Effectiveness of the air-gap method in pediatric CT examinations

Takanori Masuda (takanorimasuda@yahoo.co.jp)
Tsuchiya Sogo Byoin https://orcid.org/0000-0002-4164-4369
Yoshinori Funama
Kumamoto University: Kumamoto Daigaku
Takeshi Nakaura
Kumamoto University: Kumamoto Daigaku
Tomoyasu Sato
Tsuchiya General Hospital: Tsuchiya Sogo Byoin
Shouko Masuda
Nitta clinic
Masao Kiguchi
Hiroshima University: Hiroshima Daigaku
Takayuki Oku
Tsuchiya General Hospital: Tsuchiya Sogo Byoin
Rumi Gotanda
Kawasaki University of Medical Welfare: Kawasaki Iryo Fukushi Daigaku
Keiko Arao
Kawasaki University of Medical Welfare: Kawasaki Iryo Fukushi Daigaku
Hiromasa Imaizumi
Kawasaki University of Medical Welfare: Kawasaki Iryo Fukushi Daigaku
Shinichi Arao
Kawasaki University of Medical Welfare: Kawasaki Iryo Fukushi Daigaku
Atsushi Ono
Kawasaki University of Medical Welfare: Kawasaki Iryo Fukushi Daigaku
Junichi Hiratsuka
Kawasaki University of Medical Welfare: Kawasaki Iryo Fukushi Daigaku
Kazuo Awai
Hiroshima University: Hiroshima Daigaku

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Abstract

Background: This study aims to investigate the suitability of the air gap method for radiation dose reduction in pediatric patients during computed tomography (CT) examinations.

Methods: We use pediatric anthropomorphic phantoms with a 64 detector-row CT scanner while scanning the chest. A real-time skin dosimeter is placed on the scanner gantry and is positioned at the center of the phantom, on the dorsal surface of the body, and on the left and right mammary glands. In the conventional method, the distance between the CT table and the subject was 0 mm. In the air gap method, the distance between the CT table and subject was 150 mm. We perform a helical scan between the conventional and air-gap methods from the lung apex to the subdiaphragm. The values of the real-time skin dosimeter and image noise are measured and compared for each method.

Results: Compared with the conventional method, it was possible to reduce the exposure dose and image noise by approximately 10% and 15%, respectively, using the air gap method ($p < 0.05$).

Conclusion: The airs gap method was useful for reducing the radiation dose by approximately 10% during pediatric CT examinations compared with the conventional method.

Introduction

In recent years, computed tomography (CT) has been used in various medical settings, and it has become widely available owing to technological advances [1]. However, CT radiation doses increase the risk of cancer induction [2-5]. In particular, in pediatric CT examinations, which have long residual lifetimes, dose reduction using appropriate examination is more important than in adults. Consequently, their radiation risk is two to three times that of adults [6]; therefore, the dose should be as low as is reasonably achievable (ALARA) [7].

One method for reducing the radiation dose is the air-gap method. In CT examinations, the air-gap method is assumed to improve image quality and reduce the exposure dose because the distance between the table and the subject is increased, thereby reducing the scattered radiation dose from the table. Compared with adults, children are smaller subjects, allowing for a greater distance from the CT table. There have been no reports on the usefulness of the air-gap method in pediatric CT examinations, and it has not been verified whether it improves image quality or reduces the radiation dose. If the air-gap method is effective, it can be useful as a new pediatric dose reduction method.

The purpose of this study was to investigate the effectiveness of the air-gap method for radiation dose reduction in pediatric patients during CT examinations.

Methods

Phantoms

A pediatric anthropomorphic phantom (ATOM Phantom; CIRS, Norfolk, Virginia, USA) representing an average newborn was used in this study. The expected weight and height of the neonate were 3.5 kg and 51.0 cm, respectively. A pediatric phantom is made of radiologically equivalent tissue material with internal structures, such as an artificial skeleton, lungs, and soft tissue, to accurately simulate clinical exposure.

Positioning of the subject

In the conventional method, the pediatric phantom is positioned at a height of 0 cm above the table. In the air-gap method, the pediatric phantom was positioned at a height of 15 cm above the table using 15-cm-thick polystyrene with low X-ray absorption (Figure 1).

CT scan

A 64-detector row CT scanner (Lightspeed VCT; GE Healthcare, Milwaukee, WI, USA) was used to perform the helical scan from the lung apex to the subdiaphragm. The scan range of the neonatal phantom was 100 mm, and scan parameters were as follows: helical mode, helical pitch 0.986, beam width of 40.0 mm, section thickness of 5.0 mm, gantry rotation time of 0.4 s, 64 × 0.625-mm detector collimation, a small scan field of view setting of 100 mm, a full-mode matrix size 512 × 512 mode, and a standard reconstruction kernel. The tube voltage was 80 kVp, the tube current was fixed at 50 mA, which is commonly used in clinical practice, and CT images were acquired using a filtered back-projection algorithm under a standard kernel/filter.

