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Dosimetric Analysis of Intra-fraction Motion Detected by SGRT During Linac SRS

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Chief Physicist

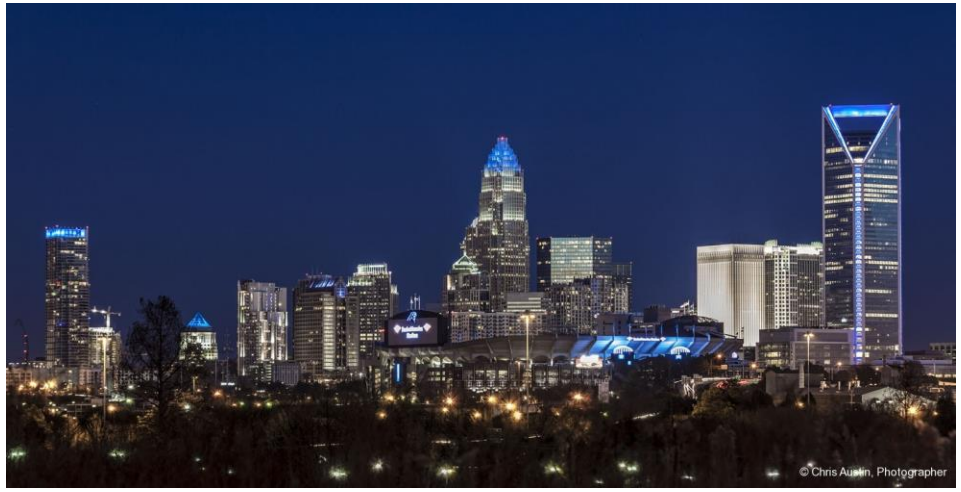
Levine Cancer Institute/Atrium Health

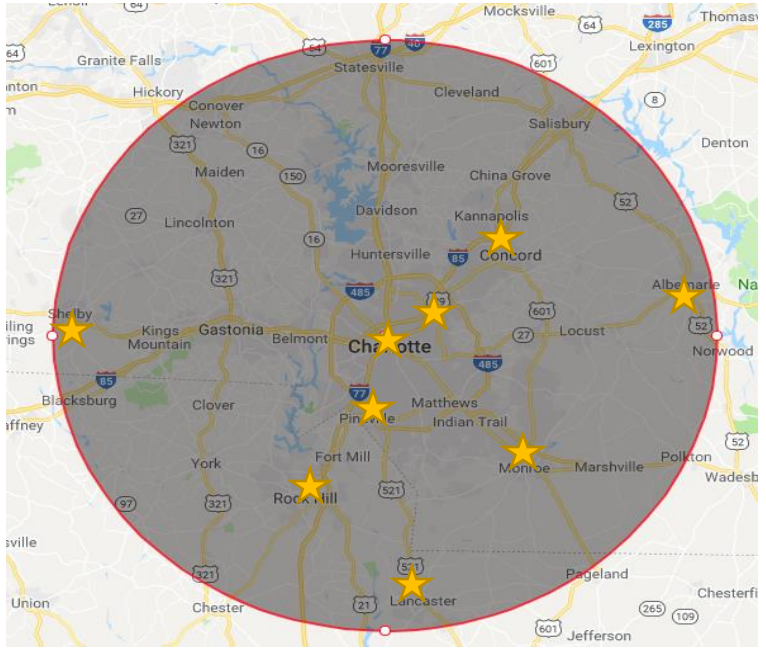
Disclosures

- VisionRT paid my travel expenses for this conference.

