the asymmetric field is 0 cm (a), 3 cm (b), or 5 cm (c) from the machine isocenter.

For the MLC, we adopted the AAPM TG-142 report and ASTRO report criteria of 1 mm to pass the Winston-Lutz test. To compare the accuracy of the symmetric field in standard Winston-Lutz test with that of the asymmetric field in off isocenter Winston-Lutz test, we created test plans with eight beams collimated either by the jaw collimator or the MLC (3 plans each; see below). We placed the Winston-Lutz phantom on three different locations as show in **Figure 2** and aligned it with the center of the mechanical field. For each plan, radiation beams were created to follow the phantom position, and the center of each radiation field was designed to be consistently coincident with the center of the metal sphere inside the phantom. A proper configuration of the gantry, collimator, and couch rotational angle was chosen with care to ensure that the centers coincided but did not collide. We then delivered each plan with EPID and exported the images from the image browser to ImagePro. Data analysis was performed using ImagePro in the daily clinic.

As noted above, three plans were created each for the jaw collimation test and for the MLC test (**Figure 2**). The field size in all test plans was 3 cm × 3 cm. **Figure 2(a)** represents the standard Winston-Lutz test in which the phantom is placed on the machine isocenter and the gantry angle, collimator angle, and couch angle are configured to avoid collision only. We used this test as a baseline to show not only the offset of the machine radiation isocenter from the mechanical isocenter, but also the uncertainty caused by the centroid isocenter defined by the treatment planning system, CT slice width effects, digital image analysis, and other variables. **Figure 2(b)** shows the off-isocenter Winston-Lutz test mechanism, in which the center of radiation field, center of the mechanical field, and center of the phantom are all 3 cm away from the central axis of the linear accelerator. **Figure 2(c)** shows a very similar off-isocenter Winston-Lutz test in which the distance is 5 cm instead of 3 cm. The test plans shown in **Figure 2(b)** and **Figure 2(c)** mimic real clinical treatment of target 1 in **Figure 1** when multiple lesions are treated using the single-isocenter technique. Our linear accelerator used the Varian coordinate system; the eight beams are configured as shown in **Table 1**.

3. Results

Figure 3 shows one sample of our measurement results from the jaw collimation Winston-Lutz test with $d_1 = 0$ cm, 3 cm, and 5 cm. In the inlet in each image, Δu is offset in the vertical direction and Δv is offset in the horizontal direction; total $\Delta = \sqrt{\Delta u^2 + \Delta v^2}$. Each beam configuration is labeled at the top of the inlet. For example, G180C90T90_3 cm indicates gantry angle = 180˚, collimator angle = 90˚, table angle = 90˚, and $d_1 = 3$ cm. The measurement results are summarized briefly at the top of each figure. **Figure 4** shows one sample of our measurement results from the MLC Winston-Lutz test with $d_1 = 0$ cm, 3 cm, and 5 cm. All notations are the same as in **Figure 3**. For better visualization, we plotted only the total Δ against d_1, which is the phantom distance from the machine isocenter for each beam configuration in **Figure 5**. **Figure 5(a)** shows the plot for the jaw collimation and (b) shows the plot for the MLC collimation.

Case study: One 79 years old female patient whose diagnosis is secondary malignant neoplasm of brain has five lesions in her brain as show in **Figure 6**. The patient underwent a radical renalectomy for a localized renal cell carcinoma. She had no adjuvant chemotherapy or radiation therapy based on an assessment of local disease. Nineteen years later she developed mild ataxia with difficulty writing and swimming. The CT and MRI image revealed five various size tumor from 0.5 cm to 1.2 cm in length in her right brain. After Neurosurgeon and radiation oncologist assessment, physician decided the SRS is best option for this patient and the patient also ac-

Table 1. Beam configuration used for the off-isocenter Winston-Lutz test in our study[a].

Beam no.	Gantry, ˚	Collimator, ˚	Couch, ˚
1	180	180	180
2	90	180	180
3	0	180	180
4	270	180	180
5	180	135	135
6	180	90	90
7	180	225	225
8	180	270	270

[a]The phantom was located 3 cm, or 5 cm from the central axis of the linear accelerator.

