Should There be More Optimisation of Cone Beam CT Imaging Used with Image Guided Radiotherapy?

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PURPOSE

Cone beam computed tomography (CBCT) is used for improving delivery of image guided radiation therapy (IGRT). Scans are performed at regular intervals during the delivery of treatment. However, less attention is paid to optimisation of radiation protection for the imaging of individual patients than in diagnostic applications. Scan lengths for multi-detector CT (MDCT) are chosen according to the height of the patient and the extent of the organs of interest, based on a scan projection radiograph. In addition, the radiation level is adjusted through automatic modulation of the tube current, based on attenuation of the patient's body. However, at the present time, standard field sizes and exposure factors for CBCT are used for all patients in the majority of centres. As a result, the doses received by the organs of each patient from CBCT scans vary substantially according to their height and girth, with smaller patients receiving higher doses. There are difficulties for CBCT in that the scan position is determined primarily by that of the planning target volume, whereas MDCT scans tend to cover standard regions of the body for most patients, but nevertheless there are significant opportunities for optimisation. In this study Monte Carlo simulations have been used to study the influence of CT beam width on organ doses. Coefficients have also been derived to facilitate assessments of effective dose for a reference patient that might be used in dose evaluations required in optimisation of CBCT procedures.

METHODS and MATERIALS

Monte Carlo (MC) simulations based on a Varian On-Board-Imaging (OBI) system have been used to derive organ doses for ICRP reference male and female phantoms for scan protocols with different beam widths. The aim was to assess the variations in organ doses when the scanned region is not adjusted for the individual patient. Default scan protocols are released in parallel with new software, and these may change the scan field as well as exposure parameters. This study compares organ and effective doses from a software version (V2.5) using a beam width of 214 mm with those from a previous version (V1.6) with a beam width of 198 mm. The results investigate the effect of variations in field size, essentially changing the ratio of field size (scan length) to patient height on organ doses. Such differences will be similar to those resulting from variations due to use of a standard field size for patients of varying height. The MC simulations used to model the kV beam from the OBI system and their validation against experimental measurements have been reported in Abuhaimed et al. (2014 and 2015). The MC model used to calculate the organ doses for the ICRP reference phantom is described in Martin et al (2016). A modified version of the standard CT dose index (CTDI) has been proposed by the IEC ($CTDI_{IEC}$) for CBCT based on measurements with longer CTDI chambers. A dose–width product can be calculated by multiplying the $CTDI_{IEC}$ by the width of the CBCT beam (Abuhaimed and Martin 2018). Coefficients have been derived that can be used for dose assessment and linked to effective dose to give dose information that can be useful for the purpose of optimisation.

RESULTS

Organ doses have been derived from the scan protocols for the thorax (Table 1) and pelvis (Table 2) with different beam widths. Since the changes in scan length were accompanied by a small increase in mAs, results have been normalised with respect to the same standard mAs value, but similar to those used for the scans. Doses to organs from the thorax scan were typically 10-18% higher, with the effective dose, which gives an indication of doses to all radiosensitive organs, being 16% higher. However, the dose to the thyroid was 48% higher in the male and 75% higher in the female, as this lay near the edge and was brought into the beam by extension of the scan field. For the pelvic protocol, organ doses were increased by 10-13% by the extension of the scan field. The effective dose applies to a reference patient, so is not generally useful for assessing doses to individuals, however, since it is derived from a summation of doses to all organs thought to be radiosensitive, it can give an indication of general increase in dose for all organs with field size. MC simulations have been used to derive coefficients to allow estimation of effective doses for reference phantoms from the dose-width product for the thorax (0.0252 mSv $(mGy\ cm)^{-1}$) and pelvis (0.0150 mSv $(mGy\ cm)^{-1}$) protocols, which could be helpful in assessing optimisation of the imaging process.

Table 1: Organ and effective doses per 250 mAs for the adult male and female ICRP phantoms resulting from thorax scan protocols using cone beams of widths 198 mm and 214 mm (scan 270 mAs).

Thorax	Male (mGy)		Female (mGy)	
Organ / Tissue	198 mm	214 mm	198 mm	214 mm
Bone marrow (red)	2.5	2.9	2.8	3.3
Breast	7.1	7.7	9.6	10.3
Lung	7.5	8.3	9.4	10.4
Stomach	3.4	4.2	2.6	3.4
Thyroid	2.5	3.7	3.2	5.6
Oesophagus	6.1	7.0	7.6	8.9
Effective dose (mSv)	3.1	3.6	3.7	4.3

Table 2: Organ and effective doses per 1000 mAs for the adult male and female ICRP phantoms resulting from the pelvic scan protocols using cone beams of widths 198 mm and 214 mm (scan 1070 mAs).

Pelvis	Male (mGy)		Female (mGy)	
Organ / Tissue	198 mm	214 mm	198 mm	214 mm
Bone marrow (red)	12.4	14.0	14.0	15.8
Colon	10.6	12.0	26.0	30.5
Urinary bladder	42.4	47.6	45.8	50.7
Prostate / Uterus	32.7	36.4	35.5	39.3
Gonads (Testes / Ovaries)	3.4	4.4	34.8	39.2
Effective dose (mSv)	6.0	7.0	11	12

CONCLUSIONS

Results of this study show that doses to radiosensitive organs in the trunk can be increased substantially by small extensions in the width of the CBCT beam used with IGRT. Since standard values of CBCT beam widths are used currently in many radiotherapy centres, and the scans are repeated regularly, sometimes on a daily basis, the doses from imaging could be reduced substantially through adjustment of the beam width as well as the exposure factors to suit individual patients. Since the scans are repeated, the appropriate beam width could be established when the procedure was first performed, and thereafter a single image used to select the patient position for subsequent scans. Since the adjustments to field size are more difficult to make with CBCT, modifications to the OBI systems may be required to facilitate optimisation. However, since the dose savings could be of the order of 10s of percentage points for smaller patients, and doses from repeated imaging can be considerable, the provision of such facilities is worthwhile. Data on effective doses from CBCT imaging can be used in making judgements on the contributions to patient dose from imaging, and thereby assist in optimisation of IGRT regimes. Coefficients have been derived to enable calculations to be made based on the dose-width product to facilitate calculations.

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