

# Estimation of CARE Dose 4D quality reference mAs conversion factors for child to adult reference patient in child protocols on Siemens Symbia SPECT-CT systems

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**Objectives** CARE Dose 4D modulates mAs through several mechanisms according to patient size and shape, whilst maintaining user-defined reference image quality on Siemens Symbia single-photon emission computed tomography (SPECT)-computed tomography (CT) systems. A 20 kg child reference was used in child protocols prior to software version VB10 and a 75 kg adult thereafter. Quality reference mAs conversion factors are estimated for delivering equivalent mAs to children between two comparable SPECT-CT systems using adult and child references for topogram-based patient-size-related dose level adaptations.

**Methods** A child phantom was scanned using child protocols on a Siemens Symbia T16 (child reference) and a Siemens Symbia Intevo Bold (adult reference). On each system, scans of the thorax, abdomen and pelvis were acquired with arms up and down, at 80 and 110 kVp. Quality reference mAs settings of 10–50 were used on the Symbia T16 and 40–200 on the Symbia Intevo Bold. These data were used to propose quality reference mAs (adult/child reference) conversion factors according to scan range, arm position and tube voltage.

**Results** Quality reference mAs for child protocols using the adult reference should multiply the child quality reference mAs by the following factors, to give comparable delivered mAs: arms up 80 kV: 3.8 (thorax), 3.8 (abdomen), 4.3 (pelvis); arms up at 110 kV: 3.8 (thorax), 4.1 (abdomen), 4.6 (pelvis); arms down at 80 kV: 4.0 (thorax), 3.7 (abdomen), 3.9 (pelvis); arms down at 110 kV: 4.3 (thorax), 4.0 (abdomen), 4.2 (pelvis).

**Conclusion** Conversion factors for child to adult dose modulation references are proposed, allowing comparable delivered mAs to a child. *Nucl Med Commun* 42: 107–112 Copyright © 2020 The Author(s). Published by Wolters Kluwer Health, Inc.

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**Keywords:** adult, child, computed tomography, dose, mAs, modulation, paediatric, tube current

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## Introduction

Computed tomography (CT) scans are performed alongside single-photon emission computed tomography (SPECT) examinations on hybrid SPECT-CT systems in both adults and paediatrics for a variety of clinical purposes. The CT scan could be performed for attenuation correction of the SPECT signal thereby providing improved image quality in the reconstructed SPECT images, anatomical localisation of foci of increased or reduced uptake seen in the SPECT images, characterisation of disease aetiology of foci in SPECT images, or for fully diagnostic purposes. The required image detail

and therefore radiation dose increases from attenuation correction through to fully diagnostic purposes [1,2]. In 2000, Shrimpton and Wall estimated effective doses between 5 and 12 mSv depending on age and anatomical range for children aged between 1 and 10 years, for diagnostic scan ranges in the chest, upper abdomen or lower abdomen/pelvis, with data from 40 scanners from seven European countries [3]. However, effective doses as low as 1.5 and 2 mSv were reported for scans of the chest and abdomen by Huda and Vance in 2007 [4]. Whilst diagnostic CT examinations are performed in some centres as part of paediatric SPECT-CT examinations, a large proportion of CT scans are also performed for the lower dose purposes of attenuation correction, localisation and characterisation. Dose length product (DLP) data from UK and Nordic CT dose surveys for hybrid SPECT-CT examinations in adults [1,2], together with the DLP to effective dose conversion factors in paediatrics published by Shrimpton and Wall [3], suggest that CT for attenuation correction only in SPECT-CT could provide doses of

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less than half a millisievert in paediatrics. These recently conducted national CT dose surveys in hybrid imaging have demonstrated a great need for CT dose optimisation in SPECT-CT [1,2], and optimisation of CT doses for children in particular is of utmost importance, since children are more at risk of the harmful effects of radiation than adults, due to their increased radiosensitivity and longer life expectancy [5].