Background on Atrium Health & Levine Cancer Institute

- Serves the Charlotte, NC Metro Area
- More than 40 hospitals and 900 care locations
- More than 65,000 employees
- Largest health system in North and South Carolina
- 9 radiation oncology clinics with 13 linacs, 11 with SGRT
- Treating 360+ patients per day
- Wake Forest University Medical School – academic core





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Objectives

- Understand the benefits of SGRT for SRS treatments
- Evaluate the potential dosimetric consequences of undetected intra-fraction motion during SRS

Advances in Radiation Oncology (2023) 8, 101151

advances in radiation oncology

www.advancesradonc.org

Scientific Article

Dosimetric Analysis of Intra-Fraction Motion Detected by Surface-Guided Radiation Therapy During Linac Stereotactic Radiosurgery

Ryan D. Foster, PhD,[a,*] Benjamin J. Moeller, MD, PhD,[b] Myra Robinson, MSPH,[c] Megan Bright, MS,[a] Justin L. Ruiz, MS,[a] Carnell J. Hampton, PhD,[c] and John H. Heinzerling, MD[b]

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Clinical Results for SGRT-guided SRS

Frameless, real-time, surface imaging-guided radiosurgery: update on clinical outcomes for brain metastases

Nhat-Long L. Pham, Pranav V. Reddy, James D. Murphy, Parag Sanghvi, Jona A. Hattangadi-Gluth, Grace Gwe-Ya Kim, Laura Cervino, Todd Pawlicki, Kevin T. Murphy

Table 2 Comparison of local control and survival rates in retrospective studies of brain metastases treated with radiosurgery reporting kaplan-meier data[a]

Study	Treatment system	Patients, n	Crude LC, %	Actuarial 1-yr LC, %	Actuarial 1-yr OS, %
Schomas *et al*. (19) [2005]	Frame-based LINAC	80	91	89	33
Bhatnagar *et al*. (18) [2006]	Frame-based Gamma Knife	205	***	71	37[b]
Brenenman *et al*. (6) [2009]	Frameless LINAC	53	***	80	44
Nath *et al*. (7) [2010]	Frameless LINAC	65	88	76	40
Pan *et al*. (17) [2012]	Frameless, surface-imaging guided LINAC	44	85	76	38
Present series	Frameless, surface-imaging guided LINAC	163	85	79	56

[a], LC indicates local control; LINAC, linear accelerator; ***, not reported; [b], estimated from Kaplan-Meier curve.

Transl Cancer Res 2014; 3(4)

Why Use Intra-fraction Monitoring During SRS?

- AAPM TG101 states: “After localization, some kind of monitoring is desirable to track patient breathing and monitor patient positioning during treatment.”

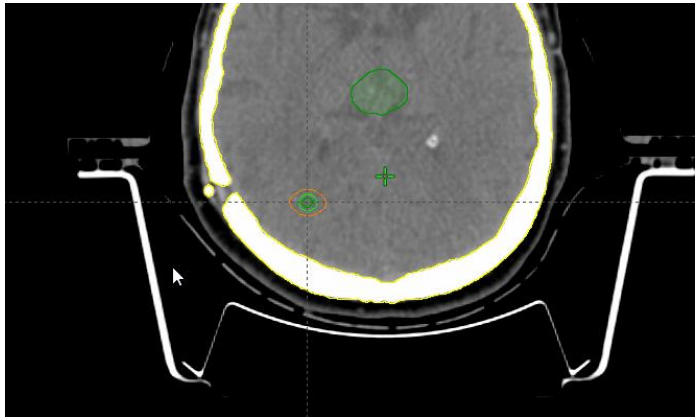
- ASTRO SRS/SBRT Safety White Paper states: “In addition to pretreatment positioning, the management of intrafraction patient movement and physiological motions (eg, breathing) must be accounted for.”

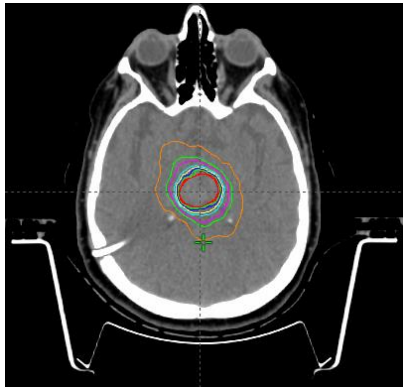
- What are the dosimetric consequences of not monitoring?

