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Correlation Between Conformity Index, Gradient Index, Heterogeneity Index And Size of Metastasis For Linac-Based Stereotactic Radiosurgery / Radiotherapy (SRS/SRT)

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ABSTRACT: *To evaluate correlation between CI, GI, HI and size of metastasis for high dose SRS / SRT using Elekta Versa HD® lineer accelerator. Sixteen patients with single metastasis were used in this study. For each of the patients, the target was defined on CT-MR deformable fused images. Agility® MLC system's features were used for patients treatment planning. Minimum segment width adjusted 0.5 cm, grid spacing adjusted 0.2 cm and statistical uncertainty adjusted 1% per plan. Patient's treatment planning were performed using Monaco 5.11® TPS with three or four non-coplanars 6 MV-FFF beams by partial VMAT technique for each patient. We determined four different size of metastasis catagory which were between 0.1 cc and 0.5 cc volume, between 0.5 cc and 1.0 cc volume, between 1.0 cc and 5.0 cc volume and between 5.0 cc and 10.0 cc volume. Also, five different plans were performed for getting different HI for each patients and maximum HI was restiricted 1.50. Correlations were determined between CI, GI, HI and size of metastasis. Also, new Plan Quality Index (pQI) suggested for plan quality level of high dose SRS / SRT plans. This pQI defines CI and GI multiplacation. The lowest pQI was determined 6.80 ± 0.5 for an average 0.33 ± 0.1 cc metastasis volume, 5.22 ± 0.6 for an average 0.83 ± 0.1 cc metastasis volume, 4.45 ± 0.3 for an average 2.94 ± 1.2 cc metastasis volume and 3.24 ± 0.2 for an average 7.72 ± 1.4 cc metastasis volume. Ideal one is the lowest GI and CI for sparing healthy tissues but GI and CI are not giving plan quality level exactly one by one. Therefore, we could determine plan quality level of treatment plan with pQI which depends on significantly size and HI of metastasis especially for less than 1cc volume. When the metastasis size is larger than 5.0 cc, size of metastasis and HI is losing its importance for pQI. Based on the correlation between HI, GI, CI and size of metastasis, we have decided that pQI should be ≤ 7.0 between 0.1 cc and 0.5 cc metastasis volume, pQI should be ≤ 6 between 0.5 cc and 1 cc metastasis volume, pQI should be ≤ 5.0 for between 1 cc and 5 cc metastasis volume and pQI should be ≤ 4.0 between 5 cc and 10 cc metastasis volume for linac based high dose SRS / SRT in clinical practice.*

KEYWORDS: *HI, GI, SRS, SRT*

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I. INTRODUCTION

Stereotactic radiosurgery (SRS) is a noninvasive, highly accurate form of radiation therapy that is increasingly used to treat benign and malignant intracranial tumors with high rates of local control. Recent large studies of patients treated with SRS for pituitary adenomas and meningiomas have shown long-term disease control of over 95% with reduced toxicity as compared to traditional external beam radiation therapy (EBRT).[1,2]

SRS has repeatedly demonstrated its safety and effectiveness when used to treat patients with brain metastases.[3-5] The aim is to give a single high ablative dose to the lesion with a sharp dose fall-off to avoid any secondary effects on surrounding healthy tissues.[6] As a result of several large trials, SRS has gained popularity by demonstrating excellent local control and uncommon toxicity.[7] SRS without whole-brain radiation therapy (WBRT) is increasingly used in the management of brain metastases, because randomized data have confirmed similar survival outcomes for up to 4 brain metastases[8-11] and nonrandomized retrospective and prospective data suggest similar outcomes for even up to 10 metastases.[12-14]

Classically, radiosurgery has relied on an invasive head frame for patient immobilization and target localization.[16] In recent years, the use of image-guided radiotherapy systems has spread, providing a foundation for a noninvasive (frameless) radiosurgical treatment.[15] Cone beam computed tomography (CBCT) technology available on the newer linear accelerators (linacs) allows generating high-resolution 3-dimensional (3D) image sets of the head at the time of SRS treatment. Chang et al.[16] concluded that CBCT imaging can be used to guide SRS treatment setup with accuracy comparable to the conventional frame-based stereotactic systems reported in the literature.[17]

