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TECHNICAL INNOVATION

A phantom study of a protective trolley for neonatal radiographic imaging: new equipment to protect the operator from scatter radiation

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Abstract

Chest radiography is commonly performed as a diagnostic tool of neonatal diseases. Contact-based radiation personal protective equipment (RPPE) has been widely used for radiation protection, but it does not provide full body protection and it is often shared between users, which has become a major concern during the coronavirus disease 2019 (COVID-19) pandemic. To address these issues, we developed a novel trolley to protect radiographers against X-ray radiation by reducing scatter radiation during neonatal radiographic examinations. We measured the scatter radiation doses from a standard neonatal chest radiograph to the radiosensitive organs using a phantom operator in three protection scenarios (trolley, radiation personal protective equipment [RPPE], no protection) and at three distances. The results showed that the scatter radiation surface doses were significantly reduced when using the trolley compared with RPPE and with no protection at a short distance ($P<0.05$ for both scenarios in all radiosensitive organs). The novel protective trolley provides a non-contact protective tool for radiographers against the hazard of scatter radiation during neonatal radiography examinations.

Keywords Chest radiography · Neonatal intensive care unit · Neonates · Personal protective equipment · Radiation protection · Scatter radiation · Trolley

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Description

Chest radiography is commonly performed as a diagnostic tool of neonatal diseases in the newborn intensive care unit (NICU). Long-term exposure to X-rays can cause a significant increase of radiation dose to radiographers [1]. Contact-based radiation personal protective equipment (RPPE) including lead apron, thyroid shield and protective glasses has been widely used for radiation protection and can be shared between radiographers. However, existing equipment cannot provide whole-body protection (e.g., thyroid shielding) [2] and can cause cross infection, which has become a major concern during the coronavirus disease 2019 (COVID-19) pandemic [3]. To address these unmet clinical needs, we developed a non-contact radiation protective trolley for newborns that can reduce the surrounding scatter radiation during radiographic examination and better protect the operator.

This observational study was conducted on phantom models (i.e. human phantoms) without patient participation; therefore, institutional review board ethics approval

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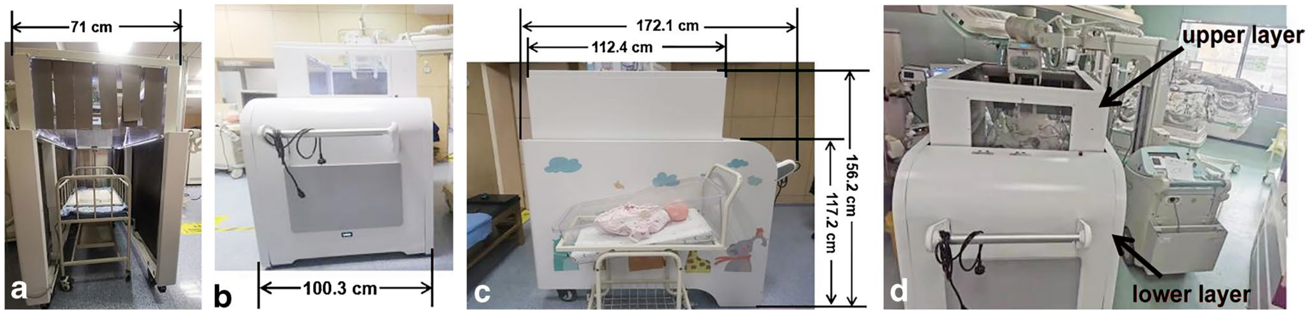