A number of factors greatly influence image quality and dose, either directly or indirectly. These include tube current and rotation time, which provides the mAs, applied tube voltage, reconstruction method, reconstruction kernel and reconstructed slice thickness, and hardware features such as X-ray tube and detector type in the case of different CT platforms. CT radiation doses must be kept as low as reasonably achievable [6], and tube current modulation is one CT scanner technology, which is key to dose optimisation in children, providing radiation exposures specific to patient size and shape, whilst maintaining a user-defined reference image quality [7]. CT image quality as measured by contrast-to-noise ratio and radiation dose are heavily influenced by the size, shape and density of the patient together with tube output, characterised by the tube voltage (kVp) and mAs. CARE Dose 4D (Siemens Healthineers, Erlangen, Germany) is available on Siemens CT systems and comprises a series of dose-saving technologies in which the tube current is adapted according to patient size, shape and density, whilst maintaining a user-defined reference image quality [8]. CARE Dose 4D provides the following: adaptation of mAs according to patient size based on the topogram (scout scan); angular modulation of the tube current to reflect patient shape; and z-modulation of the tube current to reflect patient shape (topogram-based modulation in a more fine-tuned manner).

On Symbia SPECT-CT systems (Siemens Healthineers, Hoffman Estates, IL, USA), the reference patient for child protocols is a 20 kg child prior to nuclear medicine esoft software version VB10 (CT Somaris version VC20) and is a 75 kg adult from esoft software version VB10 and onwards (personal communication, Siemens Healthcare GmbH, Regional Support Center, Erlangen, Germany). The use of an adult reference patient in child protocols has been provided to make the choice of acquisition settings easier for departments undertaking both adult and child CT for the same type of examination. However, departments used to scanning children on a Symbia SPECT-CT system using the paediatric reference for CARE Dose 4D dose modulation must make a transition in their quality reference mAs settings in child protocols when they upgrade to a system utilising the adult reference patient, either following software upgrade on the same scanner or procurement of a new scanner. In these cases, conversion factors translating the quality reference mAs setting for the 20 kg child reference patient to the quality reference mAs setting for the 75 kg adult reference patient can be helpful as a starting point for optimising reference mAs settings in child protocols.

The aim of this study was to account for differences in topogram-based patient-size-related dose level adaptations between child and adult reference patients, thereby estimating conversion factors for translating quality reference mAs between systems using the adult and child reference, to achieve the same delivered mAs to a paediatric phantom in child protocols.

## Methods

### Equipment

Data were gathered on two different SPECT-CT systems. The first scanner used in this study was a Symbia T16 (Siemens Healthineers, Hoffman Estates, IL, USA), using a 16-slice Emotion CT subsystem. This scanner operated on software version VA60D (using syngo CT software version 2007E), which utilised a 20 kg child CARE Dose 4D modulation reference. The second scanner was a Symbia Intevo Bold (Siemens Healthineers, Hoffman Estates, IL, USA), using a 16-slice Scope Power CT system. This scanner operated on software version VB20B (using syngo CT software version VC30), which utilised a 75 kg adult dose modulation reference. The Emotion and Scope Power are almost identical in their standard configuration, with choice of protocol settings and behaviour being very similar [9,10], with the exception that the minimum tube current was 20 mA on the Symbia T16 and 25 mA on the Symbia Intevo Bold. This, together with a tube rotation time of 0.6 s and pitch of 1.5 translates to minimum deliverable effective mAs of 8 on the Symbia T16 and 10 on the Symbia Intevo Bold.

The measurements in this study were made using the Paediatric Whole Body phantom PBU 70 (Kyoto Kagaku Co., Ltd, Kyoto, Japan), which represents a 20 kg child.

### Data acquisition

The thorax, abdomen and pelvis of the phantom were scanned with child protocols with three different scan ranges, each with tube voltages at 80 and 110 kV, and with the arms up and down. The phantom was first scanned on the Symbia T16 with quality reference mAs settings of 10, 20, 30, 40 and 50 using a child reference. The scans were repeated on the Symbia Intevo Bold, with adult quality reference mAs settings of 40, 80, 120, 160 and 200, using an adult reference. The remaining acquisition and reconstruction parameters were consistent across the two systems. Details of the acquisition and reconstruction settings are provided in Table 1.

