

## A Comparison of Radiation Dose Between Standard and 3D Angiography in Congenital Heart Disease

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### Abstract

**Background:** The use of three-dimensional rotational angiography (3D-RA) to assess patients with congenital heart diseases appears to be a promising technique despite the scarce literature available.

**Objectives:** The objective of this study was to describe our initial experience with 3D-RA and to compare its radiation dose to that of standard two-dimensional angiography (2D-SA).

**Methods:** Between September 2011 and April 2012, 18 patients underwent simultaneous 3D-RA and 2D-SA during diagnostic cardiac catheterization. Radiation dose was assessed using the dose-area-product (DAP).

**Results:** The median patient age and weight were 12.5 years and 47.5 Kg, respectively. The median DAP of each 3D-RA acquisition was 1093  $\mu\text{Gy}\cdot\text{m}^2$  and 190  $\mu\text{Gy}\cdot\text{m}^2$  for each 2D-SA acquisition ( $p < 0.01$ ). In patients weighing more than 45 Kg ( $n = 7$ ), this difference was attenuated but still significant (1525  $\mu\text{Gy}\cdot\text{m}^2$  vs. 413  $\mu\text{Gy}\cdot\text{m}^2$ ,  $p = 0.01$ ). No difference was found between one 3D-RA and three 2D-SA (1525  $\mu\text{Gy}\cdot\text{m}^2$  vs. 1238  $\mu\text{Gy}\cdot\text{m}^2$ ,  $p = 0.575$ ) in this population. This difference was significantly higher in patients weighing less than 45Kg ( $n = 9$ ) (713  $\mu\text{Gy}\cdot\text{m}^2$  vs. 81  $\mu\text{Gy}\cdot\text{m}^2$ ,  $p = 0.008$ ), even when comparing one 3D-RA with three 2D-SA (242  $\mu\text{Gy}\cdot\text{m}^2$ , respectively,  $p < 0.008$ ). 3D-RA was extremely useful for the assessment of conduits of univentricular hearts, tortuous branches of the pulmonary artery, and aorta relative to 2D-SA acquisitions.

**Conclusions:** The radiation dose of 3D-RA used in our institution was higher than those previously reported in the literature and this difference was more evident in children. This type of assessment is of paramount importance when starting to perform 3D-RA. (Arq Bras Cardiol. 2014; 103(2):131-137)

**Keywords:** Heart Defects, Congenital; Coronary Angiography/ radiation effects; Angiography, Digital Subtraction/ methods; Catheterization.

### Introduction

Computed tomography angiography, or three-dimensional rotational angiography (3D-RA), was introduced in the neurovascular field to improve the assessment of intracranial aneurysms and to guide interventional neurovascular procedures. 3D-RA quickly became the gold standard for an accurate diagnosis of intracranial aneurysms<sup>1</sup>. This technique is also used in electrophysiological and peripheral vascular procedures<sup>2,3</sup> and has been tested for coronary evaluation<sup>4</sup>.

Despite all the recent progress with new diagnostic modalities for congenital heart diseases, cardiac catheterization continues to be of great value in this field because of its diagnostic accuracy and therapeutic advantages.

The use of 3D-RA to assess patients with congenital heart diseases appears to be a promising technique despite the scarce literature available<sup>5-7</sup>. Notwithstanding the potential benefits of 3D-RA images in comparison to those of 2D-SA, the radiation dose must be evaluated carefully to ensure that the long-term deleterious effects of radiation to both patients and the medical team are not increased.

The objectives of the present study were to report our initial experience with 3D-RA in patients with congenital heart diseases; to compare its radiation dose to that of standard two-dimensional procedures in the same patient; and to report our initial impressions of the defects best evaluated with this tool.

### Methods

#### Sample

This is a retrospective study that comprised our initial experience with 3D-RA in 18 patients referred for diagnostic cardiac catheterization between September 2011 and April 2012. The objective of the procedure was basically to evaluate the aorta, pulmonary arteries and cavopulmonary connections, apart from one patient with patent ductus arteriosus.

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## Procedure and Radiation Exposure

All children underwent general anesthesia with orotracheal intubation. Adult patients routinely underwent conscious sedation and local anesthesia for diagnostic procedures, which did not pose any problems for three-dimensional acquisition. All patients were under pacemaker overdrive suppression during 3D-RA to allow adequate filling of the structures studied, for a preselected time frame. All patients or their parents gave informed consent prior to the procedure.

