2056 POSTER

The Determination of the Individual Margins and Individual Internal Gross Tumour Volume in Hepatocellular Carcinoma Radiotherapy Using 4D-CT

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Purpose: To research the deficiencies of conventional margins in hepatocellular carcinoma radiotherapy comparing to the individual internal gross tumour volume (IGTV) and the individual margins which were obtained by 4D-CT.

Methods: 12 hepatocellular carcinoma cases were selected, achieved the 4D-CT scan after 3D-CT scan under free breathing (FB). 4D-CT were sort in10 phases and named CT_0, CT_{10}, ... CT_{90}. GTVs were contoured manually on 3D-CT and 4D-CT (labeled as GTV_{FB}, GTV_0, GTV_{10}, ... GTV_{90}). $IGTV_1$ was obtained from GTV_{FB} using conventional margins (2 cm in Z-axial, 1.5 cm in X-axial and Y-axial), and GTV_0, GTV_{10}, ... GTV_{90} were merged into $IGTV_2$, the individual margins in three axial were obtained from GTV_{FB} to $IGTV_2$, and $IGTV_3$ were obtained from GTV_{FB} using the individual margins. The volume of GTVs and IGTVs were compared.

Results: The individual margins of every axial were not symmetrical in particular in Z axial: +X axial 0.67±0.26 cm, −X axial 0.50±0.26 cm, +Y axial 0.65±0.28 cm, −Y axial 0.70±0.29 cm, +Z axial 1.18±0.66 cm, −Z axial 0.70±0.49 cm, and there were two patients' +Z-axial margins were not sufficient, all conventional margins of others were larger than individual margins. The volume difference among GTVs was not significant ($p > 0.05$); the volume of $IGTV_3$ (125.75±35.95 cm^3) was larger than $IGTV_3$ (71.97±28.65 cm^3), and $IGTV_2$ was larger than 50.77±14.37 cm^3, the volume difference among three IGTVs was significant ($\chi^2 = 22.00$, $p = 0.00$). The value of $IGTV_3/IGTV_3$, $IGTV_3/IGTV_2$ and $IGTV_3/IGTV_1$ were 3.61±0.82, 2.41±0.42 and 1.73±0.37.

Conclusion: The symmetrical conventional margins for hepatocellular carcinoma could include partial tumour off-target or too much normal liver tissue accepted irradiation. The individual margins and individual IGTV were very necessary in hepatocellular carcinoma radiotherapy.

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Insufficiency Fractures of the Sacrum Following Stereotactic Body Radiotherapy for Sacral Tumours

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Background: There is little data on the incidence of sacral insufficiency fractures following pelvic radiation therapy and existing studies are based on conventional fractionation. Stereotactic body radiotherapy (SBRT), characterized by dose escalation with hypofractionation, may pose even greater risks to sacral skeletal integrity. This study aims to define the incidence and risk factors for sacral insufficiency fractures following single-fraction and hypofractionated SBRT to the sacrum.

Methods: Hospital records of 43 consecutive patients who underwent SBRT for sacral malignancies between September 2005 and May 2009 were reviewed.

Baseline information (age, gender, menopausal status, body mass index, use of bone-thinning agents, presence of osteoporosis) were recorded. In addition, tumour characteristics (histology, lesion appearance and extent) and treatment parameters (dose/fractionation, prior radiation/surgery) were documented.

The primary end-point was development of new fractures or progression of pre-existing fractures at the treatment site. To obtain this information, pre- and post-treatment CT and/or MRI scans were reviewed with an experienced neuro-radiologist. Secondary end-points included pain scores, analgesic use, impact on function, and local tumour control.

Results: Median follow-up was 17 months. Common tumour histologies included sarcoma, renal cell, and prostate carcinoma; 47% of sacral lesions were lytic, 37% were sclerotic and the remainder were mixed. All patients were treated with SBRT (18−24 Gy/1# to 30 Gy/5#) with 45% receiving single-fraction regimens. 14% had a history of prior radiation (median dose: 30 Gy/10#).