### Data analysis

The mean delivered mAs for the full scan range was recorded for each acquisition from the respective Patient Protocol file. Mean delivered mAs for the full scan range was plotted against quality reference mAs for all acquisitions. Different data series were thereby generated according to scanner, arm position, scan range and tube voltage. A linear fit was applied to these data series, and the quality

**Table 1 Computed tomography acquisition and reconstruction parameters for phantom scans on the Symbia T16 and Symbia Intevo Bold**

Parameter type	Parameter	Symbia T16	Symbia Intevo Bold	
Software Acquisition	Software version	VA60D (syngo CT 2007E)	VB20B (syngo CT VC30)	
	Scan range (body part) and length (cm)	Thorax (20)	Thorax (20)	Thorax (20)
		Abdomen (15.5)	Abdomen (15.5)	Abdomen (15.5)
		Pelvis (18.5)	Pelvis (18.5)	Pelvis (18.5)
	CARE Dose 4D child protocol reference patient	Child	Adult	
	Quality reference mAs (mAs)	10, 20, 30, 40, 50	40, 80, 120, 160, 200	
	Tube voltage (kV)	80, 110	80, 110	
	Tube rotation time (s)	0.6	0.6	
	Pitch	1.5	1.5	
	Collimation (detector rows × mm)	16 × 0.6	16 × 0.6	
Reconstruction	Reconstruction method	Filtered backprojection	Filtered backprojection	
	Matrix	512	512	
	Kernel	B31s (soft tissue)	B31s (soft tissue)	
	Slice thickness (mm)	5	5	
	Increment (mm)	5	5	
	Field-of-view (mm)	650	650	

reference mAs required to provide a mean delivered mAs of 10, 20, 30, 40, 50, 60, 70, 80 and 90 were interpolated for each series. For each scan range, arm position and tube voltage, the quality reference mAs conversion factor between child and adult reference patients was derived by dividing the Symbia Intevo Bold quality reference mAs by the corresponding Symbia T16 quality reference mAs, which provided the same delivered mAs for these values from 10 to 90 mAs. These conversion factors were then plotted against quality reference mAs for the child reference patient on the Symbia T16. Conversion factors, by which the quality reference mAs settings for the child reference patient should be multiplied in order to derive the appropriate quality reference mAs for an adult reference patient, were proposed for each scan range, arm position and tube voltage combination, from the points at which the conversion factor plateaued in relation to quality reference mAs for the child reference.

To further explore the relationship between quality reference mAs and child-to-adult conversion factor, a slice-by-slice analysis was made for the 40 mAs quality reference scans on both scanners, for each scan range and tube voltage setting, with arms down. In each of these series, the ratio of delivered mAs in child and adult reference scans (delivered mAs with child reference/delivered mAs with adult reference) in each slice was plotted against slice number.

## Results

Figures 1a–d show the mean delivered effective mAs values for the child (Symbia T16) and adult (Symbia Intevo Bold) reference patients plotted against the respective quality reference mAs settings, according to arm position, scan range and tube voltage. These plots demonstrate that for a given quality reference mAs, the delivered mAs is higher for acquisitions with lower tube voltage and higher attenuation structures: in this case with arms down, and for the abdominal scan range followed by pelvic and thoracic ranges, respectively.

Figures 2a and b show the quality reference mAs conversion factors (adult quality reference mAs/child quality reference

mAs) for the same delivered mAs plotted against the quality reference mAs with child reference, according to arm position, scan range and tube voltage. These plots demonstrate a nonlinear relationship between quality reference mAs and conversion factor, showing the lower the requested quality reference mAs, the lower the conversion factor. However, the conversion factor plateaus at high quality reference mAs. This finding was true for all series of scan ranges, arm positions and tube voltage, except for the abdominal scan range with arms down, which demonstrated an almost linear relationship with a gradient close to 0.

