is well specified and problems arising from defining boost volumes via contours are alleviated, as there are only shallow dose gradients in the target volume. Depending on tumor size, the normal tissues impose no or only very little constraint on the achievable level of dose escalation at isotoxicity.

Conclusions: The feasibility of hypoxia boosts on the basis of FMISO-PET using IMRT was demonstrated. Future investigations will have to concentrate on the reliability of the method in clinical applications.

26 Spinal Cord Tolerance to High Dose Fractionated 3D Conformal Proton-Photon Irradiation as Evaluated by Equivalent Uniform Dose and Dose Volume Histogram Analysis

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Purpose/Objective: To evaluate cervical spinal cord tolerance using equivalent uniform dose (EUD) and dose volume histogram (DVH) analysis in patients treated with high dose 3D conformal fractionated proton-photon therapy for chordoma and chondrosarcoma of the cervical spine and cervico-occipital junction.

Materials/Methods: 3D dose distributions were available in 85 patients who received high dose 3D conformal fractionated proton-photon treatment between November, 1982 and May, 2000. Median and mean patient ages were 49 and 44.6 years, respectively (range 3-74 years). Nine patients were < 18 years of age. Median and mean prescribed doses were 75.7 and 76.3 CGE (CGE = proton Gy $\times$ RBE 1.1), respectively (range 68.6-83.5 CGE). Median and mean follow-up was 45 and 41.3 months, respectively (range 2-117 months). Specific patient characteristics were tabulated for all patients, including age, history of smoking, diabetes and/or hypertension, and previous surgeries. Dose to the center and the surface of the cervical spinal cord was constrained to be < 55 and 67 CGE, respectively, in 72 patients. In 13 patients randomized to receive a prescribed dose of 82.9 CGE, cord center and surface constraint doses were 58 and 70 CGE, respectively. EUD, the uniform dose biologically equivalent to the non-uniform dose actually delivered, multiple cord dose parameters and dose-volume-histograms were calculated for each patient. Specific cord parameters studied included cord length and volume treated, and maximum, mean, and minimum doses to the cord center and surface. Spinal cord toxicity was graded using the EORTC/RTOG Late Effects scoring system.

Results: Thirteen patients experienced Grade 1-2 toxicity, which did not further progress. Four patients had Grade 3 toxicity. The actuarial probability of surviving free of any cord toxicity, and of surviving without Grade 3 cord toxicity was 0.78 ± 0.05 and 0.94 ± 0.03 at 5 years, respectively. Median and mean times to onset of cord toxicity were 5.6 and 11.3 months, respectively (range 2.5-49.2 months). Total dose and proton dose to the cord surface and center did not differ significantly between the group of 68 patients who did not develop toxicity and the 17 patients who had toxicity. There was also no difference in the two groups in either the volume or the length of the cord treated. Mean EUD was 54.4 CGE in the first group and 54.7 CGE in the second.

By Cox proportional hazards analysis and by logistic regression analysis, the only factor that significantly impacted the probability of cord toxicity was the number of surgeries the patients had undergone before radiation therapy ($p = 0.021$). Specifically, cord complications developed in 3 of 5 patients (60%) with 4 surgeries; 6 of 20 (30%) patients with 3 surgeries; 4 of 32 patients (12.5%) with 2 surgeries; and 4 of 28 (14.3%) patients with 1 surgery. There were no statistically significant differences between the two groups in terms of age, history of smoking, diabetes, high blood pressure, neurological symptoms or documented spinal cord compression prior to surgery or radiation therapy.

Conclusions: Conformal 3D proton techniques provide a means of contouring dose around the spinal cord in treating tumors which abut or compress the cervical spinal cord. This allows the delivery of prescribed doses ranging from 68.6 to 83.5 CGE, while constraining the dose to the cord center and cord surface to 55-58 CGE and 67-70 CGE, respectively. Although these dose constraints are higher than those normally recommended for photon treatments, the actuarial probability of surviving without Grade 3 toxicity at 5 years was 0.94 ± 0.03. The only factor impacting toxicity was the number of surgeries before radiation, suggesting that the integrity of the normal musculo-skeletal supportive tissues and vascular supply may be more important factors than the radiation dose itself. These data also suggest that the cervical spinal cord dose constraints used in treating these patients with 3D conformal proton-photon radiation therapy are appropriate.