Of the 43 patients, 5 developed sacral insufficiency fractures. In 4 of these cases, fracture progression occurred in the context of controlled local disease. Median time to fracture development was 8.2 months (range: 3.6–24.9 months). Symptoms varied from minimal pain requiring no intervention to severe pain refractory to standard analgesics and impacting on functional ability. Two of the five patients eventually underwent sacroplasty due to intractable pain, with both obtaining good pain relief. As the number of events was low, it was not possible to perform meaningful univariate/multivariate analyses to identify predictive factors for fracture progression. Radiographic local tumour control rates at 1 year were excellent (91.7%).

Conclusion: In this study, the actuarial incidence of sacral insufficiency fractures at 1 year was 8.2%, suggesting that the rate of fracture associated with sacral SBRT is low. However, larger prospective studies with longer follow-up are needed to better characterize incidence, clinical course and risk factors. In addition, novel therapeutic interventions such as sacroplasty need further study to determine their safety, efficacy and to establish indications for their use.

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IMRT as Focal Therapy in Chemo-Reduced Group II Retinoblastoma

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Background: Intensity modulated radiotherapy (IMRT) has the potential of reducing dose to adjacent critical structures, achieves better target coverage, dose uniformity and sharp dose fall-off. Therefore, aim of our present study is to assess the feasibility of IMRT as a focal therapy for chemo-reduced group II retinoblastoma with regard to target coverage and sparing adjoining critical normal structures.

Material and Methods: Two patients of chemo reduced group II retinoblastoma were undertaken for the study. Patients were immobilized in supine position with thermoplastic cast under general anesthesia. Planning CT was done with 3 mm slice thickness and Gross Tumour Volume (GTV) was delineated in CT images as per the post chemotherapy clinical, radiological and opthalamoscopic examination under anesthesia. A margin of 2 mm was given to generate Clinical Target Volume (CTV), a further expansion of 4 mm was given for Planning Target Volume (PTV). The delineated organs at risk (OAR) include optic nerve, temporal lobe, hypo-thalamo pituitary axis (HPA), lacrimal gland, orbit, cornea and the retina. Nine field non-coplanar beam arrangement was used for IMRT planning in the Pinnacle TPS for Elekta synergy linear accelerator. The planning objectives were: prescribed dose of 45 Gy/25f for PTV and HPA <37.5 Gy temporal lobes <37.5 Gy, lacrimal gland <34 Gy, orbit <20 Gy, lens <10 Gy, cornea <23 Gy and retina <40 Gy.

Results: IMRT achieved adequate coverage to the PTV. For both the patients, 95% of the PTV was covered by 98% of the isodose line. The calculated Conformity Indices (TVRI/VRI) were 0.9129±0.26. Homogeneity Indices (I_{max}/RI) were 1.1475±0.35. Quality of coverage indices (I_{min}/RI) were 0.80±0.30. For ipsilateral OAR doses, the maximum dose to the brain stem was 6.155±0.85 Gy and temporal lobe was 41.96±0.53 Gy. Maximum dose to the optic chiasm was 9.94±1.51 Gy. Optic nerve maximum dose was 46.81±0.74 Gy and cornea max dose was 21.98±9.32 Gy. Similarly, max dose for the lens and HPA were 19.51±0.50 Gy and 9.505±0.86 Gy, respectively. Maximum dose to the lacrimal was 42.41±2.32 Gy and mean was 21.62±1.37 Gy. Orbital mean doses were 17.04±2.34 Gy. The maximum doses to the retina were 46.50±0.72 Gy and mean doses were 31.75±0.67 Gy.

Conclusions: Delivery of IMRT as a focal therapy in chemo-reduced group II retinoblastoma is feasible and provides adequate dose coverage to the target volume. The IMRT spares the adjoining critical normal structures with the given priority apart from the lens.

2059 POSTER

Determination of PTV and ITV Margins for Pelvic Lymph Nodes Irradiation in Prostate Cancer Patients Using Multiple CBCT Imaging

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Background: Pelvic lymph nodes (PLN) are commonly irradiated in men with prostate cancer. Based on the ICRU definition, the Planning Target Volume (PTV) margin added to the Clinical Target Volume (CTV) can be divided in a movement related Internal Margin (IM) and a Setup Margin (SM). Traditionally, it was assumed that PLN moved closely with bone structures. Image Guided Radiotherapy (IGRT) now enables a more precise bony anatomy positioning, reducing SM. Hence, the IM has a stronger relative impact on the PTV margin. This study determines the appropriate Internal Target Volume (ITV) margin and the global PTV margin required for the treatment of PLN.