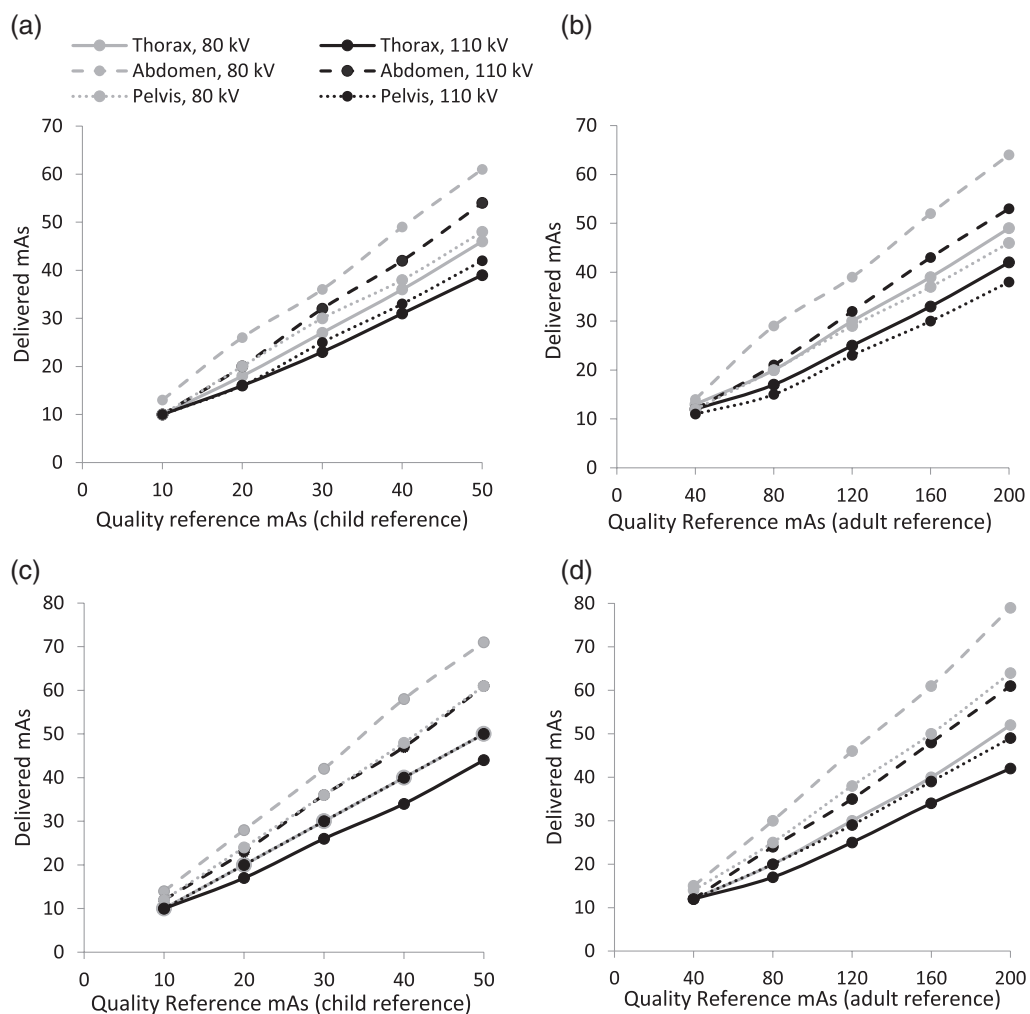
Figures 3a–c demonstrate slice-by-slice plots of the ratio of delivered mAs in child and adult reference scans (delivered mAs with child reference/delivered mAs with adult reference) against slice number in the 40 mAs quality reference scans with arms down. They show that for the abdominal scan range, the ratio of delivered mAs is relatively consistent in each slice at approximately four times the delivered mAs for the child reference as compared with the adult reference. For the thorax and pelvis, on the contrary, the delivered mAs ratio changes considerably, with lower density slices giving lower ratios than high density slices.

Table 2 proposes multiplication factors for converting quality reference mAs from child to adult reference patients, in the range 3.7–4.6, according to scan range, arm position and tube voltage.

## Discussion

This study proposed conversion factors for translating quality reference mAs settings from child to adult CARE Dose 4D reference patients in child protocols, based on measurements for two 16-slice Symbia SPECT-CT systems utilising child and adult dose modulation references, to account for differences in topogram-based patient-size-related dose level adaptations. These conversion factors provide a starting point for Nuclear Medicine departments undertaking paediatric SPECT-CT scans to translate their old quality reference mAs settings utilising a child reference patient to new quality reference

Fig. 1



Quality reference mAs vs. delivered mAs for child reference (Symbia T16) with arms up (a), adult reference (Symbia Intevo Bold) with arms up (b), child reference with arms down (c) and adult reference with arms down (d).

