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Cone beam CT

Cone beam CT for organs motion evaluation in pediatric abdominal neuroblastoma

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ABSTRACT

Background and purpose: To quantify the organ motion relative to bone in different breathing states in pediatric neuroblastoma using cone beam CT (CBCT) for better definition of the planning margins during abdominal IMRT.
Methods and materials: Forty-two datasets of kV CBCT for 9 pediatric patients with abdominal neuroblastoma treated with IMRT were evaluated. Organs positions on planning CT scan were considered the reference position against which organs and target motions were evaluated. The position of the kidneys and the liver was assessed in all scans. The target movement was evaluated in four patients who were treated for gross residual disease.
Results: The mean age of the patients was 4.1 ± 1.6 years. The range of target movement in the craniocaudal direction (CC) was 5 mm. In the CC direction, the range of movement was 10 mm for the right kidney, and 8 mm for the left kidney. Similarly, the liver upper edge range of motion was 11 mm while the lower edge range of motion was 13 mm.
Conclusions: With the use of daily CBCT we may be able to reduce the PTV margin. If CBCT is not used daily, a wider margin is needed.

Recent advances in radiotherapy have addressed the effect of patient movement, organ motion, and anatomical deformation on treatment delivery accuracy. For computer-assisted radiotherapy planning, each computed tomography (CT) slice represents a "snapshot" in a random breathing phase and does not account for the interfraction or intrafraction organ motion that can occur during a radiotherapy course [1].

Day-to-day positioning variations are another source of uncertainty for which effective strategies such as various image-guided radiotherapy (IGRT) techniques are being used with increasing frequency [2].

The intrafraction change of the gross target volume (GTV), clinical target volume (CTV), and organ at risk positions is derived from respiration, cardiac motion, and peristalsis. Trials have addressed this issue in thoracic and liver tumors, either by treating a patient using a breath hold technique or by applying respiratory gating while the patient is breathing normally [3,4]. Other methods have also been used including fluoroscopic tracking of visible anatomic or fiducial markers [5], and four-dimensional (4D) CT [6].

The interfraction organ motion needs to be taken into account during the planning process. Daily variations of hollow organ filling, weight loss or gain, tumor growth or shrinkage, and radiation-induced changes contribute to interfraction organ motion [7].

To address all these uncertainties, the International Commission on Radiation Units and Measurements report 62 recommended a margin to be added to the CTV to produce the planning target volume (PTV) [8]. However, significant clinical uncertainty is often present in defining the appropriate PTV margin according to the anatomical site, age group, and the quality of portal imaging technique in use.

The use of IGRT technologies, such as cone beam CT (CBCT), improves treatment delivery accuracy [9]. This increase in accuracy can be translated into a smaller PTV margin and thereby reducing the consequent collateral damage to normal tissues [10].

Irradiation of abdominal tumors like neuroblastoma in pediatric patients is a challenging situation. Delivering an adequate dose to the target with acceptable doses to the surrounding critical tissue is of utmost importance [11]. Reducing the PTV and the planning organ at risk volume (PRV) by regular use of CBCT may impact on achieving better planning objectives. But data regarding organ motion in this age group are scarce.

Aim of the work

To quantify the abdominal organ and the target motion in pediatric patients during IMRT in Neuroblastoma cases, using CBCT aiming for better definition of PTV and PRV margins.

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Patients and methods

CBCT of 9 patients with the diagnosis of abdominal neuroblastoma treated with IMRT was reviewed. All patients received treatment under general anesthesia (GA) with a minimum of 6 h fasting prior to treatment. The number of dataset images varied from 4 to 6 for each patient, according to the discretion of the treating physician. A total of 42 datasets were evaluated.

Planning CT scan

Planning CT scan was obtained according to the standard practice at King Faisal Specialist Hospital and Research Center (KFSH &RC), under GA with free breathing using wide bore CT. A vacuum formed body cradle customized to each patient (extending from the mid thorax to the feet) was used for immobilization. This planning CT scan was considered the basic reference for organs/target position and for motion evaluation.