Initially, patients routinely underwent standard two-dimensional imaging. Subsequent 3D-RA was performed to compare and better understand the benefits of this technique in the same patient. As we gained experience, 3D-RA images and reconstruction became easier and 2D-SA was performed only if necessary after evaluating the reconstructed three-dimensional images. This approach was adopted in six patients undergoing only one complementary two-dimensional angiography, and one patient underwent only 3D-RA, without the need for additional images. The cumulative dose (CD) was measured in all procedures. The total dose-area-product (DAP) in each angiography and number of angiographies, as well as the quality and impact of 2D-SA and 3D-RA images, were also compared.

All procedures were performed using the same equipment. The 3D-RA images were acquired with 200-degree rotation using a C-arm-mounted flat-panel monoplanar angiographic system (Artis zee, Siemens Medical Solutions, Forchheim, Germany). The images were reconstructed using a commercially available software (syngo DynaCT, Siemens Medical Solutions). The radiation settings were changed from those recommended by the manufacturer in order to reduce X-ray exposure. Three-dimensional rotational image acquisition was performed with a dose of  $0.17 \mu\text{Gy}/\text{f}$ , a frame rate of 30 frames/s, and tube voltage of 70 Kv. Post-processing reconstruction was performed on a separate workstation in the interventional suite (Leonardo Dyna CT, Siemens Medical Solutions).

In adults, 2D-SA imaging was obtained with a dose of  $0.17 \mu\text{Gy}/\text{f}$  at 10 to 15 frames/s, and tube voltage of 81 Kv. In children weighing less than 40 Kg, the dose was  $0.14 \mu\text{Gy}$  per image, frame rate of 30 frames/s, and tube voltage of 73 Kv. The anti-scatter grid was removed before the procedure in children weighing less than 20 Kg.

To evaluate radiation exposure, the software automatically calculates DAP separately for each 2D-SA or 3D-RA and for fluoroscopic images. The amount of contrast media used was assessed in this study. Institutional review board approval was obtained for this retrospective analysis.

## Statistical Analysis

Descriptive statistics, including median and interquartile range, were calculated for continuous variables not normally distributed. The results were compared using the Wilcoxon test (95% confidence level). All statistical calculations were performed using SPSS Statistics 19 (SPSS Inc, Chicago, USA).

## Results

### Sample Characteristics

The median age of the patients included in the study was 12.5 years (ranging from 1 to 44 years) and the median weight was 47.5 Kg (ranging from 9 to 100 Kg). The diagnoses included 7 patients with tetralogy of Fallot; 5 patients with aortic coarctation; 2 patients previously undergoing Fontan anastomosis; 1 patient with truncus arteriosus; 1 patient with patent ductus arteriosus; 1 patient with pulmonary artery stenosis; and 1 patient with dilatation of the ascending aorta (Table 1).

### Radiation Dose

The median CD in both 2D-SA and 3D-RA was 171 mGy (interquartile range 40.6 to 1071 mGy). The median total DAP for the 3D-RA protocol was  $1093 \mu\text{Gy}\cdot\text{m}^2$  (interquartile range 701 to  $1767 \mu\text{Gy}\cdot\text{m}^2$ ), and the median DAP for the two-dimensional study in the same patients was  $360 \mu\text{Gy}\cdot\text{m}^2$  (interquartile range 200 to  $1049 \mu\text{Gy}\cdot\text{m}^2$ ). The DAP of two-dimensional angiography alone was  $190 \mu\text{Gy}\cdot\text{m}^2$  (interquartile range 76 to  $413 \mu\text{Gy}\cdot\text{m}^2$ ,  $p = 0.01$ ).

The difference seemed to be similar in patients weighing more than 45 kilograms. In this population, the median DAP for each 3D-RA acquisition was  $1525 \mu\text{Gy}\cdot\text{m}^2$  (interquartile range 1074 to  $2031 \mu\text{Gy}\cdot\text{m}^2$ ) compared to  $413 \mu\text{Gy}\cdot\text{m}^2$  in each 2D-SA acquisition in the same patient ( $p = 0.01$ ). If we consider a mean of three two-dimensional angiographies for an adequate procedure, no difference was found in radiation exposure between two-dimensional study and 3D-RA ( $1525 \mu\text{Gy}\cdot\text{m}^2$  vs.  $1238 \mu\text{Gy}\cdot\text{m}^2$ ,  $p = 0.575$ ).