Materials and Methods: Rectum, bladder and nodal CTVs of 7 patients were delineated on 70 CBCT in addition to their planning CT contours by the same clinician based on current RTOG guidelines. Volume analysis was performed following two registration techniques. First, an offline automatic

bony structure fusion without any translational or rotational limitations was done. Secondly, the treatment isocenter position was reproduced with only a translation registration. In the first technique, target volume deformation and translation relative to the best bony anatomy match enabled the evaluation of the IM. With the second technique, direct evaluation of the complete PTV (combined IM and SM) margin is possible. For both, we tested symmetric and asymmetric margins around the nodal CTV ranging from 0 to 10 mm. For each patient, the tested margins were applied on all CTs and CBCTs data sets forming either an ITV or a PTV. This way, different virtual planning and treatment sequences were simulated. For each sequences, statistics of the relative volume of nodal CTV not overlapping the planned PTV or ITV was measured. Margin recipes were compared based on their maximum relative Non Overlapping CTV Volume (NOV) for 95% of treatment fractions, 90% of possible planning and 90% of patients. Delineation error was evaluated by repeating contouring of the same images.
Results: The symmetric expansion analysis showed that with a NOV threshold of 3%, the obtained margins are 4 mm and 5 mm for ITV and PTV respectively. For asymmetric ITV, with same NOV threshold, the margins are 3 mm in all directions except anteriorly and internally which are 5 mm. With one observer, the measured delineation error was 1 mm. This value might increase with multiple observers.
Conclusion: In the future, we will validate this geometric margin analysis with a dosimetric approach involving 3 different methods of adaptive radiation therapy where PLN are treated with a bony anatomy match while simultaneously treating the prostate located by implanted gold markers. These techniques may further reduce both prostate and PLN margins.

2060 POSTER

Flattening Filter-free Beams for Extreme Hypofractionated Radiotherapy of Localized Prostate Cancer

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Background: Short hypofractionated schedules for localized prostate cancer are investigated with high-dose-rate brachytherapy or Cyberknife® stereotactic body radiotherapy (SBRT). We tested the ability to deliver the dose of 38 Gy in 4 fractions and distributions of flattening filter-free (FFF) photon beams with TrueBeam® linear accelerator SBRT plans.
Material and Methods: Treatment planning study was performed on CT scans of 7 patients with localized carcinoma of prostate using 10 MV FFF photon beams (X10FFF) of TrueBeam® linear accelerator (Varian Medical Systems). Planning target volume (PTV) included the prostate and base of seminal vesicles defined by MRI and CT imaging, plus a 2 mm volume expansion in all directions, except posterior, where the prostate abutted the rectum and expansion was reduced to zero. Urethra and rectum were identified on MRI and CT imaging and delineated on CT slices where PTV contour was present. Volumetric intensity modulated arc therapy (VMAT) plans were prepared in Eclipse® treatment planning system (PRO 8.9, AAA 8.9). The prescribed dose (PD) was 4 x 9.5 Gy = 38 Gy. PTV coverage was 95% of PD, allowing maximum dose of 200% of PD. Maximum dose (Dmax) for organs at risk (OAR) including rectum and rectal mucosa was 100% and 75%, for urethra and bladder 120% of PD, respectively. Two 360º arcs with maximum dose rate of 2400 monitor units (MU)/min were used. Plans were normalized to Dmax. Number of MU, treatment delivery time, dose parameter for PTV coverage and dose to OAR were recorded.
Results: Prescription isodose was 74.8–81.0%. PTV coverage, urethra, rectum and bladder statistics are shown in the table.

	Mean ± 1 Standard Deviation
PTV V100 (%)	97.72±0.16
PTV D90 (Gy)	39.15±0.13
Urethra Dmax (Gy)	41.42±1.07
D10 Urethra (Gy)	40.47±0.81
D50 Urethra (Gy)	39.71±0.78
Rectum solid	9.04±1.50
Rectal mucosa Dmax (Gy)	28.95±1.07
Rectal mucosa D1 (Gy)	27.47±0.98
Rectal mucosa D10 (Gy)	21.99±1.15
Rectal mucosa D25 (Gy)	14.77±2.31
Bladder solid	3.34±1.51
Bladder Dmax (Gy)	35.92±2.39

On average 3677 MU ± 542 were used and maximum dose rate was 1462–2400 MU/min. Average dose rate was 1961 MU/min ±468. Treatment delivery time for all patients was 2 min.
Conclusion: Non-invasive FFF SBRT is feasible and dose constraints for PTV coverage and OAR are met similar to high-dose-rate brachytherapy or Cyberknife®. Homogeneous target coverage is achieved while sparing urethra and rectum. FFF SBRT for localized prostate cancer allows fast and safe delivery of extreme hypofractionated radiotherapy and may help to reduce the impact of organ motion.