Fig. 1 The novel X-ray radiation protective trolley for newborns. **a-c** Clinical images show the width of the top (**a**), width of the bottom (**b**) and lengths and heights (**c**) of the protective trolley. **d** Application during radiographic examination. Once the detector is placed against the newborn's back, the upper layer of the protective trolley and the front lead rubber roller shutter are raised. The protective trolley covers the entire newborn bed during radiographic examination

was not required. The novel X-ray radiation protective trolley consisted of two layers: upper and lower (Fig. 1). The lower layer was fixed while the upper layer could be lowered and raised. The upper layer was lowered to the level of the lower layer when moving the trolley to avoid blocking the operator's view. There was a hole in the upper layer to allow the adjustment of anode tube location before radiographic imaging. The trolley was 100 cm wide and 172 cm long. The total heights of the lower and upper layers were 117 cm and 50 cm, respectively. The height of the trolley was 156 cm when the upper layer was raised. The trolley was made of steel with lead equivalents embedded inside. The trolley had a total mass of 200 kg. Both sides of the trolley and the rear wall (lead equivalent of 2.0 mm) were protected by fixed lead sheets, while the anterior side was covered by suspending lead rubber sheets (lead equivalent of 0.5 mm). The trolley was electrically driven to cover the bed of the neonate and the direction controlled by two universal wheels on the bottom, making it highly mobile.

During radiographic examination, the flat-panel X-ray detector was placed against the newborn's back. The upper layer of the protective trolley and the suspending lead rubber sheets were raised and the protective trolley pushed forward to cover the entire newborn bed. The suspending lead rubber sheets were lowered and the X-ray machine tube adjusted to the imaging position. We used a mobile digital radiography machine (MUX-100DJ; Shimadzu Corp., Kyoto, Japan) set on conventional neonatal imaging conditions, including a tube voltage of 54 kV, tube current of 1.2 mAs and source image distance (SID) of 90 cm. The field of view (FOV) was set to 10×12.5 cm. There was no additional filtration.

We evaluated the protection efficiency by detecting the radiation dose in the radiosensitive organs of human phantoms. We used a polymethylmethacrylate (PMMA) phantom (X-Check FLU X-ray test phantom; PTW Freiburg, Freiburg, Germany) and human phantom (PH-2B adult whole-body imaging model; Kyoto Science, Japan) to simulate the newborn and the operator, respectively. The phantom of the newborn had a size of 25×25×4 cm, which was derived from the radioactive properties of the newborns. It was placed on the bed, with an X-ray detector placed between the back of the phantom and the bed to simulate the infant during a radiographic examination and generate scatter radiation. The human phantom was located beside the bed to simulate the operator in a standing position. We measured scatter radiation dose using JC-5000 radiation detector (Shanghai Jianchi Radiation Testing Equipment Co., Shanghai, China), which detected the X and γ air-kerma rate using thallium (TI)-doped sodium iodide (NaI) scintillation crystals. The dose linearity, dose rate linearity and energy linearity were within ±12%, ±15% and ±30%, respectively. During radiographic examination, the scatter radiation detector was positioned on the eye lens, thyroid, mammary glands and gonads of the human phantom to evaluate the scatter radiation surface dose on these radiosensitive organs of the operator.

We compared the radiation doses in three scenarios: (a) no protection, (b) protection with RPPE where the lead equivalent was 0.5 mm and (c) protective trolley for newborns. The human phantom was placed at distances of 0.75 m, 1.50 m and 3 m from the X-ray tube under the different protective scenarios. The detection points were set on the radiosensitive organs of the human phantom (Fig. 2). We measured each exposure 17 times for each radiosensitive organ and used an average of these measurements in our analysis. At each distance, we compared the scatter radiation surface doses of a radiosensitive organ derived by different protective methods. Moreover, we compared the scatter radiation dose and environmental background dose when using the neonatal protective trolley. After conducting multiple comparison tests, we performed statistical analyses using SPSS 18.0 (IBM Corp., Armonk, NY), where significance level was defined as P-value less than 0.05.