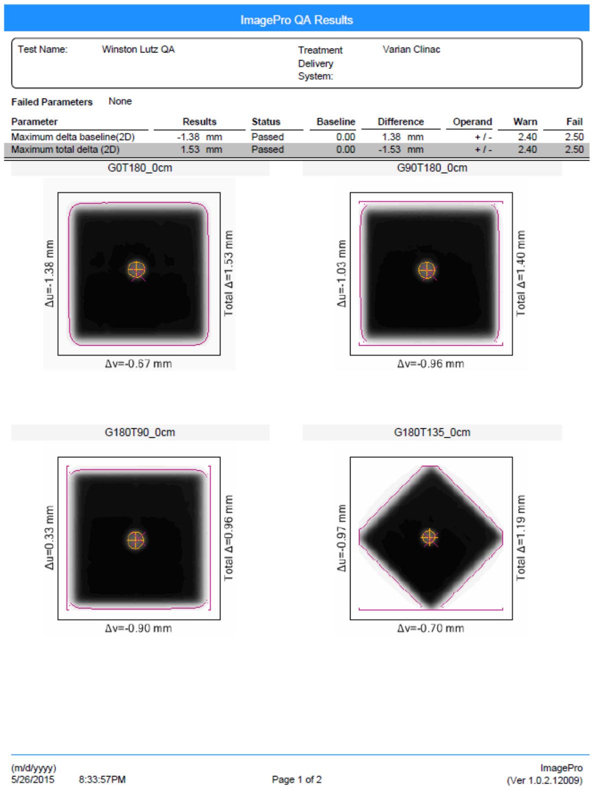

Figure 3. One sample of image analysis of the jaw collimation measurement results.

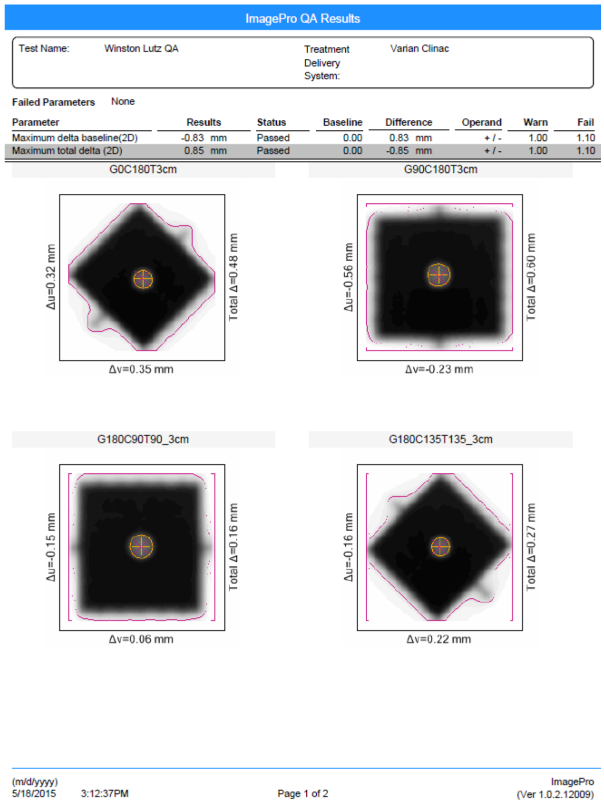

Figure 4. One sample of image analysis of the multileaf collimation measurement results.

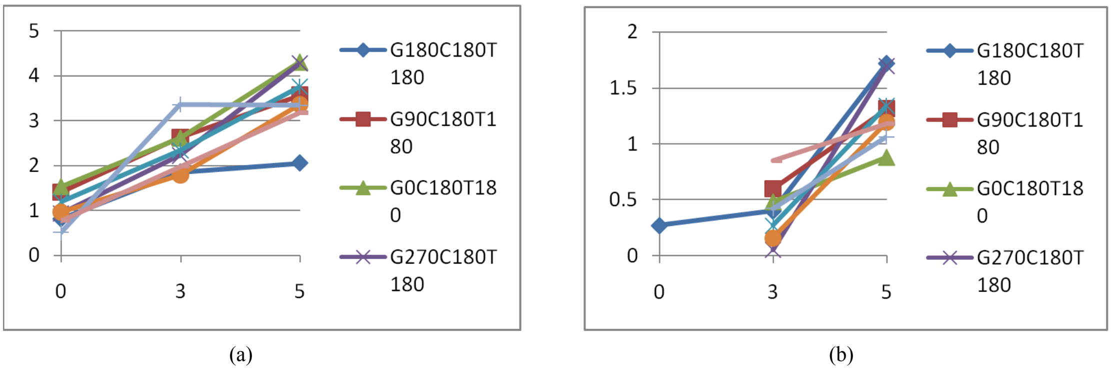

Figure 5. (a) Total Δ for d_1 = 0 cm, 3 cm, and 5 cm for the jaw collimation Winston-Lutz test. (b) Total Δ for d_1 = 0 cm, 3 cm, and 5 cm for the MLC collimation Winston-Lutz test.

