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Advantages of Whole-liver Intensity Modulated Radiation Therapy in Children With Wilms Tumor and Liver Metastasis

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Summary

This study was undertaken to demonstrate the dosimetric advantages of IMRT in children with Wilms tumor (WT) undergoing whole-liver (WL) radiation therapy (RT). Treatment plans with IMRT and standard AP-PA for left- and right-sided WT were performed. The dose coverage of WL PTV and radiation protection of the remaining kidney were significantly better for IMRT compared with AP-PA. The use of 4-dimensional CT scans for planning also improved dose coverage of the WL PTV.

Purpose: To demonstrate the dosimetric advantages of intensity modulated radiation therapy (IMRT) in children with Wilms tumor (WT) undergoing whole-liver (WL) RT.

Methods and Materials: Computed tomography simulation scans of 10 children, either 3 (3D) or 4-dimensional (4D), were used for this study. The WL PTV was determined by the 3D or 4D liver volumes, with a margin of 1 cm. A total of 40 WL RT plans were performed: 10 each for left- and right-sided WT with IMRT and anteroposterior-posteroanterior (AP-PA) techniques. The radiation dose-volume coverage of the WL planning target volume (PTV), remaining kidney, and other organs were analyzed and compared.

Results: The 95% dose coverage to WL PTV for left and right WT were as follows: 97% ± 4% (IMRT), 83% ± 8% (AP-PA) ($P<.01$) and 99% ± 1% (IMRT), 94% ± 5% (AP-PA) ($P<.01$), respectively. When 3D WL PTV was used for RT planning, the AP-PA technique delivered 95% of dose to only 78% ± 13% and 88% ± 8% of 4D liver volume. For left WT, the right kidney V15 and V10 for IMRT were 29% ± 7% and 55% ± 8%, compared with 61% ± 29% ($P<.01$) and 78% ± 25% ($P<.01$) with AP-PA. For right WT, the left kidney V15 and V10 were 0 ± 0 and 2% ± 3% for IMRT, compared with 25% ± 19% ($P<.01$) and 40% ± 31% ($P<.01$) for AP-PA.

Conclusions: The use of IMRT and 4D treatment planning resulted in the delivery of a higher RT dose to the liver compared with the standard AP-PA technique. Whole-liver IMRT also delivered a significantly lower dose to the remaining kidney.

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Introduction

Children with favorable-histology Wilms tumor (WT) and liver metastasis who were treated on National Wilms Tumor Study Group (NWTS)-4 and -5 had a 5-year event free survival of 76%. The survial rates for children treated with or without primary surgical resection or radiation therapy (RT) of the liver metastasis were 86%, 68%, and 77%, respectively (1). Radiation therapy has been an integral component of the multimodality regimen for liver metastases in the NWTS and Childrens Oncology Group (COG) protocols. Although liver RT is not recommended after complete resection of a solitary metastasis, it is routinely used in patients with partially resected or unresected metastases and in patients who receive up-front chemotherapy before surgery. Children with solitary lesions are treated with small-field RT, and those with diffuse liver metastasis receive whole-liver (WL) RT. All WT protocols recommend the use of a pair of opposing anteroposterior and posteroanterior (AP-PA) fields to deliver WL RT to 19.8 Gy. Renal blocking is required to limit the remaining kidney dose to $\leq$14.4 Gy. The main advantage of intensity modulated radiation therapy (IMRT) over 3-dimensional (3D) conformal RT is its ability to irradiate tumor-bearing tissues with greater precision while minimizing the dose to adjacent normal structures (2). This study was undertaken to determine the dosimetric advantages of WL IMRT compared with the standard AP-PA technique.