The results appear in Table 1. The dose of scatter radiation received by the operator was significantly reduced when

Fig. 2 Clinical images of the three protection scenarios for scatter radiation: (**a**) no protection, (**b**) protection with radiation personal protective equipment and (**c**) the protective trolley for newborns

Table 1 Reduction of scatter radiation using the novel trolley compared to other protection conditions (i.e. no protection and contact-based radiation personal protective equipment [RPPE]), with differences calculated from the average value of 17 measurements

Distance (m)	Reference protection condition	Eye lens	Thyroid	Mammary gland	Gonad
0.75	No protection	**−99.2%**[a]	**−99.3%**	**−99.2%**	**−99.3%**
	Contact-based RPPE	**−65.1%**	**−41.6%**	**−31.0%**	**−31.2%**
1.5	No protection	**−99.1%**	**−99.1%**	**−99.2%**	**−99.2%**
	Contact-based RPPE	**−32.1%**	**−62.6%**	−4.0%	+1.3%
3.0	No protection	**−97.8%**	**−97.7%**	**−97.3%**	**−97.3%**
	Contact-based RPPE	−8.6%	−2.9%	−0.1%	+2.1%

[a] *Bold font P*<0.05, or significant, in paired comparisons

the protective trolley was used, as compared with no protection. Compared with the contact-based RPPE, when the operator was 0.75 m away from the tube, the dose of scatter radiation received by the operator was also significantly reduced. When the operator was 1.5 m away from the tube, the protective trolley had a significantly stronger protective effect than the contact-based RPPE at the level of the thyroid and the eye lens. Regarding the mammary gland and gonad, the protective effects of the two protecting devices were equivalent. When the operator was far from the X-ray machine (3 m from the tube), RPPE and the trolley showed comparable protective effects (Figs. 3 and 4).

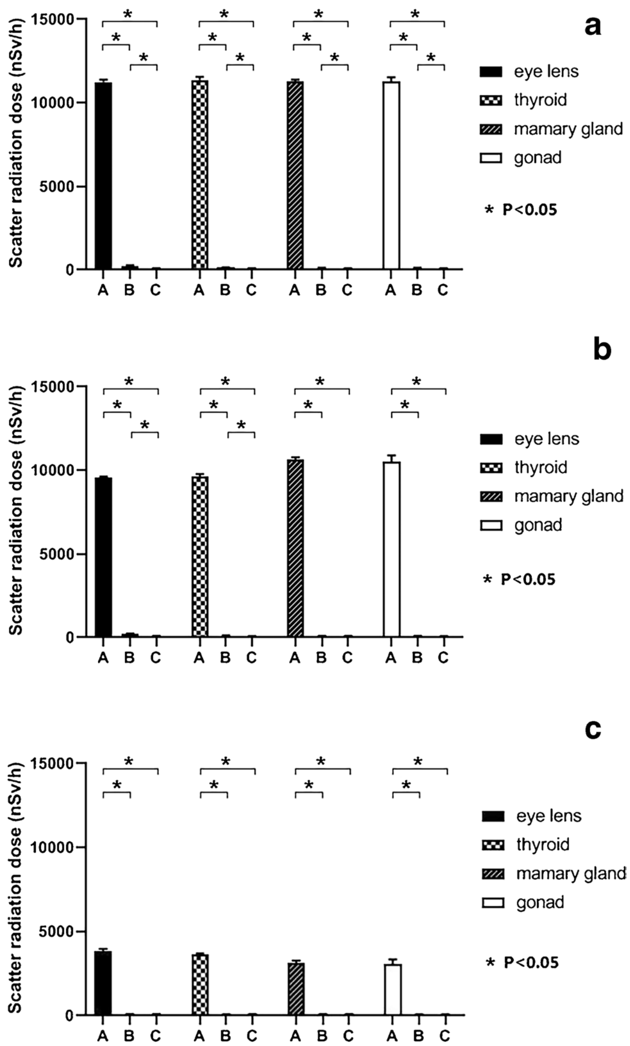

Fig. 3 Graph shows a comparison among protection methods and the scattered radiation dose to each radiosensitive organ of the human phantom. **a–c** Graphs represent the three distances, 0.75 m (**a**), 1.5 m (**b**) and 3.0 m (**c**). *A* no protection, *B* protection with radiation personal protective equipment (RPPE), *C* protective trolley for newborns. When using the protective trolley during radiologic imaging (i.e. radiography) the scatter radiation dose received by the operator was not statistically different from the environmental background dose (P>0.05) at any distance

