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What is the underestimation of radiation dose to the pediatric thyroid gland from contrast enhanced CT, if contrast medium uptake is not taken into account?

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ABSTRACT

Purpose: To assess the underestimation of radiation dose to the thyroid of children undergoing contrast enhanced CT if contrast medium uptake is not taken into account.
Methods: 161 pediatric head, head & neck and chest CT examinations were retrospectively studied to identify those involving pre- and post-contrast imaging and thyroid inclusion in imaged volume. CT density of thyroid tissue in HU was measured in non-enhanced (NECT) and corresponding contrast-enhanced CT (CECT) images. Resulting CT number increase (ΔHU) was recorded for each patient and corresponded to a % w/w iodine concentration. The relation of %w/w iodine concentration to %dose increase induced by iodinated contrast uptake was derived by Monte Carlo simulation experiments.
Results: The thyroid gland was visible in 11 chest and 3 neck CT examinations involving both pre- and post-contrast imaging. The %w/w concentration of iodine in the thyroid tissue at the time of CECT acquisition was found to be 0.13%–0.58% w/w (mean = 0.26%). The %increase of dose to thyroid tissue was found to be linearly correlated to%w/w iodine uptake. The increase in radiation dose to thyroid due to contrast uptake ranged from 12% to 44%, with a mean value of 23%.
Conclusions: The radiation dose to the pediatric thyroid from CECT exposure may be underestimated by up to 44% if contrast medium uptake is not taken into account. Meticulous demarcation of imaged volume in pediatric chest CT examinations is imperative to avoid unnecessary direct exposure of thyroid, especially in CT examinations following intravenous administration of contrast medium.

1. Introduction

The number of CT examinations performed annually has been steadily rising over the last two decades [1,2]. Pediatric CT exams represent over 10% of all CT exams performed globally and are likely to rise in frequency in the next decades due to high availability and rapid image acquisition [3]. As recently reported, more than 50% of CT examinations may be performed following intravenous administration of iodinated contrast medium [4]. However, the use of intravenous iodinated contrast agents has recently been associated with increased radiation dose to exposed organs in adult patients [4–6]. Radiosensitive tissues, such as the thyroid gland, have been reported to receive considerably higher radiation dose from CT, if acquisition is performed after contrast medium administration [4,5].

Current CT dosimetry methods may result in considerable underestimation of dose in contrast enhanced CT scans if the effect of iodine uptake to the exposed tissues is not taken into account. This underestimation may be particularly important in the case of pediatric patients, which are considered more radiosensitive compared to adults and present significantly elevated lifetime cancer risk following exposure to ionizing radiation [7,8]. The thyroid gland is primarily exposed during head-and-neck CT examinations, whereas primary exposure of the thyroid during chest CT scans may be occasionally unavoidable due to the close proximity of the thyroid to the thorax in children.

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The purpose of this study was to evaluate the underestimation of radiation dose to the thyroid of pediatric patients subjected to CT imaging following administration of contrast medium.

2. Materials & methods

2.1. Pediatric CT studies

The electronic database of our hospital was utilized to retrospectively identify all head, neck, head & neck and chest CT examinations performed on patients aged from 1 day to 16 years old which included a non– enhanced CT (NECT) followed by a contrast-enhanced CT (CECT) scan. Among these, the examinations in which the thyroid gland was visible in both enhanced and unenhanced image series were selected. All CT examinations were performed either on a Siemens Somaton Sensation 16-slice CT scanner (Siemens AG, Forchheim, Germany) or on a GE Revolution HD 64-slice CT scanner (GE Healthcare, Waukesha, WI, USA).

2.2. Determination of contrast induced increase of thyroid CT number and tissue iodine uptake

The CT number of thyroid tissue expressed in Hounsfield units (HU) was measured before and after contrast administration in corresponding NECT and CECT scans. Regions of interest (ROIs) were placed in the same regions of the thyroid on corresponding NECT and CECT images, as centrally as possible, with attention to avoid the major vascular structures of the neck and the trachea. To improve accuracy, one ROI was positioned in each thyroid lobe in every reconstructed image where thyroid tissue was depicted and the area-weighted average was determined. The total number of ROIs employed for each thyroid ranged from 2 to 7, depending on thyroid visualisation and patient size. A mean HU value was calculated for each thyroid examined using the formula:

$$mean\ HU\ value = \frac{\sum (HU_{ROI_i} \cdot Area_{ROI_i})}{\sum Area_{ROI_i}}$$

where HU_{ROIi} and $Area_{ROIi}$ are the average HU and the area of i-th ROI, respectively.