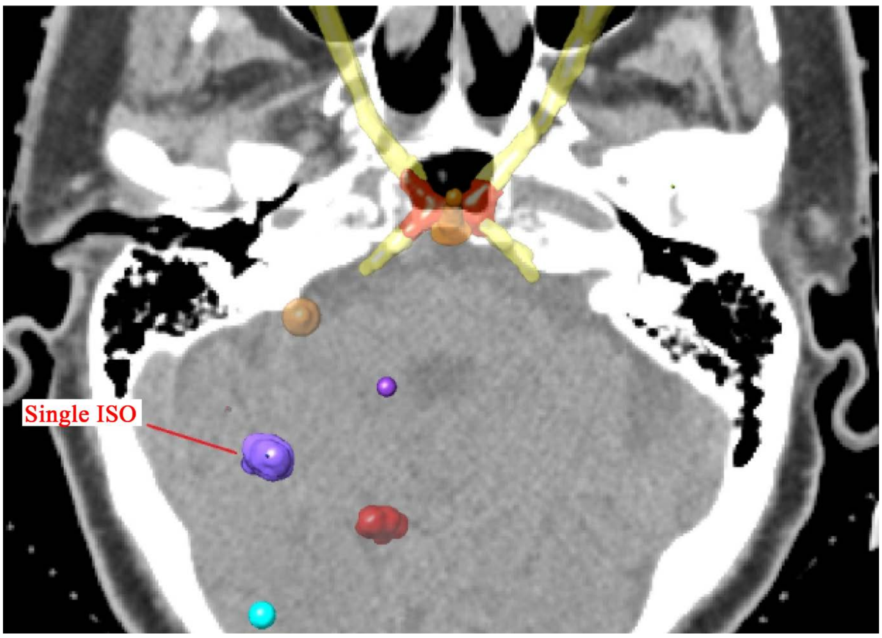

Figure 6. Five lesions map inside the patient in the case study.

Table 2. Estimated time cost in Muti-isoceter vs. Single-isocenter technique.

Technique	Number of beams used	Planning time (h)	Physics QA time (h)	Patient setup time (h)	Imaging verification time (h)	Beam delivery time (h)	Total time
Multi-isocenter	25	8	3	0.8	1	1	13.8
Single-isocenter	7	4	1	0.20	0.3	0.3	5.8

cepted the doctor's suggestion during discussion. Each lesion is prescribed at 21 Gy for one fraction. The central lesion is chosen as isocenter as shown in **Figure 6**. The distance between center lesion and other lesion is less than 3 cm. Two kinds of plan are created in this case. One plan use single-isocenter technique in which the iso-center is located in the central lesion. Other plan use multiple-isocenter technique in which five isocenters are located on each of five lesions. After DVH analysis for comparing two plans, both plans can achieve the same goal to deliver the prescribed dose to targets and spare the normal tissue well. But the planning time, physics QA time, patient setup time, imaging verification time and beam delivery time are big different. The estimated times per our clinic are listed in **Table 2**. After discussion among radiation oncologist, physicist and dosimetrist, the single isocenter technique was used. The overall planning, QA and treatment times using single iso is 7 - 8 hours shorter than using the multiple iso. Doctor will follow up the patient closely after treatment.

4. Discussion

In our experiments, the off-isocenter Winston-Lutz test predicted that the further the distance from the machine isocenter, the larger the deviation of the mechanical field from the radiation field. Our results indicated that use of the single-isocenter technique to treat multiple lesions is efficient and accurate only when the maximum distance from the center of the mechanical field to the machine isocenter is within 3 cm for the machine in our clinic.

