Effective radiation dosage of three-dimensional rotational angiography in children

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Aims
Three-dimensional rotational angiography (3DRA) is a relatively new but promising imaging technique in the paediatric catheterization laboratory. However, data on effective dose (ED) of this technique in children are lacking. The purpose of this study is to provide ED of 3DRA and to correlate this with parameters readily available in daily practice. Furthermore, the effect of dose-reducing techniques is evaluated.

Methods and results
Effective doses were calculated with Monte Carlo PCXMC 2.0 in 14 patients who underwent a total of 17 3DRAs at our paediatric catheterization laboratory. Median age was 5.7 years (range 1 day – 16.6 years). Median ED was 1.6 milliSievert (mSv) (range 0.7 – 4.9). Effective dose did not correlate with age and body surface area but did correlate with dose area product (DAP) and milliGray (mGy) with \( r^2 \) of 0.75 and 0.83, respectively. Reduction of the total amount of frames from 248 to 133 per rotation resulted in further dose reduction of over 50% with preserved image quality.

Conclusion
The median ED of 3DRA in children is 1.6 mSv and correlates with DAP and mGy. This dose can be halved by applying frame reduction. A significant further dose reduction can be achieved by obtaining additional knowledge of the equipment used.

Keywords
Congenital heart disease • Radiation dosing • Image-guided intervention • Interventional radiology • Angiography

Introduction
Three-dimensional rotational angiography (3DRA) is a new and promising imaging technique in the paediatric catheterization laboratory (cathlab). It provides real-time 3D images and may be used for diagnostic purpose, or to guide and evaluate the effect of percutaneous interventions in congenital heart disease.1,2 Data on radiation dose in 3DRA are scarce and although calculations concerning effective dose (ED) using phantoms are available in adults,2 data on ED in paediatric catheterization are completely lacking.3–6

All published data concerning the radiation burden in paediatric cardiology describe milliGray (mGy) or dose area product (DAP) since these values are readily provided by modern radiological imaging systems.7,8 Unfortunately, previous research suggests that DAP does not correlate with ED7 and tissue weighting factors of the patient are not taken into account.10 As ED is the only parameter predictive of stochastic effects, it is extremely important to acquire ED data in the paediatric age group. Especially since this is the patient group at greatest risk for the development of stochastic effects.10 The only published data on ED in 3DRA derive from adult electrophysiology (EP) and report a worrisome mean dose of 6.6 ± 1.8 milliSievert (mSv) per 3DRA run, with a paradoxically higher ED in slender patients.9 This might imply that dystrophic patients are at risk for an even higher ED.

The aim of this study was to calculate ED of 3DRA runs performed in paediatric patients. Furthermore, we aimed to correlate ED with parameters readily available in the cathlab. Finally, we evaluated the effect of dose-reducing techniques on ED and image quality, according to the as low as reasonably possible (ALARA) concept.11

Methods
Data collection
Data of 3DRA runs performed during the first 3 months of 2012 at our paediatric cathlab (Artis zee biplane, Siemens, Erlangen, and Germany)
What's new?

- Three-dimensional rotational angiography (3DRA) provides real-time 3D images in the cathlab and can serve as a roadmap to guide interventions.
- The median effective dose of a 3DRA run in children is 1.6 mSv.
- This dose can be significantly lowered when applying simple dose-reducing techniques.

Categories: 0, 1, 5, 10, and 15 years, and adults. Using the patients’ BMI, ED can be calculated.

Since every frame of the 3DRA run is obtained from a different angle, ED calculations have to be performed for every single of the 300 frames acquired. The Siemens CareAnalytics program provides DAP values for every single frame (and angle). Dose area product values were multiplied by a 0.8 absorption factor if the table was in between the X-ray tube and the patient. The absorption factor was calculated by studying the table material at our cathlab. Effective doses were calculated with the Monte Carlo program using these corrected DAP data. This process has been extensively described before. ED’s were calculated taking into account patients bioinfo-mathematical data (age, length, and weight) and X-ray beam geometry data (beam width and height, longitudinal and axial angles, focus to skin distance and data concerning tube potential, filter material, and thickness).

Data analysis

Data are presented as median (range) and mean (± standard deviation (SD)). Linear regression analysis was used to calculate correlations between ED and age, length, weight, BSA, DAP, mGy, and tube current.

Dose reduction

Dose reduction can be achieved by collimation of the X-ray beam and by limiting the maximum tube current during 3DRA. Furthermore, the number of f/s for each rotational angiography can be reduced (30 f/s instead of 60 f/s). We will describe our experience with these dose-lowering techniques and their effect on image quality briefly.