However, if we only evaluate patients weighing less than 45 Kg, this difference is even greater. The median DAP from a single 3D-RA acquisition in this population was  $713 \mu\text{Gy}\cdot\text{m}^2$  (interquartile range 422 to  $1090 \mu\text{Gy}\cdot\text{m}^2$ ) and the median DAP for each two-dimensional acquisition in the same patient was  $81 \mu\text{Gy}\cdot\text{m}^2$  ( $p = 0.008$ ). If we consider a mean of three angiographies for an adequate study, the median DAP is  $242 \mu\text{Gy}\cdot\text{m}^2$  (interquartile range 183 to  $423 \mu\text{Gy}\cdot\text{m}^2$ ). This difference is still favorable to 2D-SA acquisitions in this population ( $p = 0.008$ ). Some of these results are summarized in Table 2.

### Imaging Quality and Additional Information

Of 11 patients undergoing both a complete two-dimensional standard evaluation and subsequently a 3D-RA, we verified that 3D-RA provided additional information in 3 (27%). Apart from 1 patient with patent ductus arteriosus, all other images were acceptable and at least comparable to those of 2D-SA.

## Discussion

Children and adults with congenital heart disease are increasingly more frequently undergoing successive diagnostic or therapeutic radiation-based procedures. The harmful cumulative long-term effects of X-ray exposure are well known and extensively described in the literature.

**Table 1 – Demographics of Patients Included In The Study**

Patient	S-X	Age (years)	Weight (Kg)	Diagnosis	Air Kerma (milligray)	DAP/3D-RA ( $\mu\text{Gy.m}^2$ )	DAP 2D ( $\mu\text{Gy.m}^2$ )	2D-SA (n)	dose/2D-SA ( $\mu\text{Gy.m}^2$ )
1	M	4	12	Post-Fontan	82	429	325	4	81
2	F	11	22	Tetralogy of Fallot	115	663	323	4	81
3	M	16	100	Aortic Coarctation	226	2546			
4	F	12	37	Truncus Arteriosus	166	792	930	5	186
5	M	1	10	Tetralogy of Fallot	41	410	193	2	96
6	M	12	42	Aortic Coarctation	176	1012	51	1	51
7	M	29	89	Aortic Coarctation	586	2435	991	1	991
8	M	39	74	Tetralogy of Fallot	707	1998	4607	4	1152
9	M	18	60	Tetralogy of Fallot	116	942	292	1	293
10	M	3	9	Patent Ductus Arteriosus	94	415	187	3	62
11	M	27	60	Tetralogy of Fallot	1071	1690	1107	4	277
12	M	9	36	Post-Fontan	185	1167	949	5	190
13	M	12	33	Tetralogy of Fallot	176	1360	360	5	72
14	F	31	57	Pulmonary Artery Stenosis	144	1130	440	2	220
15	M	16	53	Tetralogy of Fallot	803	1360	4791	9	532
16	M	8	33	Aortic Coarctation	105	713	60	1	60
17	F	44	60	Aortic Stenosis - Ascending Aorta Dilatation	281	2043	1501	1	1501
18	M	13	60	Aortic Coarctation	134	1056	207	1	207

DAP: Dose-area-product; 3D-RA: Three-dimensional rotational angiography; 2D: Two-dimensional standard angiography.

**Table 2 – Comparison between DAP of one 3D-RA and one and three 2D-SA**

Angiography (n)	Rotational (1)	Standard (1)	p	Standard (3)	p
Median DAP ( $\mu\text{Gy.m}^2$ )	1093	190	< 0.01	569	0.210
> 45Kg					
Median DAP ( $\mu\text{Gy.m}^2$ )	1525	413	0.01	1238	0.575
< 45Kg					
Median DAP ( $\mu\text{Gy.m}^2$ )	713	81	0.008	242	0.008

DAP: Dose-area-product; 3D-RA: Three-dimensional rotational angiography; 2D-SA: Two-dimensional standard angiography.

DAP has been previously correlated with peak skin dose and can be used as a reliable and online parameter to guide radiation exposure during cardiac catheterization<sup>8-10</sup>.

New advances in technology intend to improve diagnostic accuracy without increasing the risks for patients<sup>11,12</sup>.

The use of 3D-RA was initially described for the assessment of intracranial aneurysms and was also reported in electrophysiological and peripheral vascular procedures, as well as for the assessment of coronary arteries<sup>1,4,13-18</sup>.