As shown in **Figure 5(a)**, when d_1 was greater than 3 cm, the deviation was above the 2.5-mm in-house criteria for about half of the eight beams. This means that four radiation fields will most likely be 2.5 mm off from the setup mechanical fields if target 1 in **Figure 1** is treated using the jaw collimator only. When d_1 was 5 cm, the deviation was above 3 mm, up to 4.3 mm for the beam G0C180T180_5cm (gantry angle = 0˚, collimator angle = 180˚, and table angle = 180˚). As shown in **Figure 5(b)**, for the MLC setting, when d_1 was 3 cm, the deviation was below 1 mm, which meets AAPM TG-142 and ASTRO SRS/SBRT report criteria. When d_1 reached about 4 cm, the deviation of some beams reached the 1-mm tolerance threshold. When d_1 was 5 cm, most beams deviated much more than 1 mm. One beam G180C180T0_5 cm offset goes to, up to 1.72 mm for gantry angle = 180˚, collimator angle = 180˚, and table angle = 0˚; this is about 72% higher than standard tolerance threshold noted in TG-142. Overall, the further the asymmetric field center from the machine isocenter, the higher the deviation of the center of the mechanical field from the center of the radiation field. Results shown in **Figure 5(b)** indicate that 3 cm was the maximum distance for the accuracy to stay within the tolerance threshold in our linear accelerator. In the clinic, both jaw and MLC are used to collimate the beam together. Therefore, we will need to consider the deviation from both the jaw and the MLC. In the case study patient, all five lesions are very close and four of them are within 3 cm distance from central lesion. This is met our off-isocenter Winston –Lutz test criteria. It is very good example to use single-isocenter technique to make the planning, physics QA and whole treatment process more efficient than multi-isocenter technique.

Both mechanical and radiation field uncertainty led to measurement deviation in the off-isocenter Winston-Lutz test, as illustrated in **Figure 7**. It is easy to understand that for any couch rotation (**Figure 7(a)**), when the couch rotates to angle Φ, uncertainty of this angle, ΔΦ, is always present. Absolutely accurate mechanical control and measurement is impossible in real world. Because of this uncertainty, the further the phantom from rotational origin point is, the larger the offset ($S_2 > S_1$). In addition to this mechanical uncertainty, radiation field uncertainty occurs when the penumbra goes from symmetric (**Figure 7(b)**) to asymmetric (**Figure 7(c)**). **Figure 7(b)** shows a symmetric radiation field from the linear accelerator, collimated by either the jaw or MLC collimator. For this field, which is aimed at the isocenter, the penumbra is well studied and the field size congruence is frequently tested in monthly and annual quality assurance procedures. Moreover, the radiation isocenter and mechanical isocenter are adjusted frequently by service engineers, and the standard Winston-Lutz test is performed under this condition. However, when the field is off from the isocenter (*i.e.*, asymmetric), as shown in **Figure 7(c)**, the penumbra becomes asymmetric and the accuracy of the radiation field size measurement is affected. Radiation field size uncertainty is especially increased during gantry rotation, collimator rotation, and couch rotation, during which the center of the radiation field changes. Therefore, the center of the radiation in an asymmetric radiation field is more uncertain than in a symmetric field, and this uncertainty increases as the center of the radiation field moves further from the isocenter.

5. Conclusion

The findings of the current study have important implications for clinical plan design and beam selection during SRS/SBRT for the treatment of multiple lesions in linear accelerator-based systems. Our results illustrate that in our clinic, the use of the single-isocenter technique to treat multiple lesions is efficient and accurate only when the maximum distance from the center of the mechanical field to the machine isocenter is within 3 cm. This conclusion is based on all tests performed using both the standard and the off-isocenter Winston-Lutz test in one of our linear accelerators. Because different machines have different deviation data, every clinic that performs the linear accelerator MLC-based SRS/SBRT procedure should perform the off-isocenter Winston-Lutz test in addition to the standard Winston-Lutz test and should use its own deviation data table. Physicists should evaluate the results to determine whether they meet the criteria. This is why we recommend that the off-isocenter Winston-Lutz test be added as a supplementary item to the TG-142, TG-101, and Astro SRS/SBRT reports. With the innovative development of the off-isocenter Winston-Lutz test in the linac based SRS/SBRT procedure,