This study has been received by the medical ethics board of the University Medical Center Utrecht and was waived from further review.

Results

Patient characteristics are shown in Table 1. A total of seventeen 3DRA runs were performed in 14 patients. Three patients underwent both pre- and post-interventional 3DRA. The median ED was 1.6 mSv (range 0.7–4.9). Effective dose was independent of age, length, weight, and BSA (Table 2). A correlation was found between ED and DAP, mGy and tube current (Table 2 and Figures 1–4).

Dose reduction

Collimation

Four patients underwent an uncollimated diagnostic 3DRA before intervention and a collimated 3DRA afterwards. Except for collimation, all runs had the same settings regarding the tube current and voltage, filtration and f/s. Collimation led to a mean reduction of the X-rayed surface of ~20%. The mean uncollimated DAP was 937 μGy m² (± 468), the mean collimated DAP was 549 μGy m² (± 263.3).

Tube current

Only 4 of 14 patients had EDs > 2.8 mSv. All of these patients had high tube currents (> 200 mA compared with a mean tube current of 118.4 mA ± 104). Rotations were re-examined, but no X-ray absorbing material causative of the observed high tube current (such as scissors, arms, or a headrest) was present in the work field.

The Artis zee determines its tube current and voltage during 15 frames of fluoroscopy performed in the starting position before the actual 3D run. Tube current is therefore not determined by the...
Amount of contrast used. The high ED’s encountered are most likely to result from insufficient acquired frames before the actual 3DRA run resulting in suboptimal acquisition with maximization of tube current to preserve image quality.

Frame reduction
One 5-day old, three kilogram neonate underwent pre- and post-interventional 3DRA with different frame rate settings. Pre-interventional 3DRA was performed with a reduced frame rate of 30 f/s (1.5° rotation per frame, total of 133 frames), resulting in a DAP of 20.14 mGy m². Post-interventional 3D was performed with a frame rate of 60 f/s (0.8° rotation per frame, total of 248 frames), resulting in an almost tripled DAP of 53.35 mGy m². The image quality of the low-dose 3DRA run remained excellent in this patient and was of equal quality compared with the high-dose 3DRA (Figure 5).

Discussion
This is the first study to present ED in children undergoing 3DRA. Median ED was 1.6 mSv in 14 patients undergoing 17 3DRA runs. Effective dose correlated with DAP and mGy and can even be significantly further reduced by applying several simple dose-reducing techniques.

Effective dose
Radiation dose should be as low as reasonable achievable (ALARA concept) in any X-ray guided procedure. Therefore, ED calculations are essential after introduction of new X-ray imaging techniques such as 3DRA. The relation between CT scanning and the increased risk of cancer has been well established in the paediatric population. Effective doses in the paediatric cathlab are comparable and often even higher than those acquired with CT scanning, stressing the importance of ED calculation in this patient group.

Effective dose calculations in 3DRA with the PCXMC software have not been reported to date. In contrast with static fluoroscopy or angiography, is the radiated field in 3DRA larger than the patient. The PCXMC software corrects the difference between the radiated field and patient size, to secure a correct calculation of ED. The median ED of 1.6 mSv in the present study is significantly lower than the only other available data on ED in 3DRA to date, reporting a worrisome mean ED of 6.6 ± 1.8 mSv in adults.
Three-dimensional rotational angiography is a powerful tool that may significantly reduce or even abandon the need of (repeated) cineangiography as all diagnostic information is acquired in one run. With the observation that cineangiography accounts for almost three quarters of the ED of 4.6 mSv in diagnostic procedures, 3DRA may lead to further dose reduction in the paediatric cathlab. With 3DRA, optimal projections for interventions can be established and 3DRA provides a roadmap to guide the intervention. This can potentially lead to a dramatic decrease in ED in complex interventions where repeated cineangiography is often needed to reach optimal projections and to guide the intervention. The observation that other studies found even higher ED’s in paediatric catheterization (median ED’s up to 40 mSv) suggests that 3DRA may have an important role in dose reduction in a vulnerable population at risk for stochastic effects. Future studies are needed to confirm this. Adult data show an inverse relation between ED and BSA. We were not able to confirm this correlation; however, our study population is relatively small and obesity was not present. In contrast to adult data, we did find a correlation between ED and DAP and mGy. Although DAP and mGy cannot be translated one to one to ED, a reliable estimation of ED seems possible using parameters readily provided by cathlab equipment. This enables paediatric cardiologists to inform parents about the radiation burden immediately after the procedure. It also enables the physician to judge whether the 3DRA was properly performed with a radiation dose as low as reasonably achievable or not. We were not able to confirm a correlation between ED and patient size. Adult literature shows a strong correlation between DAP and patient size and the paediatric phantom study by Glatz et al. shows an increasing correlation of ED with age without calculating correlation coefficients. The absent correlation between ED and patient size may be due to our small sample size and therefore larger studies are needed.