The rationale for incorporating this technology in the field of congenital heart disease was to obtain additional information not available from 2D-SA. Despite the scarce information in the literature<sup>5,19,20</sup>, the use of 3D-RA in this

context reduces the number of necessary acquisitions and brings the possibility of increasing accuracy in the assessment of patients with defects with a complex anatomy; however, it is not yet well established whether 3D-RA adds information on these defects.

In 2010, Kapins et al<sup>20</sup> first described a series of 53 cases of diagnostic catheterization using 2D-SA and 3D-RA in patients with congenital heart disease and a mean weight of 28.5Kg<sup>20</sup>. At least half of the patients benefited from this new technology in the planning of their further surgical or percutaneous procedures. No differences were found in DAP between two-dimensional angiographies and 3D-RA ( $356 \times 374 \mu\text{Gy.m}^2$ )<sup>20</sup>.

Glatz et al. described the use of 3D-RA in 41 cases of congenital heart disease<sup>5</sup>. Despite providing high-quality diagnostic imaging in over 70% of cases, this technique provided additional information in less than 30% of the cases studied. After using a phantom test to measure the DAP for different settings, the authors found a radiation dose of approximately  $122 \mu\text{Gy}\cdot\text{m}^2$  for a 10 year-old child and  $471 \mu\text{Gy}\cdot\text{m}^2$  for an adult male.

In 2011, Glockler et al<sup>19</sup> evaluated and reported their experience in 62 patients with a median weight of 14.4 Kg undergoing rotational angiography for the assessment of pulmonary arteries, aorta, and cavopulmonary connections. In this study, the images were considered superior to those of conventional angiography in 90.3% of cases and very useful for guiding interventional procedures using overlaying three-dimensional images. The median DAP from each run was  $111 \mu\text{Gy}\cdot\text{m}^2$ .

More recently, Berman et al<sup>21</sup> described the usefulness of 3D-RA in patients previously undergoing cavopulmonary connections with a clear understanding of the mechanism of pulmonary stenosis<sup>21</sup>. The median DAP was  $306 \mu\text{Gy}\cdot\text{m}^2$  in this population with a median weight of 15.7Kg. The authors reported unpublished data with even smaller doses in three-dimensional procedures after working with the company and physicists.

The lower dose of radiation exposure compared to that used in our study can be explained by the lower median weight of patients in all these studies reported. This linear dose variation among patients of different weights has already been described in the literature<sup>6-10</sup>.

In the present study, the median DAP of one run of 3D-RA was higher than that of a two-dimensional view alone. However, if we consider that multiple two-dimensional projections are sometimes necessary, this difference is considerably reduced and the benefits from 3D-RA can surpass the slightly increased radiation dose.

In the subgroup of patients with less than 45Kg, the difference detected between both groups was much higher. Even comparing to 3 two-dimensional angiographies, the difference in radiation exposure was favorable to the standard technique and may not justify the benefits obtained from this technique in this particular population.

However, if we consider only patients weighing more than 45 Kg, the difference between each 3D-RA and 2D-SA alone was not prohibitive. Considering the need for multiple two-dimensional views, this difference was similar, or even favorable to 3D-RA and can support the recommendation of the use of 3D-RA for the assessment of patients with aortic coarctation or Fontan anastomosis, and for the evaluation of the right ventricle and pulmonary arteries.

The difference observed in the pediatric population and the higher radiation exposure, when compared to that reported in the literature, led our local physicist to work hard together with the manufacturer's technicians to reduce radiation exposure from 3D-RA performed in our institution. This effort eventually resulted in an important reduction in the radiation dose and reinforced the importance of this assessment whenever any center intends to start performing tridimensional angiographies. As already described by

Berman et al<sup>21</sup>, this confirms that cooperation between local staff and companies is a process that must be continuously evaluated and the goal is to achieve the lowest possible radiation dose without losing image quality. If not adequately surveyed, the dose can be prohibitive and may not justify the benefits obtained from the technique in certain patient populations. We strongly recommend this evaluation to all institutions that perform 3D-RA. Further prospective studies quantifying the radiation dose both on the patient's skin level and on the operator are necessary to answer some questions regarding radiation exposure in 3D-RA, primarily in children with congenital heart disease, and to determine whether rotational angiography can safely replace 2D-SA acquisitions. Akhtar described the presence of a learning curve for rotational angiography with benefits obtained in the latter half of rotational procedures<sup>15</sup>. In the field of congenital heart diseases, the learning curve is essential for elucidating which cases will benefit from rotational 3D-DSA studies without requiring additional two-dimensional acquisitions.