Linear accelerator (LINAC) based SRS is a well established and commonly used irradiation technique that is capable of providing a high dose to the target whereas sparing doses to critical structures via a steep dose gradient outside the lesion.[18] After micromultileaf became popular to install on LINAC, intensity-modulated radiosurgery (IMRS) was tested as a means of treating irregularly shaped targets, with micromultileaf providing the intensity modulation. The main advantages of IMRS are high conformity dose distribution and better sparing for OARs, and multileaf collimators with smaller leaf widths were found to have better sparing results in the case of small OARs than wider leaf multileaf collimators did. Then Otto[19] purposed volumetric modulated arc therapy (VMAT) that combined advantages of dynamic conformal arc (DCA) therapy and intensity modulated radiotherpy (IMRT). Several published feasibility studies and applications of single-fraction VMAT for intracranial targets.[20]

Versa HD® & Monaco® TPS features to support SRS / SBRT treatment; Dynamic delivery Monaco® TPS + Agility® can move the Y jaws from segment to segment and jaws can be parked at different positions for each segment even it can be parked within a MLC leaf. The MLCs and Jaws can be placed in 1 mm increments

The challenge for SRS and SRT is to accurately and precisely deliver high dose radiation to the target and minimize normal tissue damage in short courses (1-5 fractions) with modern radiation therapy tecniques such as IMRT, VMAT and DCA etc.

II. MATERIALS AND METHOD

Patients were scanned with 1 mm slice thickness by using Siemens Biograph mCT.S20 PET/CT (Siemens, USA). The necessary precision of target localization required MRI / CT fusion before the treatment. Versa HD® (Crawley, Elekta) linear accelerator which equipped with Agility® (Crawley, Elekta) multi leaf collimator (MLC) system used with 6 MV Flattening Filter Free (FFF) energy for treating patients. As an image guided radiation therapy (IGRT) method, we performed XVI 5.0 cone beam CT system with 6 dimensional hexapod coach for eliminating the patient missalignment positioning in 6 dimension. All calculation parameters were grid spacing 0.2 cm, minimum segment width 0.5 cm, max. 180 of control points per arc, fluence smoothing medium, statistical uncertainty 1% per plan, increment of gantry 30° and dose to medium. Patient's treatment planning were performed using Monaco 5.11® treatment planning system (TPS) with three or four non-coplanars 6 MV-FFF beams by partial VMAT technique for each patient (**Figure1**). Monte Carlo algorithm were used for all calculation. We determined four different size of metastasis catagory which are between 0.1cc and 0.5cc volume, between 0.5cc and 1.0cc volume, between 1cc and 5cc volume and between 5cc and 10.0cc volume. Also, five different plans were performed for getting different HI for each patients and maximum HI was restiricted 1.50.

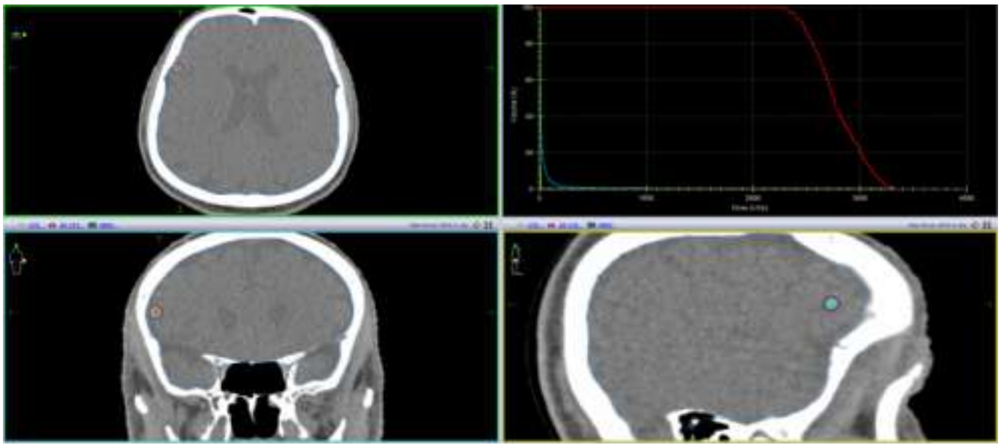

FIGURE 1. Review of stereotactic radiosurgery treatment planning

- PIV : Prescription Isodose Volume
- TV : Target Volume
- Gradient Index$_{Paddick}$ (GI): Description of the steep dose gradient outside the target
- GI = PIV0.5 / PIV
- Conformity Index $_{RTOG}$ (CI) : Define to determine the quality of conformation
- CI = PIV / TV