Apart from the ALARA concept, there are no international guidelines concerning the maximal amount of radiation children may be exposed to during cardiac catheterization. In most cases, catheterization is necessary and radiation exposure subsequently inevitable. However, the radiation burden may be significant. We have performed complex procedures taking up to 8 h with an ED of 100 mSv (unpublished data). An international survey evaluating ED’s for standardized procedures, dose-reducing techniques as well as accepted ED’s could lead to a global reduction of the radiation burden in children with congenital heart defects.

**Dose reduction**

A 50% dose reduction can be achieved in 3DRA by lowering the frame rate from 60 f/s to 30 f/s. This has been suggested by phantom studies and is confirmed by the present study. Frame rate reduction resulted in an ED of <1 mSv in one patient where we applied this technique. This result is easily explained by halving the amount of 2D slices and thus halving the amount of radiation. The major concern when applying this technique is image quality. At our institution we currently perform all 3DRA’s with 30 f/s setting and although a systematic evaluation of image quality is warranted, we did not experience a deterioration of image quality due to the lowering of the frame rate. Up until now, after performing >150 3DRA’s with a 30 f/s setting, no iteration was required because of insufficient image quality. Theoretically, this can be
explained by the fact that in children the region and volume of interest is much smaller than in adults. Therefore, high-resolution 3D images can still be obtained with a reduced amount of frames. This may differ in adult patients but in our experience 30 f/s is always sufficient for excellent 3D images, even in larger patients. (Figure 5). Furthermore, the injection site may influence image quality. We always inject contrast in the cavity proximal to the region(s) of interest, to prevent motion artifacts in this region by the injection catheter and inadequate contrast delivery (e.g. LV injection for aortic arch visualization).

Four patients had a relatively high ED. High tube currents were causative of the high ED’s in all. X-ray absorbing material in the radiation field necessitating high tube currents for proper image acquisition (scissors, head rest or body parts) were excluded as a cause for the observed high tube currents.

A 3DRA run is performed with a set voltage and filtration. Tube current is determined by the equipment using fluoroscopy images obtained just before the 3DRA run. A 3DRA run can technically be performed after one acquired frame. However, the Artis zee Siemens system actually needs 15 frames for optimal image acquisition. In case of improper acquisition (for example by acquiring a limited amount of frames before the actual 3DRA run) the tube current is automatically increased to its programmed maximum output to preserve optimal image quality. A 3DRA run may therefore be performed in suboptimal settings resulting in high ED’s. The confirmation settings to assure the investigator that the system is ready for 3DRA acquisition have to be optimized in this sense. It is important that the cardiologist performing 3DRA should get acquainted with these technical specifications by the provider as otherwise patients are unnecessarily exposed to excessive radiation. For the Artis zee Siemens 15 frames of fluoroscopy have to be obtained in advance (1.5 s of fluoroscopy when using 10 f/s) as prearrangement. Since the tube current used in 3DRA is determined before the actual 3D run, the amount of contrast medium used or the weight of the patient do not influence ED.

Collimation should be applied whenever possible since it significantly reduces radiation. This has been proven in adults and is

**Figure 5** 3DRA in a 5-day-old neonate with pulmonary atresia, showing a major aortopulmonary collateral artery originating from the left subclavian artery. A pre-interventional 3D-run with contrast injection in the left ventricle was performed with low framerate (30 f/s), resulting in images with an excellent image quality (top images). Post-interventional 3D with contrast injection in ascending aorta was performed with standard framerate (60 f/s, bottom images). 3D reconstructions are shown on the left side, and 2D CT images on the right side.
confirmed by our study. This is even more relevant in children since the absolute region of interest in children is often small and the possibilities to zoom are very limited.

**Limitations**

This study comprises only a small series of patients. And although the calculated EDs are all true, correlations should be interpreted with care and larger studies are warranted to confirm these findings. Furthermore, a systematic evaluation of image quality using different frame rates should be performed.

**Conclusion**

The median ED of 3DRA in children is 1.6 mSv and correlates with DAP and mGy. This dose can be halved by applying frame reduction. A significant further dose reduction can be achieved by obtaining additional knowledge of the equipment used.

**Conflict of interest:** none declared.

**References**