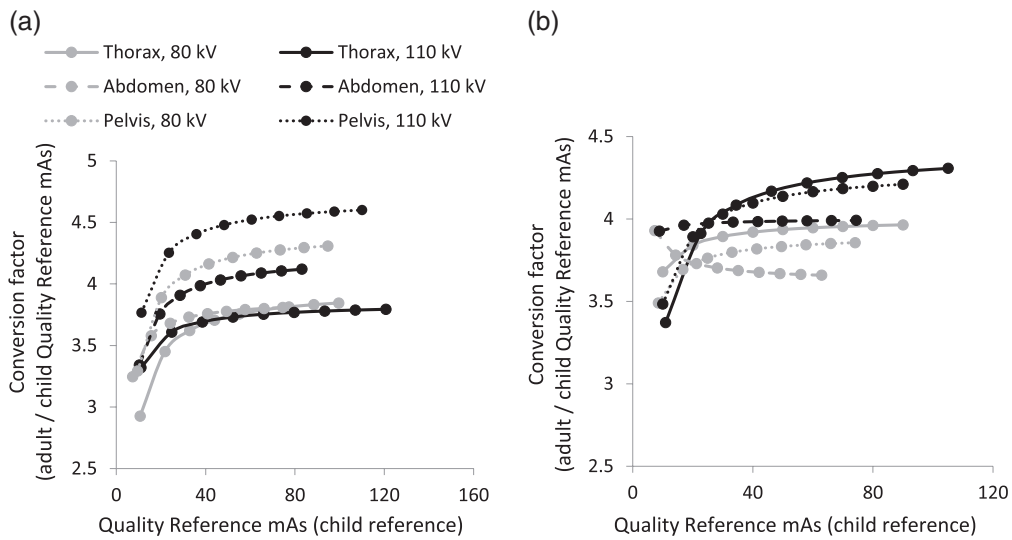
mAs settings using an adult reference patient, following procurement of a new SPECT-CT system or software upgrade using software version VB10 and beyond.

Child-to-adult quality reference mAs conversion factors are proposed in Table 2, in the range 3.7–4.6, with slight variations in conversion factor according to scan range, arm position and tube voltage. Figures 1a–d demonstrate that for a given quality reference mAs, the delivered mAs is higher for acquisitions with lower tube voltage and higher attenuation structures: in this case with arms down, and for the abdominal scan range followed by pelvic and thoracic ranges. The increase in delivered mAs with increasing attenuation is expected, in order to maintain the reference level of image quality, which forms the basis of the CARE Dose 4D principle. The higher delivered mAs with lower tube voltage is also in line with expectation, since lower kV photons have a lesser penetrating power and are thereby

more easily attenuated. This in turn increases image noise, thus requiring greater delivered mAs to compensate and reach the reference image quality.

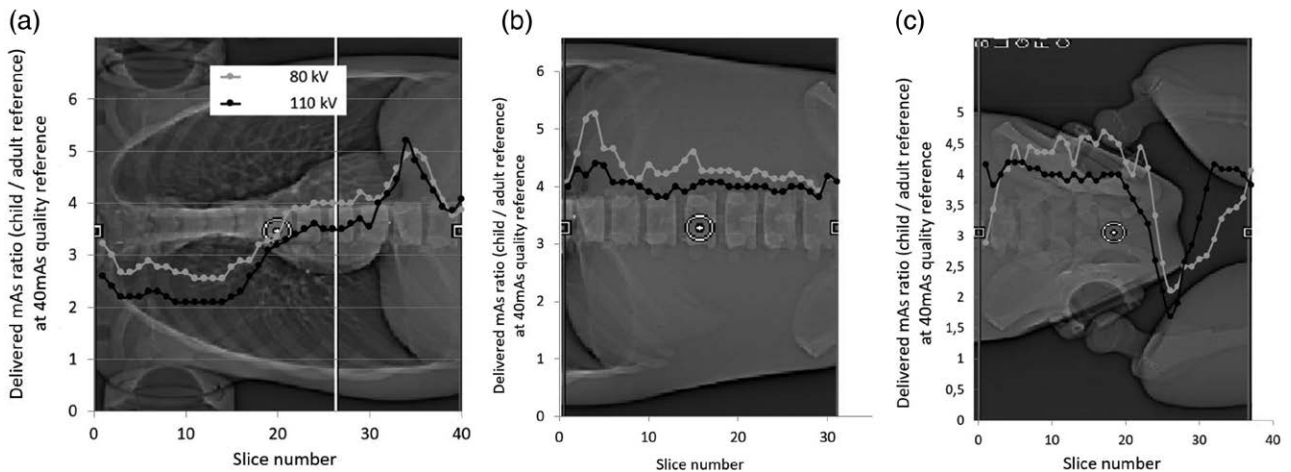
Figures 2a and b show that the child-to-adult quality reference mAs conversion factors for the same mean delivered mAs across the scan range are nonlinear, with the lower quality reference mAs settings providing a smaller difference between quality reference mAs for child and adult reference patients. However, the curves plateau at higher quality reference mAs settings, showing more consistent conversion factors at high quality reference mAs values. This finding was true for all series, except for the abdominal scan range with arms down. The reason for this phenomenon is explained by the slice-by-slice analyses in Fig. 3a–c. These data show that the conversion factor is reduced in slices or ranges with low density. Low density slices allow a reduction in