Dosimeters and dose measurement and computed tomography dose index

A real-time skin dosimeter (RD - 1000; Trek Corporation, Kanagawa, Japan) was placed in the scanner gantry, and the RD - 1000 dosimeter was positioned at the center of the phantom, on the dorsal surface of the body, and on the left and right mammary glands (Figure 2) [8]. The pediatric anthropomorphic phantom was then scanned 10 times for each method, and the measured dose values of the RD - 1000 were compared for both the conventional and air-gap methods. We then measured the CT dose index volume (CTDIvol) values on the CT console.

Comparison of radiation doses from 10-cm ionization chamber, computed tomography dose index volume, and RD-1000

Because it was necessary to confirm the accuracy of the CTDIvol of the console-displayed dose, we compared the measured CTDIvol of the console-displayed dose for the CT system and the 10-cm ionization chamber. The CTDIvol showed good linearity of the reference dose with the 10-cm ionization chamber. Because it was necessary to confirm the traceability of the RD-1000, we compared the doses from the 10-cm ionization chamber and the RD-1000 using a general X-ray radiography system. The RD-1000 demonstrated good linearity of the reference dose with the ionization chamber.

Measurement of image noise

The image noise [standard deviation (SD) of CT values] was measured at the center of the phantom at the level of the mammary glands area within a 10.0-mm diameter region of interest. A radiologist with 26 years of experience performed the measurements. For each scan, image noise was measured five times at a total of five points at the margins and at the center. The mean of the image noise was calculated and the image noise was compared for each protocol.

Statistical analysis

The Mann-Whitney U test was used to compare the measured dose values, image noise, and CTDIvol measurements; differences with a P-value < 0.05 were considered statistically significant. Statistical analyses were performed using the free statistical software platform R (version 3.0.2; R Project for Statistical Computing, http://www.rproject.org/).

Results

For the conventional method, the medium and range for interquartile range (IQR) of measured dose values were 1.44 mGy (1.43–1.46) at the center, 1.46 mGy (1.45–1.47) at the back, and 1.64 mGy (1.63–1.66) at the mammary gland, respectively. For the air-gap method, the medium and range for IQR of measured dose values were 1.30 mGy (1.30–1.30) at the center, 1.35 mGy (1.33–1.35) at the back, and 1.53 mGy (1.46–1.58) at the mammary gland. Compared with the conventional method, it was possible to reduce the exposure dose by approximately 10% using the air-gap method ($p < 0.05$, Table 1).

The median and range for IQR of image noise were 9.3 (9.1–9.3) hounsfield unit (HU) for the conventional method and 8.0 (7.8–8.0) HU for the air-gap method. Compared with the conventional method, it was possible to reduce the image noise by approximately 15% using the air-gap method ($p < 0.05$, Table 2).

The CTDIvol values on the CT console were 1.81 mGy for the conventional method and 1.81 mGy for the air-gap method.

Discussion

Compared with the conventional method, it was possible to reduce the exposure dose and image noise by approximately 10% and 15%, respectively, using the air-gap method. The CTDIvol values at the CT console were comparable for the conventional and air-gap methods using the pediatric phantom.

The air-gap method is effective for radiation dose reduction in pediatric CT examinations, and our results showed that the radiation doses were significantly reduced at all measurement positions. This is considered to be due to the decrease in the scattered dose from the table incident on the pediatric phantom owing to the increased distance between the table and the phantom. We believe that this is because the scattered dose from the table has an effect on the reduction of the exposure dose.

The air-gap method is also effective at reducing image noise in pediatric CT examinations. In our study, the image noise was significantly reduced in pediatric phantom examinations. This may be due to the increased distance between the CT table and the subject, which also increased the number of direct X-rays. We believe that the air-gap method can be used to further reduce exposure in pediatric CT.

There are various methods of achieving radiation dose reduction in pediatric CT examinations, such as automatic tube current modulation [9-12], low-voltage scanning [13-16], and iterative reconstruction [17-19]. In our study, there were no reports of radiation dose reduction using the air-gap method in pediatric CT examinations, and to the best of our knowledge, this is the first such study.

An air gap with a low X-ray absorbing material is required during pediatric CT examinations. A previous study compared the radiation dose and image quality when a commercially available fixation device and a polystyrene fixation device made of low-absorbent material were applied to children and the authors reported that the use of this polystyrene fixation device made of low-absorbent material can reduce the radiation dose by approximately 25% [8]. Although caution should be exercised in pediatric CT examinations by keeping the patient some distance from the CT table during the air-gap method, the use of these devices may enable a further reduction of radiation exposure.