- Heterogeneity Index (HI) : Dose that covers x% of tissue (x= High Dose Ref. %5) / Dose that covers y% of tissue (y= High Dose Ref. %95)

- pQI : New plan quality index
- pQI = CI x GI

III. RESULTS

Correlations were determined between CI, GI, HI and size of metastasis, it is shown in **Table 1**. Also, new plan quality index (pQI) suggested for plan quality level of high dose SRS / SRT treatment plans. This pQI defines CI and GI multiplacation. The lowest pQI was determined 6.80 ± 0.5 for an average 0.33 ± 0.1 cc metastasis volume, 5.22 ± 0.6 for an average 0.83 ± 0.1 cc metastasis volume, 4.45 ± 0.3 for an average 2.94 ± 1.2 cc metastasis volume and 3.24 ± 0.2 for an average 7.72 ± 1.4 cc metastasis volume. Correlation graphs of pQI - HI for different size of target volumes are shown in **Figure 2, 3, 4, and 5**.

TABLE 1. Correlation between HI, CI, GI and pQI for different size of metasteses

Patient	PTV (cc)	HI	CI	GI	pQI		Patient	PTV (cc)	HI	CI	GI	pQI
1	0.292	1.12	1.14	12.96	14.77		**9**	1.731	1.11	1.07	8.01	8.57
		1.16	1.09	11.45	12.48				1.17	1.05	5.65	5.94
		1.27	1.11	7.80	8.66				1.33	1.04	4.42	4.60
		1.33	1.14	6.60	7.50				1.39	1.05	4.35	4.57
		1.47	1.27	5.40	6.86				1.50	1.05	4.19	4.40
2	0.355	1.12	1.14	11.80	13.45		**10**	2.231	1.13	1.17	6.80	7.96
		1.21	1.17	8.20	9.59				1.23	1.15	5.40	6.21
		1.29	1.13	7.02	7.93				1.25	1.12	5.20	5.82
		1.38	1.13	6.02	6.80				1.37	1.13	4.75	5.37
		1.44	1.16	5.67	6.58				1.44	1.06	4.36	4.62
3	0.490	1.16	1.15	9.30	10.70		**11**	4.427	1.12	1.12	5.16	5.78
		1.21	1.09	7.05	7.68				1.21	1.04	4.88	5.06
		1.31	1.26	5.57	7.02				1.31	1.03	4.57	4.71
		1.39	1.27	5.00	6.35				1.42	1.08	4.38	4.73
		1.45	1.44	4.75	6.84				1.50	1.10	4.26	4.69
4		1.10	1.21	10.80	13.07		**12**	3.385	1.11	1.08	7.20	7.78
		1.18	1.30	7.50	9.75				1.19	1.11	5.40	5.99
	0.168	1.25	1.34	6.20	8.31				1.24	1.10	4.92	5.41
		1.30	1.38	5.80	8.00				1.39	1.12	4.10	4.59
		1.49	1.42	5.21	7.40				1.48	1.10	3.71	4.08
5	0.810	1.14	1.12	9.80	10.98		**13**	6.024	1.12	1.01	4.23	4.27
		1.24	1.15	6.05	6.96				1.21	1.02	3.70	3.77
		1.34	1.14	5.32	6.06				1.33	1.01	3.35	3.38
		1.42	1.18	4.81	5.68				1.44	1.02	3.00	3.06
		1.50	1.20	4.21	5.05				1.50	1.03	3.01	3.10
6	0.789	1.13	1.23	9.46	11.64		**14**	7.202	1.10	1.00	4.22	4.22
		1.20	1.16	7.54	8.75				1.18	1.05	3.85	4.04
		1.29	1.19	6.14	7.31				1.27	1.00	3.37	3.37
		1.35	1.32	5.75	7.59				1.40	1.05	3.55	3.71
		1.46	1.18	5.06	5.97				1.47	1.02	3.32	3.39
7	0.757	1.09	1.08	9.19	9.93		**15**	6.385	1.08	1.02	4.46	4.55
		1.20	1.15	6.76	7.77				1.19	1.01	3.59	3.63
		1.31	1.08	5.68	6.15				1.29	1.01	3.48	3.51
		1.40	1.12	5.07	5.68				1.40	1.01	3.07	3.10
		1.50	1.11	4.69	5.21				1.50	1.03	3.02	3.11
8	0.964	1.11	1.06	6.87	7.28		**16**	9.107	1.13	1.20	4.46	5.35
		1.22	1.10	5.79	6.37				1.20	1.21	3.96	4.79