The resulting mean HU values from each patient from NECT and CECT scans were used to calculate the CT number increase (ΔHU) value accordingly:

$$\Delta HU = meanHU_{CECT} - meanHU_{NECT}$$

The thyroid CT number increase (ΔHU) induced by contrast medium uptake was corresponded to a certain percent mass fraction of iodine (i.e.% w/w iodine concentration). Previously reported regression equations of the CT number increase against iodine concentration produced for CT acquisitions at 80, 100, 120 and 140 kV were employed [4].

2.3. Determination of contrast-induced increase of absorbed dose to thyroid

The Monte Carlo N-particle transport code (MCNP, version 4C2) was employed to simulate CT exposures performed on a General Electric Revolution HD CT scanner (GE Healthcare, Waukesha, WI, U.S.A) and a Siemens Somaton Sensation 16-slice CT scanner (Siemens AG, Forchheim, Germany), both installed at our institution. A mathematical phantom was formulated with the exact geometric characteristics and composition of the standard body polymethyl-methacrylate (PMMA) phantom containing aqueous solutions of iodine at the peripheral holes. Aqueous solutions of iodine with concentration 0.0, 0.1, 0.3 and 0.5% w/w were considered. The standard elemental compositions of PMMA and iodine-water solutions were implemented in the mathematical phantom. CT exposures of the mathematical PMMA phantom positioned at isocenter were simulated through Monte Carlo experiments. The absorbed dose to spherical volumes of interest (VOIs) of 8 mm in diameter was determined for CT beams produced at 80, 100 and 120 kV. VOIs were appropriately placed in the volume occupied by the iodine solutions. Given the geometrical symmetry of the cylindrical holes with respect to the center of the phantom and the alignment of the phantom with the isocenter, any differences in measured absorbed dose were attributed on the difference in iodine concentration of aqueous solutions. Plots of absorbed dose% increase against iodine concentration% w/w were produced and linear regression analysis was employed to determine corresponding mathematic functions for exposures at 80, 100 and 120 kV.

The contrast-induced% increase in radiation dose to the thyroid of each pediatric patient subjected to CT was estimated for the specific thyroid iodine uptake during acquisition using the plots of% absorbed dose increase against iodine concentration.

3. Results

Pediatric head, neck and chest CT examinations performed within a 3-year period in our institution were categorized regarding type, contrast administration and thyroid inclusion in imaged volume as shown in Table 1. The thyroid was not found to be included in imaged volume of pediatric head CT examinations. The thyroid was included in imaged volume of all pediatric neck and the majority of pediatric chest CT

Table 1
Number of pediatric CT examinations performed within a 3-year period in our institution categorized regarding type, contrast administration and thyroid inclusion in imaged volume.

Head/Sinus/Petrous Bone	Number of examinations	Chest	Number of examinations	Neck/head &neck	Number of examinations
NECT (−) Thyroid	55	NECT (−) Thyroid	0	NECT (−) Thyroid	0
NECT (+) Thyroid	0	NECT (+) Thyroid	28	NECT (+) Thyroid	8
CECT (−) Thyroid	0	CECT (−) Thyroid	3	CECT (−) Thyroid	0
CECT (+) Thyroid	0	CECT (+) Thyroid	20	CECT (+) Thyroid	0
NECT + CECT* (+) Thyroid	0	NECT + CECT* (+) Thyroid	11	NECT + CECT* (+) Thyroid	3
NECT + CECT (−) Thyroid	22	NECT + CECT (−) Thyroid	9	NECT + CECT** (−) Thyroid	2
Total	77	Total	71	Total	13

(−): not included in imaged volume, (+): included in imaged volume.
* Studies meeting the inclusion criteria.
** Thyroid was inadequately visualized to allow for accurate measurements