Methods and Materials

Patient data and organ contouring

The computerized tomography (CT) simulation scans of 10 children (median age 7 years, range 2-18 years) who were treated with RT in our department were used for this study. The CT simulations were performed on a Philips CT simulator (Cleveland, OH) (85-cm bore, 60-cm field of view), and the CT slice thickness was 2-3 mm at 2- to 3-mm intervals. The CT scans were either 3D (4 children) or respiration-gated 4D (6 children). The 4D liver scans were done on a Philips CT scanner using bellows under free-breathing conditions, and the scans were binned according to the respiratory phases ranging from 0 through 90. A composite maximum-intensity projection (MIP) scan was created from the gated scans. For children who had 3D scans the WL planning target volume (PTV) was determined by contouring the 3D WL volumes with an additional margin of 1 cm, as recommended in current COG protocols. For patients who had 4D scans, a WL internal target volume was generated by outlining the liver volumes on the 4D-CT MIP scans. An additional margin of 1 cm was added to the 4D WL volume to obtain the 4D liver PTV. The main organ at risk from radiation toxicity was the remaining kidney. The normal tissues that were contoured for analysis include the remaining kidney, heart, ventricles, and lungs.

Treatment planning and dose-volume analysis

All 10 patients were simulated to have a left- or right-sided WT requiring WL RT. The CT data were used to perform WL RT plans with IMRT and AP-PA techniques (ADAC Phillips Pinnacle^3 8.0 m planning system, Cleveland, OH) using 6-MV X-rays (Elekta SLI linear accelerator, Crawley, UK; 10-mm leaf thickness at isocenter). Thus, a total of 40 WL RT plans were performed: 10 plans each for IMRT and AP-PA for right and left WT, respectively. The RT plans were performed using 6-MV X-rays. Tissue heterogeneity corrections were used during treatment planning. The total prescribed dose to the liver was 19.8 Gy in 11 fractions. In accordance with COG protocol guidelines, an AP-PA kidney block was inserted over the remaining kidney with the AP-PA technique to limit the renal dose to $\leq$14.4 Gy. For the IMRT technique a 7-beam IMRT plan with approximately 70 total segments was used. The WL volume and WL PTV coverage by the prescribed dose and the normal tissue organ volumes (V) receiving > RT doses (Gy)—V18, V15, V10, and V5—were compared for the 2 techniques. The radiation dose-volume data to the remaining kidney, whole heart, left and right ventricles, and lungs were analyzed.

Statistical analysis

The percentage volumes of target organs (WL and WL PTV) and organs at risk (kidney, heart, ventricles, lungs) receiving specific doses from the AP-PA and IMRT techniques were compared using the 2-tailed paired-samples t test. Statistical significance was defined as $P<.05$.

Results

Liver dose coverage with IMRT and AP-PA techniques

Data are displayed in Table 1. For left-sided WT patients, the WL coverage without margins by 95% dose was 99% $\pm$ 1% (IMRT) compared with 86% $\pm$ 10% (AP-PA) ($P<.01$). For right-sided WT the WL coverage without margins was 100% $\pm$ 0 (IMRT) compared with 96% $\pm$ 3% (AP-PA) ($P<.01$). The dose coverage to the WL PTV for left- and right-sided WT was 97% $\pm$ 4% (IMRT), 83% $\pm$ 8% (AP-PA) ($P<.01$), 99% $\pm$ 1% (IMRT) and 94% $\pm$ 5% (AP-PA) ($P<.01$), respectively (Figs. 1 and 2).

Liver dose coverage with 3D and 4D scans

The 4D WL PTV (mean 2418 cm^3, range 1103-4003 cm^3) was significantly larger than the 3D WL PTV (mean 2277 cm^3, range 1058-3875 cm^3) by 6.5% $\pm$ 2.9% ($P<.01$). This significant

Table 1 Liver dose from IMRT and AP-PA techniques

Volume covered by 95% of prescribed dose	Left-sided Wilms tumor			Right-sided Wilms tumor		
	IMRT (%)	AP-PA (%)	P	IMRT (%)	AP-PA (%)	P
Liver			<.01			<.01
Mean	99	86		100	96	
SD	1	10		0	3	
Liver PTV			<.01			.01
Mean	97	83		99	94	
SD	4	8		1	5	

Abbreviations: IMRT = intensity modulated radiation therapy; AP-PA = anteroposterior-posteroanterior.