Our study had some limitations. First, our investigation was a phantom study; accordingly, we plan to confirm our findings in a clinical study. Second, we did not compare the diagnostic accuracy and motion artifacts that are associated with these devices. Finally, we performed our study using a single CT scanner model obtained from a single vendor.

Conclusion

The air-gap method is believed to be effective at achieving a radiation dose reduction of approximately 10% in pediatric patients during CT examinations compared with the conventional method.

Statements And Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

T.M. contributed to the study design, data collection, algorithm construction, image evaluation, and the writing and editing of the article; Y.F. carried out the data collection, image evaluation, and the reviewing and editing of the article; T.N. performed supervision, project administration, image evaluation, and reviewing and editing of the article. All authors read and approved the final manuscript.

Ethics approval

This study was phantom study.

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Tables

Table 1 Comparison between the measurement values obtained for the conventional and air-gap methods.

	Conventional method	Air-gap method	p value
Measurement value of the body center (mGy)	1.44 (1.43 - 1.46)	1.30 (1.30 - 1.30)	< 0.05
Measurement value of the body back (mGy)	1.46 (1.45 - 1.47)	1.35 (1.33 - 1.35)	< 0.05
Measurement value of the right mammary glands (mGy)	1.61 (1.61 - 1.64)	1.51 (1.46 - 1.55)	< 0.05
Measurement value of the left mammary glands (mGy)	1.67 (1.66 - 1.68)	1.54 (1.46 - 1.62)	< 0.05

Table 2 Comparison of the image noise obtained for the conventional and air-gap methods.

	Conventional method	Air-gap method	p value
Image noise (Hounsfield units)	9.3 (9.1 - 9.3)	8.0 (7.8 - 8.0)	< 0.05

Figures

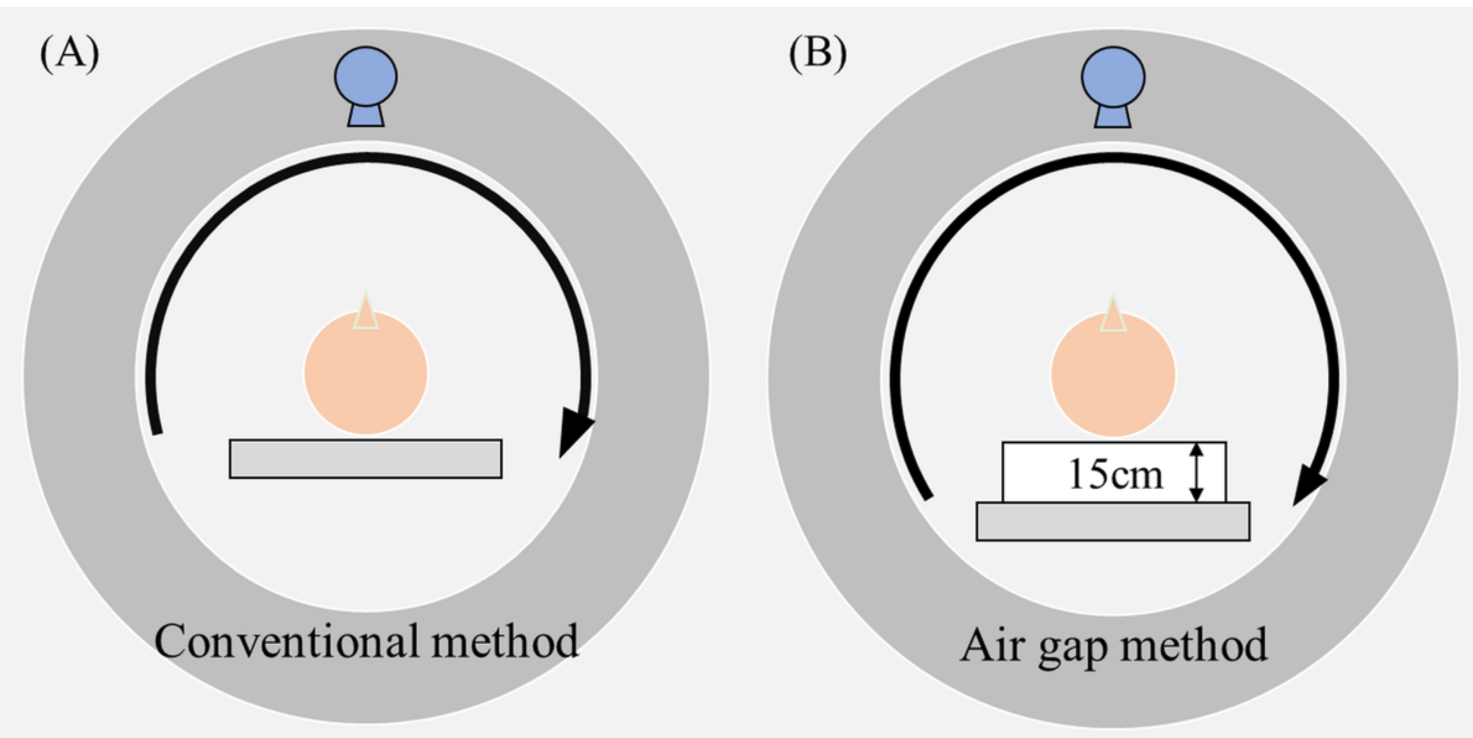

Figure 1

Comparison of the direct X-ray range and subject positioning between the conventional and air-gap methods.