2061 POSTER

Clinical Evaluation of 6 Degree-of-freedom X-ray Image-guidance Fusion Algorithm and Robotic Positioning System for Frameless Cranial Radiosurgery

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Purpose: (1) To use stereoscopic x-rays paired with infrared (IR) tracking (ExacTrac®) to determine patient positioning error in frameless cranial radiosurgery, and (2) to evaluate the effects of region-of-interest (ROI) exclusion on 6D fusion results.
Methods and Materials: (1) Positioning errors were quantified through restrospective analysis of ExacTrac images taken for 17 patients (23 targets). All images (196) were sorted into 2 categories: initial and verification. Initial images are acquired after patient setup using an IR camera system and fiducial array. Verification refers to subsequent images used to check patient position. Corrections greater than the tolerance of 0.7 mm/1º were required in 49/173 image sets requiring patient repositioning, no corrections were made in the remaining 124 sets.
(2) ROIs including (i) air external to the skull, (ii) mandible, and (iii) neck are often manually excluded from 6D fusion. The effect of various ROI exclusion on the 6D fusion was assessed by repeating fusions using varying ROIs for 12 patients.
Results: See the table.

Displacement	Study					
	(1) Deviation detected in:			(2) Difference in fusion: no blocking vs. blocking of ROI:		
	Initial	Verification		(i)	(ii)	(iii)
		Correction	No correction			
Translation (mm)						
Lat	0.3±1.2	0.3±0.9	0.0±0.3	0.05±0.07	0.03±0.04	0.07±0.07
Lng	−0.2±1.9	0.5±1.1	0.1±0.3	0.06±0.04	0.16±0.28	0.09±0.10
Vrt	−1.1±0.9	−0.6±1.2	−0.1±0.3	0.05±0.04	0.19±0.40	0.06±0.06
Rotation (degrees)						
Lat	0.0±0.9	0.0±0.9	0.0±0.3	0.08±0.09	0.21±0.25	0.12±0.09
Lng	0.2±1.0	0.0±0.0	−0.1±0.3	0.06±0.03	0.19±0.35	0.20±0.21
Vrt	0.0±0.6	0.5±0.9	0.0±0.3	0.11±0.25	0.22±0.46	0.12±0.19

Mean±SD (SD = Std. Dev.)

(1) The largest shifts were detected upon initial positioning in the mask using the IR array only. SD of applied corrections was up to 1.2 mm/0.9º. In 71% of image sets, detected shifts were below the pre-determined tolerance (SD 0.3 mm/0.3º in all directions).
(2) ROI exclusion effects 6D fusion. Minimal differences were seen when excluding air only but deviations up to 1.4 mm/1.6º were seen when bony anatomy (lower jaw & neck) were excluded from 6D fusion.
Conclusion: Large initial positioning errors (>1 mm) were detected with ExcaTrac when using the mask, fiducial array and camera only for patient setup. Intrafraction motion greater than 0.7 mm/1º were observed in 29% of images. Residual shifts detected by ExacTrac are on the order of 0.3 mm (95% CI < 0.7 mm). Excluding bony anatomy that is not rigid with respect to intracranial target (lower jaw and neck) will effect the magnitude of shifts detected using 6D fusion.

2062 POSTER

Comparative Study Between Coplanar and Non-coplanar Techniques in Radiotherapy of Abdominal Tumours

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Background: Radiotherapy treatment using 3D techniques for abdominal tumours is usually extremely difficult if we focus on gastric or pancreatic cancers, due to the irregularity of the PTV's and the proximity of many organs at risk. Of these, the most critical are often the kidneys due to its constraints that are hard to achieve. To overcome this, in our center are using non-coplanar treatment techniques, and the comparison with previously used techniques is the aim of our study.