		1.32	1.13	5.05	5.71				1.27	1.09	3.53	3.85
		1.41	1.15	4.90	5.64				1.41	1.19	3.25	3.87
		1.47	1.07	4.36	4.66				1.50	1.06	3.24	3.43

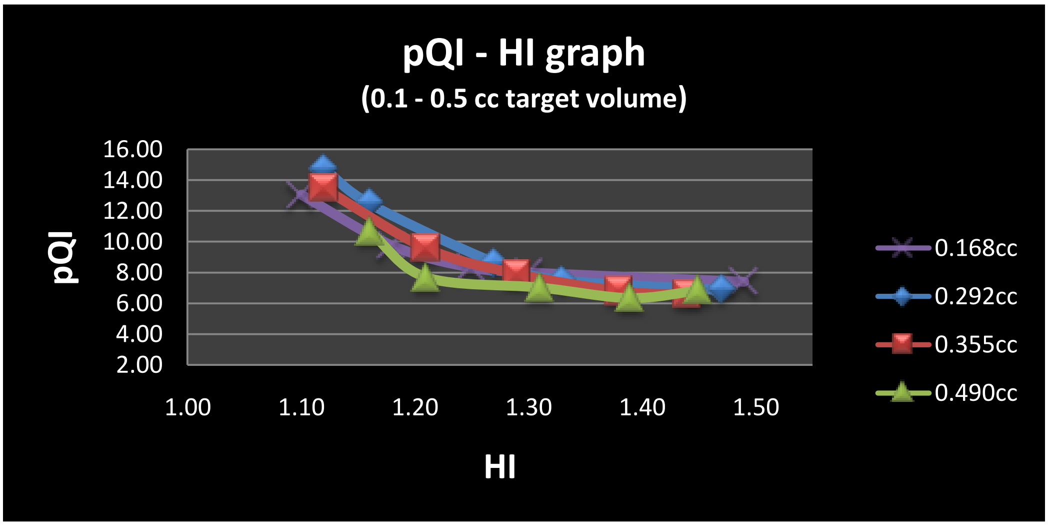

Figure 2. Correlation graph of pQI and HI for 0.1 - 0.5 cc target volume

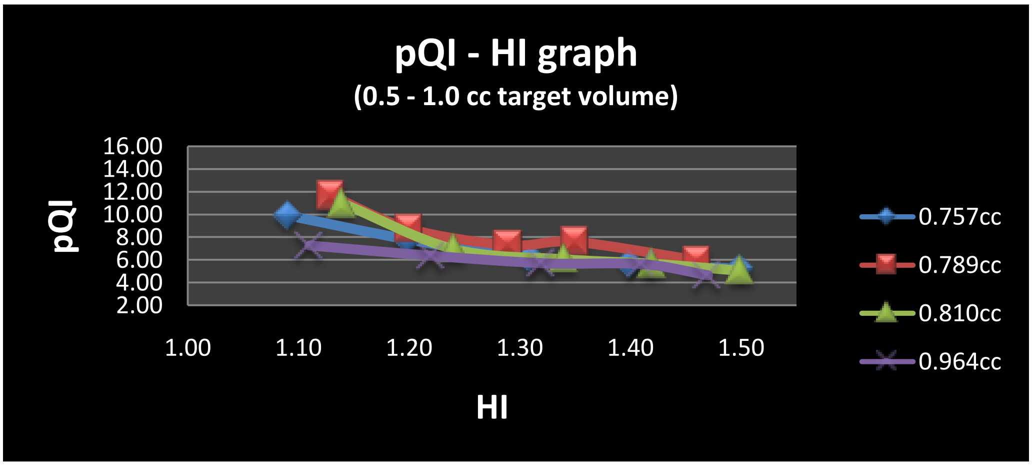

Figure 3. Correlation graph of pQI and HI for 0.5 - 1.0 cc target volume

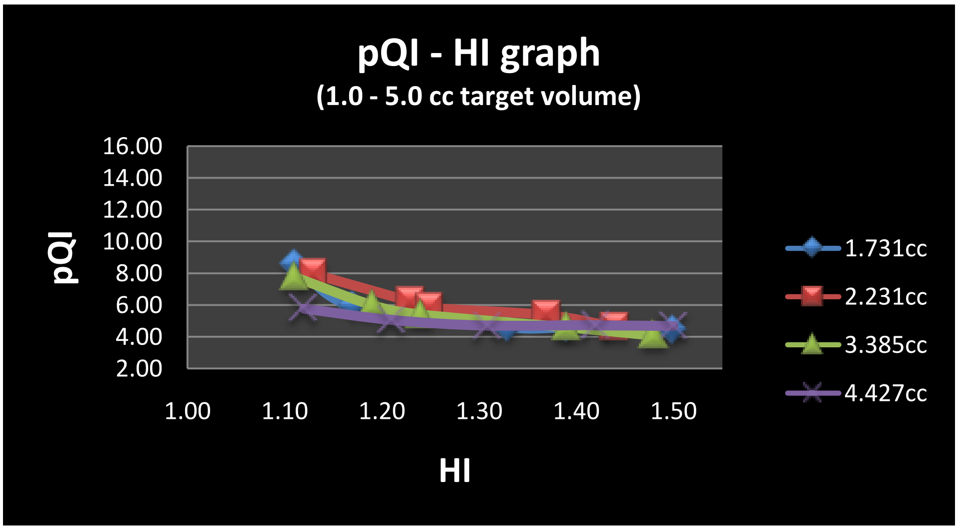

Figure 4. Correlation graph of pQI and HI for 1.0 - 5.0 cc target volume

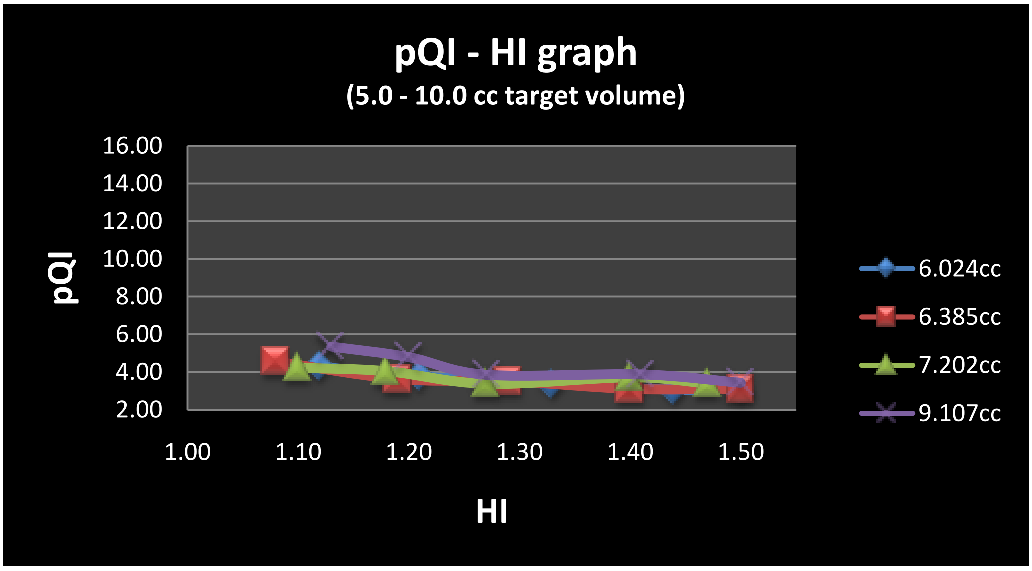

Figure 5. Correlation graph of pQI and HI for 5.0 - 10.0 cc target volume

IV. DISCUSSION

Ideal one is the lowest GI and CI for sparing healthy tissues but GI and CI are not giving plan quality level exactly one by one. Therefore, we could determine plan quality level of treatment plan with pQI which depends on significantly size and HI of metastasis especially for less than 1cc volume. When the metastasis size is larger than 5cc, size of metastasis and HI is losing its importance for pQI. Based on the correlation between HI, GI, CI and size of metastasis, we have decided that pQI should be ≤ 7.0 between 0.1cc and 0.5cc metastasis volume, pQI should be ≤ 6 between 0.5cc and 1cc metastasis volume, pQI should be ≤ 5.0 for between 1cc and 5cc metastasis volume and pQI should be ≤ 4.0 between 5cc and 10cc metastasis volume for linac based high dose Stereotactic Radiosurgery / Radiotherapy (SRS/SRT) in clinical practice.

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