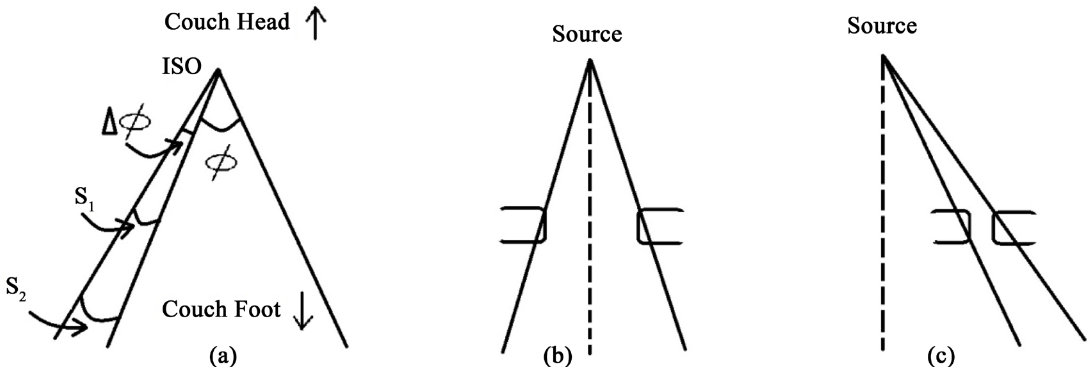

Figure 7. Sketches illustrating the causes of measurement deviation: mechanical uncertainty with couch rotation (a) and radiation field uncertainty when the penumbra goes from symmetric (b) to asymmetric (c).

the authors believe the single isocenter technique will become more and more popular in the future multiple lesion stereotactic radiation therapy. This study well delineated the details of off-isocenter Winston-Lutz test for medical physic field. It contains very valuable information for physicist implementing this method into their own clinic. It also will trigger the further study on this topic in all other SRS/SBRT modality. Per the name convention, we will call this test as Winston-Lutz-Gao test.

References

[1] Schell, M.C., Bova, F.J., Larson, D.A., *et al*. (1995) Stereotactic Radiosurgery. *The Report of AAPM Task Group*, **42**, 1-88.

[2] Benedict, S.H., Yenice, K.M., Followill, D., *et al*. (2010) Stereotactic Body Radiation Therapy: The Report of AAPM Task Group 101. *Medical Physics*, **37**, 4078-4101. http://dx.doi.org/10.1118/1.3438081

[3] Klein, E.E., Hanley, J., Bayouth, J., *et al*. (2009) Task Group 142 Report: Quality Assurance of Medical Accelerators. *Medical Physics*, **36**, 4197-4212. http://dx.doi.org/10.1118/1.3190392

[4] Solberg, T.D., Balter, J.M., Benedict, S.H., Fraass, B.A., Kavanagh, B., Miyamoto, C., Pawlicki, T., Potters, L. and Yamada, Y. (2012) Quality and Safety Considerations in Stereotactic Radiosurgery and Stereotactic Body Radiation Therapy: Executive Summary. *Practical Radiation Oncology*, **2**, 2-9. http://dx.doi.org/10.1016/j.prro.2011.06.014

[5] Solberg, T.D., Balter, J.M., Benedict, S.H., Fraass, B.A., Kavanagh, B., Miyamoto, C., Pawlicki, T., Potters, L. and Yamada, Y. (2011) Quality and Safety Considerations in Stereotactic Radiosurgery and Stereotactic Body Radiation Therapy: Supplemental Material. *Practical Radiation Oncology*, **2**, 1-49.

[6] Nath, S.K., Lawsonm J.D., Simpson, D.R., *et al*. (2010) Single-Isocenter Frameless Intensity-Modulated Stereotactic Radiosurgery for Simultaneous Treatment of Multiple Brain Metastases: Clinical Experience. *International Journal of Radiation Oncology*Biology*Physics*, **78**, 91-97. http://dx.doi.org/10.1016/j.ijrobp.2009.07.1726

[7] Lau, S.K.M., Zhao, X., Camona, R., *et al*. (2014) Frameless Single-Isocenter Intensity Modulated Stereotactic Radiosurgery for Simultaneous Treatment of Multiple Intracranial Metastases. *Translational Cancer Research*, **3**, 383-390.

[8] Huang, C. (2012) Treatment of Multiple Brain Metastases Using Stereotactic Radiosurgery with Single-Isocenter Volumetric Modulated Arc Therapy: Comparison with Conventional Dynamic Conformal Arc and Static Beam Stereotactic Radiosurgery. Graduate Program in Medical Physics, Duke University, Durham (NC).

[9] Lutz, W., Winston, K.R. and Maleki, N. (1988) A System for Stereotactic Radiosurgery with a Linear Accelerator. *International Journal of Radiation Oncology*Biology*Physics*, **14**, 373-381. http://dx.doi.org/10.1016/0360-3016(88)90446-4

[10] Rowshanfarzad, P., Sabet, M., O'Conner, D.J. and Greer, P.B. (2011) Isocenter Verification for Linac-Based Stereotactic Radiation Therapy: Review of Principles and Techniques. *Journal of Applied Clinical Medical Physics*, **12**, 1-10.

[11] Childress, N., Jones, J. and Kry, S. (2011) Winston-Lutz IGRT Test. http://www.medphysfiles.com/