Patient Characteristics & Treatment Planning

Table 1 Treatment characteristics for study patients

Characteristic	N = 25 subjects	
Treatment, n (%)		
MLC	13	52.0%
Cone	12	48.0%
Fractions, n (%)		
1	21	84.0%
3	4	16.0%
Dose per fraction, n (%)		
900 cGy	4 (MLC)	16%
1500 cGy	1 (MLC)	4%
1800 cGy	3 (MLC)	12%
2100 cGy	17 (12 cone, 5 MLC)	68%
GTV volume (cc)		
Median (range), all patients	1.05	0.03-29.48
Median (range), MLC	5.22	0.4-29.48
Median (range), cone	0.26	0.03-1.05
PTV volume (cc)		
Median (range), all patients	1.61	0.13-44.25
Median (range), MLC	8.38	0.79-44.25
Median (range), cone	0.56	0.13-1.61
Margin, n (%)		
0 mm	1 (MLC)	4%
1 mm	20 (12 cone, 8 MLC)	80%
2 mm	3 (MLC)	12%
3 mm	1 (MLC)	4%





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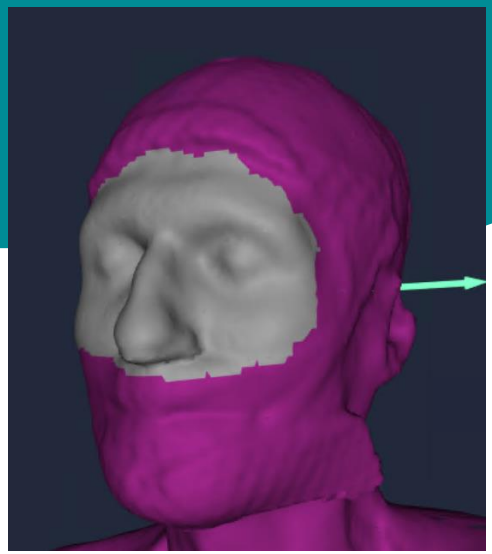
Treatment Procedure



- SGRT tolerances were 1 mm and 1°
- SGRT reference capture taken before CBCT
- MD matches CBCT, shift patient and take another SGRT reference
- Linac is interlocked with SGRT
- Out of tolerance, repeat CBCT, shift and take SGRT reference
- Treated 55 patients between January 1, 2017 and September 30, 2020
- 25 patients had intra-fx 3D vector shifts ≥ 1 mm on CBCT

Shift summaries, median (range), mm		
Vector	1.5	1.0-6.6
Vertical	0.3	0-1.1
Longitudinal	1.4	0.2-6.2
Lateral	0.5	0-2.2
Rotation	0.0	0-1.5
Roll	0.1	0-1.0
Pitch	0.3	0-2.1

Abbreviations: GTV = gross tumor volume; MLC = multileaf collimator; PTV = planning target volume.

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Simulated Dosimetry

- Shifted the isocenter in the TPS using the intra-fx CBCT shifts
- Ignored rotations
- Estimate of the delivered dose had the motion been undetected
- Assumed that the motion occurred before treatment began
- Evaluated PTV coverage, GTV dose and V12

Radiation Therapy for Brain Metastases: An ASTRO Clinical Practice Guideline

Vinai Gondi, MD,[a,*] Glenn Bauman, MD,[b] Lisa Bradfield, BA,[c] Stuart H. Burri, MD,[d] Alvin R. Cabrera, MD,[e] Danielle A. Cunningham, MD,[f] Bree R. Eaton, MD,[g] Jona A. Hattangadi-Gluth, MD,[h] Michelle M. Kim, MD,[i] Rupesh Kotecha, MD,[j] Lianne Kraemer,[k] Jing Li, MD, PhD,[l] Seema Nagpal, MD,[m] Chad G. Rusthoven, MD,[n] John H. Suh, MD,[o] Wolfgang A. Tomé, PhD,[p] Tony J.C. Wang, MD,[q] Alexandra S. Zimmer, MD,[r] Mateo Ziu, MD,[s] and Paul D. Brown, MD[t]

Table 7 Risks of symptomatic radionecrosis with WBRT and/or SRS

KQ4 Recommendation	Strength of Recommendation	Quality of Evidence (refs)
1. For patients with brain metastases, limiting the single-fraction V_{12Gy} to brain tissue (normal brain *plus* target volumes) to ≤10 cm^3 is conditionally recommended. Implementation remark: Any brain metastasis with an associated tissue V_{12Gy} >10 cm^3 may be considered for fractionated SRS to reduce risk of radionecrosis (see KQ1).	Conditional	Low 12,88

Abbreviations: KQ = key question; SRS = stereotactic radiosurgery; WBRT = whole brain radiation therapy.