27 SMART (Simultaneous Modulated Accelerated Radiation Therapy) Boost Technique–Correlation of Subjective Xerostomia and Dosimetric Parameters of the Parotid Glands

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Purpose/Objective: To correlate the dosimetric parameters of the parotid glands with subjective xerostomia in treatment of head and neck cancers with IMRT (Intensity Modulated Radiation Therapy) utilizing the SMART boost technique.

Materials/Methods: From January 1996 to June 2000, 30 patients with at least 6 months follow-up were evaluated for subjective xerostomia after being treated definitively for head and neck cancer with the SMART boost technique. The primary tumor is treated with accelerated fractionation (2.4 Gy/fraction) while regions at risk for microscopic disease are treated at conventional fractionation (2.0 Gy/fraction). Threshold limits for the ipsilateral and contralateral parotid glands were 35 Gy and 25 Gy respectively. Dosimetric parameters of the parotid glands were evaluated. The median follow-up time was 38.5 months (mean 39.9 months). These patients responded to a subjective salivary gland function questionnaire. The results of the dosimetric parameters and questionnaire were statistically correlated using the two-sided chi-squared test, ANOVA tables, and Fisher's exact test.

Results: Xerostomia: Xerostomia was assessed with a subjective salivary gland function questionnaire. Nine patients (30%) felt that their mouth was very comfortable. Eleven patients (36.7%) had slight dryness (RTOG grade 1), six (20%) had moderate dryness (RTOG grade 2), and four (13.3%) developed severe dryness (RTOG grade 3). Patients with more dryness had significantly higher mean and maximum dose to the contralateral parotid gland ($p = 0.008$ and 0.038).

The maximum dose to the contralateral parotid gland also correlated ($p = 0.031$) with a sense of dryness while eating. Patients

who had difficulty with swallowing and needed to sip liquids to swallow dry foods had significantly higher mean and maximum doses to both parotid glands.

The contralateral parotid mean and maximum doses as well as the volume of parotid above tolerance correlated with patients who felt the amount of saliva in their mouth was "too little" ($p = 0.021$, 0.005, and 0.017). The mean doses of both parotids as well as the maximum dose of the contralateral parotid gland and percentage of each parotid gland above tolerance significantly correlated with patients who complained of altered sense of taste. Questions related to thirst, difficulty with speech or sleep, and the need to carry water daily did not correlate statistically with the dosimetric parameters of the parotid glands.

Questions that statistically correlated with the dosimetric parameters of the parotid glands had clustering of the mean doses to the parotid glands. Patients who responded favorably to questions regarding overall dryness, difficulty eating, amount of saliva, and altered taste had average contralateral mean parotid doses ranging from 12.6 to 16.2 Gy while patients who responded negatively had average mean doses ranging from 21.3 to 24.5 Gy. A similar clustering of mean doses was seen in the ipsilateral parotid gland for questions regarding difficulty swallowing and altered taste. The average ipsilateral mean parotid doses ranged from 17.8 to 21.1 Gy for patients who responded favorably compared with 26.6 to 28.3 Gy for patients who responded negatively.

Conclusions: The salivary gland function questionnaire correlated significantly with the dosimetric parameters of the parotid glands. The threshold for worsening subjective xerostomia in this review was in the range of 21 to 26 Gy for the ipsilateral parotid and between 16 and 21 Gy for the contralateral parotid. These results will alter our prescription thresholds and treatment plan evaluation regarding the parotid glands. IMRT in the treatment of head and neck cancer can be exploited to preserve the parotid glands and decrease xerostomia. This is feasible even with an accelerated treatment regimen like the SMART boost. More patients need to be evaluated utilizing IMRT to identify the relevant dosimetric parameters and define the threshold for which subjective xerostomia is apparent.