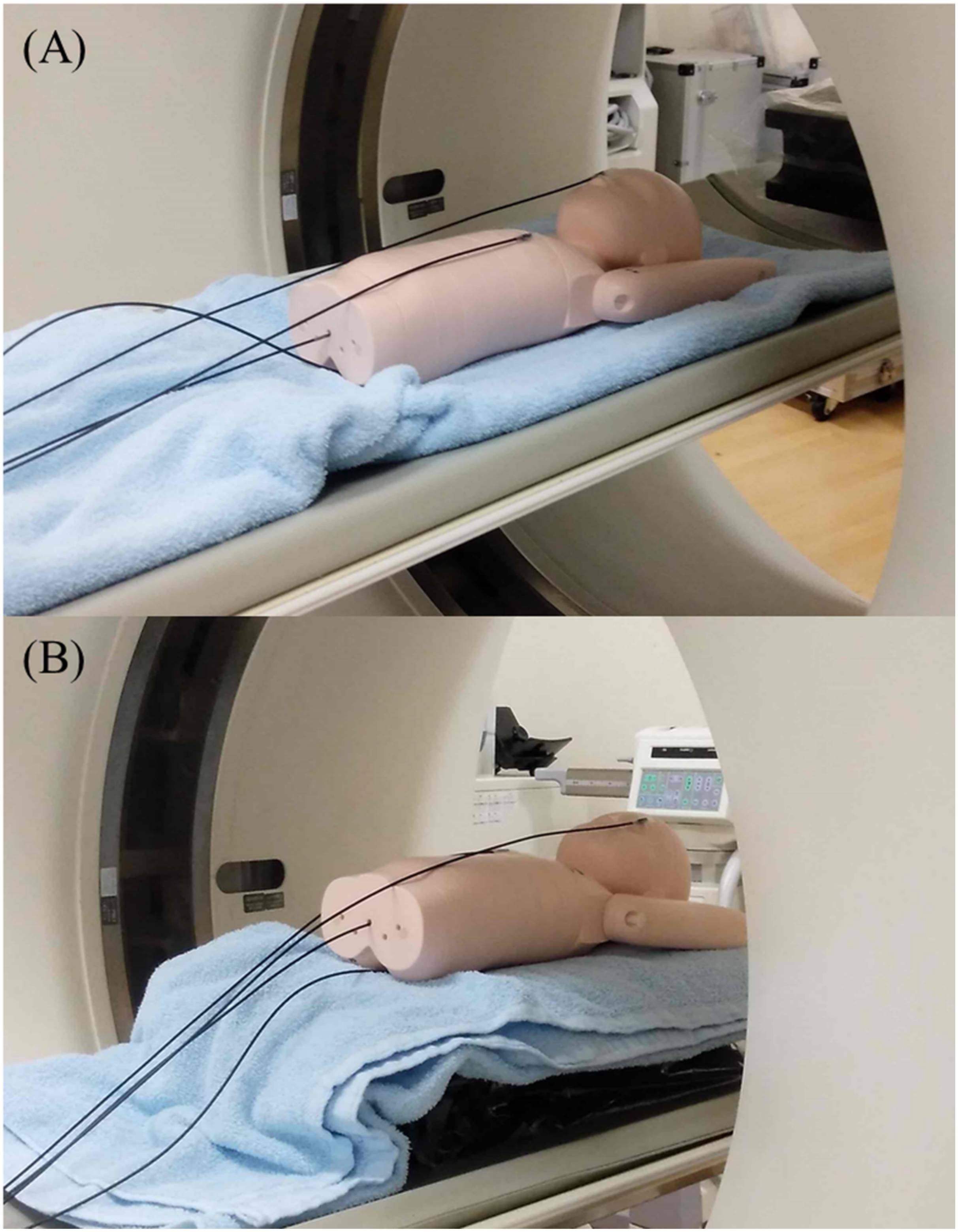

Figure 2

In the conventional method, the subject was gently positioned at a distance of 0 mm from the CT table and the subject at the center (A). In the air-gap method, the distance between the CT table and the subject is 150 mm at the center (B).