HyTEC Organ-Specific Paper: Brain and Eye

Single- and Multifraction Stereotactic Radiosurgery Dose/Volume Tolerances of the Brain

Michael T. Milano, MD, PhD,* Jimm Grimm, PhD,† Andrzej Niemierko, PhD,‡ Scott G. Soltys, MD,§ Vitali Moiseenko, PhD,‖ Kristin J. Redmond, MD,¶ Ellen Yorke, PhD,# Arjun Sahgal, MD,** Jinyu Xue, PhD,†† Anand Mahadevan, MD,† Alexander Muacevic, MD,‡‡ Lawrence B. Marks, MD,§§ and Lawrence R. Kleinberg, MD¶

Thus, the QUANTEC recommendation to limit single-fraction V12Gy to ≤5 to 10 cm^3 remains prudent,[20]

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Results

Table 2 **Dosimetric comparison of actual and simulated plans for all patients**

Dosimetric indices	Actual	Simulated	Median difference (actual - simulated)	*P* value*
V12 (cc), median (range)	2.78 (0.32-151.25)	3.02 (0.33-151.32)	−0.01 (−1.5-0.09)	.006
GTV minimum dose (%), median (range)	102.80 (91.70-118.60)	93.80 (15.00-106.00)	15.8 (−1.9-86.08)	<.001
PTV coverage %, median (range)	98.10 (98.00-99.00)	87.89 (36.60-99.56)	10.24 (−1.56-61.40)	<.001
GTV minimum dose (cGy), median (range)	2225.0 (1376.0-2719.0)	1901.8 (271.1-2752.3)	308.2 (−52.3-1548.3)	<.001

Abbreviations: GTV = gross tumor volume; PTV = planning target volume.
* Wilcoxon signed rank tests.

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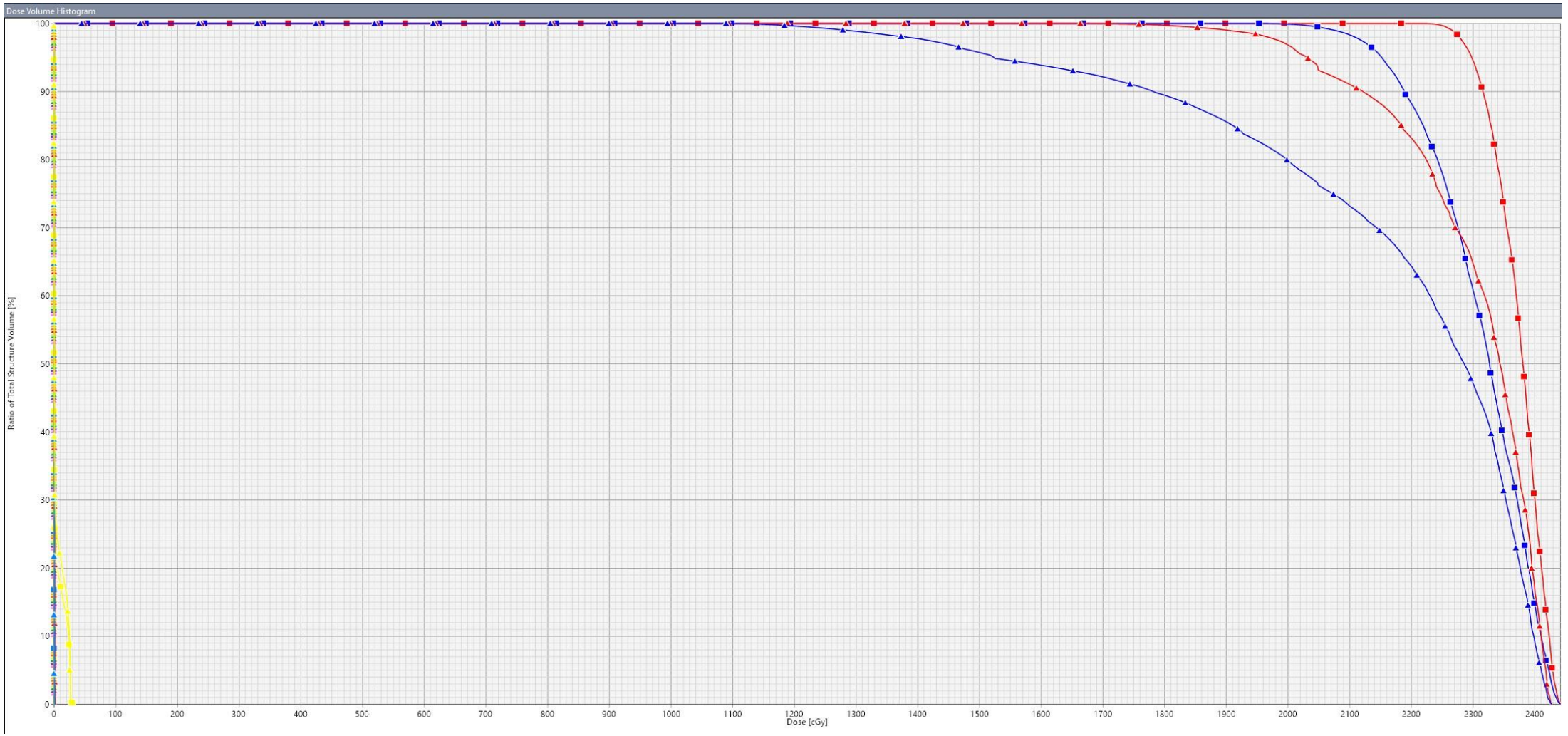
Example patient