28 Endothelial Dose Enhancement Due to Stent Struts in an In-Stent Restenosis Model for Intravascular Brachytherapy Sources

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Purpose/Objective: High doses received by the endothelium and intima have been associated with the major complication of late thrombosis in intravascular brachytherapy (IVBT). The endothelial doses may be further enhanced by the back-scattered radiation from stent struts in the patients with in-stent restenosis. The amount of enhancement may depend on the type (gamma or beta) and energy of radiation, material and geometry of the stent, and distance from the stent strut surface. The purpose of this work is to quantify dose enhancement to the endothelium in the presence of steel struts using Monte Carlo simulation with ultra-fine 10micron spatial resolution for various IVBT sources.

Materials/Methods: We have studied four beta sources (P-32 balloon shell, P-32 wire, Y-90 coil, Ce/Pr-144 coil) and three gamma sources (I-125 wire, Yb-169 wire, Ir-192 wire). These radionuclides differ in their characteristic energies, 1.7 MeV, 2.3 MeV, 3.0 MeV for beta sources of P-32, Y-90, Ce/Pr-144, and 30 keV, 90 keV, 370 keV for gamma sources of I-125, Yb-169, Ir-192. For the coil source, we assumed a thin cylindrical shell of radioactive source. For P-32, we have studied two different types of geometry, one with a balloon shell and the other one with a wire. For the wire source, the radioactive core was in nitinol encapsulation. For each source, we determined the dose distributions with and without stent using Monte Carlo (MCNP4C) method. Steel stent struts of 63.5 micron thick and 100 micron wide were used for simulation and multiple struts were 30° apart equally spaced and radially placed at 1.5mm from the center of the source. Dose distributions were calculated using pie-shaped scoring voxels with ultra-fine (10micron) resolution up to 120micron from the strut surface on the luminal side. Stent factors, defined as ratios of doses with and without stent, were determined and plotted against angle and radial distances and compared for various sources studied.

Results: On the luminal side of the struts, we observed dose enhancement for all the IVBT sources except Ir-192. The stent factors are tabulated for the various sources in 10micron steps on the luminal side from the strut surface. For a given source, the stent factor is the highest adjacent to a strut, and decreases as the distance from the strut surface increases. For the three beta emitting sources, P-32, Y-90, and Ce/Pr-144, the maximum stent factors were 1.23, 1.19, and 1.14, respectively. For the gamma emitting sources, I-125, Yb-169, and Ir-192, the maximum stent factors were 1.19, 1.04, and 1.00, respectively. For each type of radiation, the stent factor increases as the energy of radiation decreases. The most pronounced dose enhancement was observed with P-32, the lowest energy beta source, and I-125, the lowest energy gamma source studied.

Conclusions: Dose enhancements to the endothelium due to stents for various IVBT sources have been quantified. These results suggest that patients with in-stent restenosis may receive higher luminal dose than those without stent. The amount of dose enhancement depends on the type and energy of radiation. The stent factors should be incorporated in treatment planning calculations of endothelial doses.

Table. Stent factors for IVBT sources

d (micron)	P-32 wire	P-32 shell	Y-90 coil	Ce/Pr-144 coil	I-125 wire	Yb-169 wire	Ir-192 wire
10	1.23	1.22	1.19	1.14	1.19	1.04	1.00
20	1.18	1.17	1.15	1.12	1.15	1.03	1.00
30	1.16	1.14	1.11	1.09	1.13	1.03	1.00
40	1.12	1.11	1.10	1.08	1.11	1.02	1.00
50	1.11	1.11	1.08	1.08	1.09	1.02	1.00
100	1.06	1.05	1.05	1.04	1.04	1.01	1.00

d: distance from stent strut surface on the luminal side