Fig. 2



Quality reference mAs conversion factors between adult and child reference patients vs. quality reference mAs with child reference for arms up (a) and down (b).

Fig. 3



Slice number vs. delivered mAs ratio (child/adult reference scans) for the thorax (a), abdomen (b) and pelvis (c) with arms down at 40 mAs quality reference.

delivered mAs in each slice to meet the required reference image quality, yet the delivered mAs is limited by the lower threshold of mAs deliverable by the scanner. Thus, at low quality reference mAs in low density structures, the mAs delivered according to the child and adult reference patients is limited by the lower tube current threshold. This results in more comparable delivered mAs than at high quality reference mAs or in high density structures, where the lower tube current threshold is not reached. In this study, the minimum tube rotation

time (0.6 s) and maximum pitch (1.5) available on these systems were used in these acquisition protocols, as shown in Table 1, to allow the systems to reach their lowest deliverable mAs. The child-to-adult quality reference mAs conversion factors proposed in Table 2 were derived from the plateaued areas of the curves for each series, which were not confounded by limitations on minimum deliverable mAs. In clinical practice, the conversion factors proposed in Table 2, although derived at high mAs, are also valid for use at low quality reference



**Table 2 Proposed conversion factors for child to adult reference patients according to scan range, arm position and tube voltage**

Scan range	Child-to-adult quality reference mAs conversion factor			
	Arms up		Arms down	
	80 kV	110 kV	80 kV	110 kV
Thorax	3.8	3.8	4.0	4.3
Abdomen	3.8	4.1	3.7	4.0
Pelvis	4.3	4.6	3.9	4.2

mAs. However, at low quality reference mAs, the magnitude of difference between delivered mAs with adult and child references would be less than the quality reference mAs conversion factor due to limitation by the minimum deliverable mAs.

Several factors should be borne in mind in relation to the study design. First, the Symbia Intevo Bold utilises a 16-slice Scope Power CT system, whereas the T16 uses a 16-slice Emotion CT system. Although these are different CT systems, the performance characteristics and computed tomography dose index 100 (CTDI<sub>100</sub>) dose measurements of the two systems are very similar [7,8] and the two systems are considered comparable. Furthermore, the important factor in this investigation is the relationship between input quality reference mAs and delivered effective mAs, for these systems utilising the respective adult and child dose modulation references. Second, this work only considers the influence of topogram-based patient-size-related dose level adaptations between child and adult reference patients and does not consider the behaviour of angular modulation, which is not driven by the quality reference mAs. Third, the resulting conversion factors are not checked regarding the real outcome in clinical reality. In this study, conversion factors are estimated in a limited set-up based on a single phantom representing a 20 kg child, which is intended to provide a starting point for comparing protocols with child and adult reference patients. However, the user must check that the quality reference mAs settings informed by these conversion factors do provide comparable outcomes in terms of dose and image quality, and should also consider optimising their protocols in relation to other factors influencing dose and image quality.

## Conclusion

Quality reference mAs conversion factors have been derived for translating quality reference mAs between Siemens Symbia SPECT-CT systems and software versions using child and adult reference patients for topogram-based patient-size-related dose level adaptations. The conversion factor varies slightly according to scan range, arm position and tube voltage. These conversion factors are important for translating old quality reference mAs settings utilising a child reference patient to new quality reference mAs settings using an adult reference patient, following procurement of a new SPECT-CT system or software upgrade to VB10 onwards.

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## Conflicts of interest

Natalie A. Bebbington is employed as an applications specialist and physicist at Siemens Healthcare A/S, Denmark. For the remaining authors, there are no conflicts of interest.

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