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Other Studies

Dosimetric consequences of translational and rotational errors in frame-less image-guided radiosurgery

Matthias Guckenberger*, Johannes Roesch, Kurt Baier, Reinhart A Sweeney and Michael Flentje

Rad Onc 2012, 7:63

Table 1 Patient positioning errors prior to cone-beam CT based image-guidance (IG) and immediately following image-guided radiosurgery (IG-RS)

	Prior IG (n = 98)			Post IG-RS (n = 64)		
	Average	StDev	Max	Average	StDev	Max
LR [mm]	0.1	2.1	10.3	0.1	0.6	1.8
SI [mm]	−0.8	1.7	5.4	−0.3	0.8	3.0
AP [mm]	−2.7	2.0	9.9	−0.2	0.4	1.4
3D vector [mm]	3.9	1.9	11.9	0.9	0.6	3.0
Max Rotation [°]	1.7	0.8	4.0	0.6	0.5	3.0

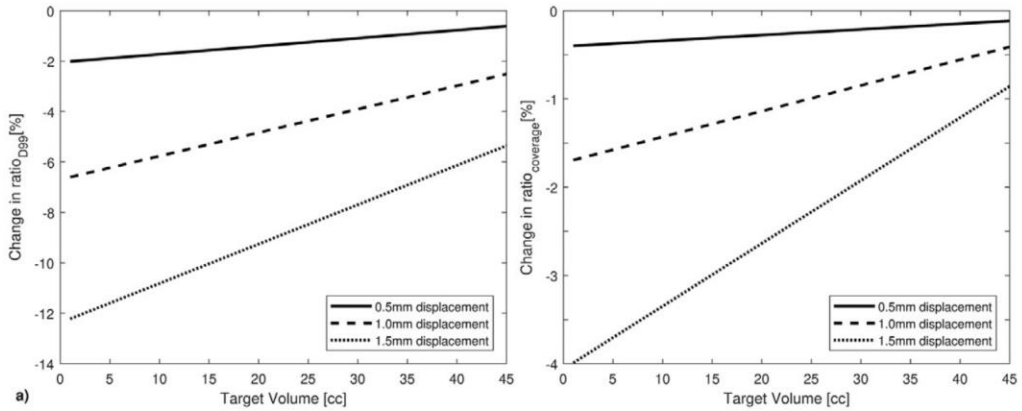
Table 3 Dose distributions to the target with simulation of 0 mm, 1 mm and 2 mm safety margins 1) in the treatment plan (plan), 2) in the scenario of radiosurgery without image-guidance (No IG), 3) in the scenario of radiosurgery after image-guided correction of translational errors only and not rotations (IG trans) and 4) simulating errors observed immediately following image-guided radiosurgery (Post IG-RS)