Target and tissue delineation

The gross tumor volume was defined as the primary tumor volume visualized on the CT scan done between cycle 4 of chemotherapy and surgery (GTVpre). The CTV comprised the GTVpre plus a 15 mm margin, and the PTV included the CTV plus a 10 mm margin in the craniocaudal direction (CC), and 5 mm margin in the other directions. Organs at risk (OAR) included the kidneys, liver, and the vertebral bodies. The CTV was automatically generated from the GTV by the treatment planning software and was then altered manually to generate a 2 mm rather than a 15 mm margin on the kidneys, liver, and vertebral bodies. The PTV was planned to receive a cumulative dose of 21.6–25.2 Gy given in daily fractions of 1.5 or 1.8 Gy.

CBCT

CBCT was acquired using the on-board imager (OBI, Varian Medical Systems), a system specifically developed for IGRT applications. The OBI consists of a diagnostic X-ray tube and a kV-flat panel imager, both mounted on robotic arms and designed for orthogonal radiographs for 3-D patient set-up and cone beam kVCT (CBCT). Full Fan beam was used for all patients to develop the CBCT datasets. The patients' anatomy settings as detected in the CBCT datasets were automatically registered to the planning CT. The CBCT datasets were then evaluated for PTV coverage and OAR.

Treatment was delivered on a Varian 2100C linear accelerator equipped with Rapid Arc (Varian Medical Systems). CBCT was taken in the first 3 days of treatment, and then once weekly or more throughout the treatment course as per discretion of the treating physician. These CBCT datasets were matched and compared with the treatment planning CT.

Organs motion

All measurements were done offline using Varian system (ARIA offline review). For each dataset, the kidneys position was assessed in relation to the nearest vertebral body in the craniocaudal (CC), anteroposterior (AP), and mediolateral (ML) directions. The CC and ML movements were assessed in the coronal view. The upper pole of the kidney was chosen as the point of interest. In order to confirm that the same coronal plane is used every time we measured the kidney length in different planes and we used the plane with the maximum kidney length. The AP movement was assessed from the most anterior surface in the axial view at the level of the renal artery. The liver position was assessed in the CC direction for the upper border and the most lateral part of the lower border separately in the coronal view. Again, in order to confirm that the same plane is chosen every time we measured the liver length in different coronal planes and we used the plane with the maximum liver length. For the four patients treated for gross residual disease, the position of the target was assessed, in respect to the nearest vertebra, in the CC, AP, and ML directions in a similar way.

Evaluation of the effect of change in the PTV on dose to critical structures

After initial evaluation of the target and critical structures movements, and in order to evaluate the value of reducing the PTV based on these measurements, two PTVs were generated for each case. In the first one (PTV1), a margin of 1 cm was generated in the superior inferior direction and a margin of 5 mm in the other directions. For the second PTV (PTV2), a margin of 5 mm was generated in the superior inferior direction and a margin of 3 mm in the other directions. IMRT planning was done in order to compare doses to the critical structures in both PTVs using the same constraints. IMRT planning was done using Eclipse Varian system.

Statistical method

Quantitative data were presented as mean and standard deviation using SPSS version 15.

Ethical considerations

The study has been approved by the research committee at King Faisal Specialist Hospital and research center. All data were retrospectively reviewed. CT datasets were done according to the department guidelines for pediatric tumors, and at the discretion of the primary physician based on the PTV and PRV used in each case.

Results

The mean age of the studied patients was 4.1 ± 1.6 years. The mean liver volume was 479.5 ± 163 cc. The mean right and left kidney volumes were 44.5 ± 12 and 49 ± 14.8 cc, respectively.

Target position

The mean CTV volume was 144.9 ± 130. Only 4 patients had gross residual disease. Conspicuous calcifications within the residual tumor made correlation and measurements easier on CBCT (Fig. 1). The range of target movement in the CC direction was 5 mm, and it was limited to 3 and 2 mm in the AP and ML directions, respectively.

Kidney position

The right kidney movement was mainly in the CC direction and it ranged from 4 mm inferiorly in one case to 10 mm superiorly in another case compared to the planning CT. But the range of movement was limited to 10 mm only. The movement in the other two directions was limited to 1 mm. The left kidney range of movement in the CC direction was less than the right kidney as it ranged from 4 mm inferiorly to 8 mm superiorly compared to the planning CT and when we examined each case individually, the range was limited to 8 mm. All measurements were done with respect to the upper pole. It was clear that not all of the changes were related to movement as there was also a change in the kidney size between fractions (Fig. 2).