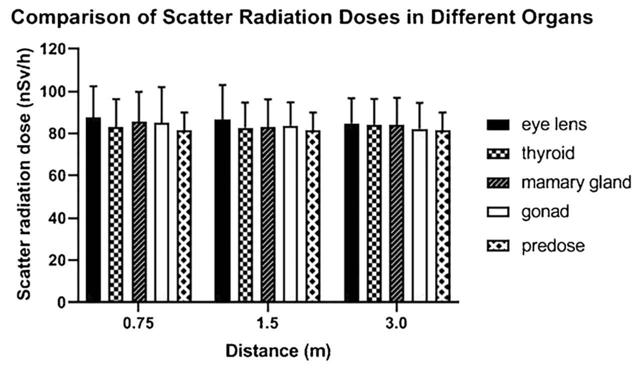

Fig. 4 Graph compares the scattered radiation incurred by each sensitive organ of the human phantom, as well as the environmental background dose, at the three distances

Discussion

There are three methods to reduce radiation: time, distance and shielding. Our results demonstrate that the novel protective trolley can significantly reduce the scatter radiation dose to the radiographer with extra shielding in the form of a novel shroud, with the protective effect proving better than that of contact-based RPPE at a short distance, which is in accordance with the observational results of Fakhoury et al. [4]. A possible explanation is that there are gaps in RPPE while the protective layers of our trolley are intact. Compared with existing mobile radiation protection walls/screens, the trolley can provide much wider protection in different directions and with higher mobility. Meanwhile, the lead rubber sheets allow for the use of monitoring devices of physiological parameters (e.g., respiratory rate) in the chamber. In our experiments, it took ~0.5–1 min to set up the trolley before examination, which is comparable to the time needed for staff to position themselves at a safe distance from the X-ray device when there is no protection. As far as we know, ours is the first attempt to develop a device that can effectively protect medical staff in neonatal wards against the risk of scatter radiation using a non-contact approach.

Recently, there has been increasing awareness of the potential risks of radiation dose in newborns and staff [5–9]. Longo et al. [8] found that when the distance was greater than 1 m from the irradiation field, the scatter doses absorbed by staff and any adjacent patients during hospitalization were less than the exposure limit for the general public. Cakir et al. [9] suggested that the radiation exposure levels of premature infants and staff need to be monitored continuously. Following the ALARA (as low as reasonably achievable) principle [10], several researchers have reported the use of scatter radiation protection devices to protect medical staff from radiation during X-ray radiography in which the operator wears heavy RPPE, making operations inconvenient [11]. The RPPE (gowns, glasses, gloves) can be used over the radiographers' lead aprons, though admittedly this can be an issue when RPPE is not readily available or is in short supply. Another issue is that other newborns in the same ward are unprotected. The novel protective trolley can overcome these limitations to meet the clinical needs.

In addition, the RPPE cannot be reused by operators without the risks of operator cross-infection or of passing bacteria or viruses to newborns [12]. However, the non-contact protective trolley might reduce this risk of cross-contamination of operators and newborns, and this deserves further investigation. While the trolley would need to be sterilized and cleaned after each use, as for standard shields and lead aprons, the cleaning would be easy to perform because of the smoothness of the surfaces.

Our study has some limitations. Most important, the working environment of the NICU was not fully simulated. It might be difficult for the radiographer to watch the newborn's respiratory movements during chest radiography when using the trolley, where design optimization is needed. The trolley was designed for standard newborn cribs/beds and would not be applicable to NICU patients who have multiple support devices or intravenous pumps or monitors. Additionally, this study did not examine the scatter radiation from multiple X-ray devices. Therefore, our results need further validation in different application scenarios. Finally, the radiation dose received by other newborns needs further investigation.

In summary, our novel protective trolley can largely reduce the scatter X-ray radiation exposure of the radiographer during neonatal radiographic examination, while potentially providing a non-contact radiation protection method for clinical applications.

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Declarations

Conflicts of interest None

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