Safety margin		Plan		No IG		IG trans		Post IG-SRS	
0 mm	Absolute CI	0.96	±0.06	0.72	±0.19	0.96	±0.06	0.94	±0.07
	<95% planned CI			91%		3%		14%	
1 mm	Absolute CI	1.00	±0.01	0.82	±0.19	1.00	±0.01	0.99	±0.01
	<95% planned CI			70%		0%		0%	
2 mm	Absolute CI	1.00	±0.04	0.90	±0.17	1.00	±0.04	1.00	±0
	<95% planned CI			40%		0%		0%	

Absolute values of the coverage index (average ± standard deviation) and percent of the patients with <95% planned target coverage are summarized.

Quantifying the Sensitivity of Target Dose on Intrafraction Displacement in Intracranial Stereotactic Radiosurgery

Jannie Schasfoort, MSc,[a,*] Mark Ruschin, PhD,[b] Arjun Sahgal, MD,[b] R. Lee MacDonald, PhD,[b] Young Lee, PhD,[b] Carola van Pul, PhD,[c] Patrick Langenhuizen, PhD,[d] Patrick Hanssens, MD,[e,f] Guus Beute, MD,[e] Frits Wittkamper, PhD,[g] and Jan-Jakob Sonke, PhD[g]



PRO 12, 2022

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Why is this important?

Predictors of Tumor Control in Patients Treated With Linac-Based Stereotactic Radiosurgery for Metastatic Disease to the Brain

David A. Schomas, MD, John C. Roeske, PhD,* R. Loch MacDonald, MD, PhD,*†*
Patrick J. Sweeney, MD, Neil Mehta, MD,* and Arno J. Mundt, MD**

Results: At a median follow up of 8.8 months, 11 BM failed (8.7%). The 1-and 2-year actuarial LC rates were 88.6% and 77.2%, respectively. The most significant factors correlated with LC were prescription ($P = 0.0004$) and minimum tumor ($P = 0.002$) doses, and tumor volume ($P = 0.04$). On multivariate analysis, the sole factor correlated with LC was minimum tumor dose ($P = 0.03$).

Am J Clin Onc, Vol 28, No 2, April 2005

Radiosurgery for brain metastasis: impact of CTV on local control

Georges Noël[a,*], Jean Marc Simon[a], Charles-Ambroise Valery[b], Philippe Cornu[b], Gilbert Boisserie[a], Dominique Hasboun[c], Dominique Ledu[a], Bernadette Tep[a], Jean-Yves Delattre[d], Claude Marsault[c], François Baillet[a], Jean-Jacques Mazeron[a]

In this study, margin was the only independent prognostic factor that was significant in multivariate analysis ($P = 0.04$). There was a decrease in the 24-month local control rate between the two groups according to minimum GTV treatment dose, 50.7 ± 12.7% and 89.7 ± 7.4% for metastases treated respectively with a mean GTV minimum dose of 14.6 Gy and 16.8 Gy ($P < 0.001$). This observation

R & O, 68, 2003

Significant correlation between gross tumor volume (GTV) D98% and local control in multifraction stereotactic radiotherapy (MF-SRT) for unresected brain metastases

Guillaume Dupic[a,*], Lucie Brun[a], Ioana Molnar[b,c], Brice Leyrat[a], Vincent Chassin[d], Juliette Moreau[a], Véronique Dedieu[d], Toufic Khalil[e], Pierre Verrelle[a], Michel Lapeyre[a], Julian Biau[a]

GTV $D_{98\%}$ is a strong reproducible significant predictive factor of local control in stereotactic radiotherapy for brain metastases.

R & O, 154, 2021

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Conclusions

- SGRT is an attractive option for patient set-up and intra-fraction monitoring
- Patients do move during SRS treatments – possibly a lot!
- Continuous monitoring is necessary
- Intra-fraction motion can lead to underdoses and worse local control

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