Three-dimensional rotational angiography is very useful in patients diagnosed with aortic coarctation. A single acquisition can demonstrate the size of the ascending aorta, features from the aortic arch hardly viewed in two-dimensional studies, and the presence of aneurysm in patients previously undergoing percutaneous or surgical procedures (Figure 1). In one patient, additional information on aortic arch tortuosity was available because of the spatial resolution provided by three-dimensional reconstruction. The possibility of evaluating the ascending aorta with the same contrast injection is useful in patients at an increased risk of progressive dilatation. An additional 2D-SA injection in these patients does not seem to be useful to provide more information from three-dimensional reconstruction.

In the assessment of the pulmonary arteries, the possibility of reconstruction can allow visualization of the spatial relationship not feasible in two-dimensional procedures and is useful for guiding or planning percutaneous and surgical interventions. Considering eight patients previously operated on for pulmonary circulation (7 patients with tetralogy of Fallot and 1 patient with truncus arteriosus) and one patient with native pulmonary artery stenosis, three-dimensional assessment was elucidative with clear and useful images of the pulmonary branches, subvalvar region, and previously implanted stents (Figure 2). The images were considered superior to 2D-SA acquisitions in patients with aneurysmatic right ventricular outflow tract and those with tortuous branches of the pulmonary artery, providing optimal assessment of these lesions. Finally, stent fractures and neointimal hyperplasia were better evaluated in two-dimensional angiographies, with little additional information to be obtained from 3D-RA.

In patients with Fontan anastomosis, the slow flow from the right atrial or conduit anastomosis sometimes makes visualization of the pulmonary arteries difficult and requires a lot of different two-dimensional projections. This issue is not a concern in 3D-RA and only one acquisition can delineate the anastomosis and pulmonary branches clearly. In the two patients previously undergoing Fontan anastomosis, 3D-RA provided better images than four or five two-dimensional angiographies in different projections. Careful placement of



**Figure 1** – Bare stent previously implanted in a patient with aortic coarctation with an adequate late result.

the angiographic catheter ensured good visualization of the conduit, pulmonary arteries, and Glenn anastomosis.

The only case in which 3D-RA did not provide good visualization was that of a patient with ductus arteriosus. The defect could not be well reconstructed and we suspect it was a technical problem related to the learning curve period.

The fact that intravascular stenosis like neointimal hyperplasia with or without stent fractures could be better visualized in two-dimensional views could be related to failure of contrast filling of this part of the vessel during the acquisition time. Glatz has already described the “dropout” phenomenon in areas of tight stenosis or stented regions and warned about the risks of misdiagnosis that not uncommonly occur with computed tomography or cardiac magnetic resonance and that could also be present during 3D-RA<sup>5</sup>.

### Limitations

The retrospective single-center design is a limitation of our study. Moreover, the patients included in this study comprised the initial experience with 3D-RA in our institution, and only 11 patients underwent both 3D-RA and a complete 2D-SA study. However, we considered it was necessary due to the scarce literature available in the beginning of the experience. From our point of view, the

lack of information on the benefits of and radiation exposure from three-dimensional angiography in the assessment of congenital heart diseases justified the use of both approaches in the same patient. The amount of contrast used was not assessed, which is another limitation of the study and can be an additional benefit of this approach.

### Conclusion

The use of 3D-RA seems to be of great value in the field of congenital heart diseases. The radiation dose of 3D-RA performed in our institution was higher than that of 2D-SA and this difference was more evident in children. The radiation dose was even higher than that previously reported in the literature for 3D-RA. The information obtained from this initial experience and the comparison with the literature available were of paramount importance to work on radiation dose reduction.

### Author contributions

Conception and design of the research: Manica JLL, Medeiros RF; Acquisition of data: Manica JLL, Rossi Filho RI, Fischer LS, Medeiros RF, Broetto G, Borges MS; Analysis and interpretation of the data: Manica JLL, Fischer LS, Medeiros RF, Broetto G;



**Figure 2** – Late post-operative period of truncus arteriosus with a tubular stenosis of the left pulmonary artery.

Statistical analysis: Manica JLL; Writing of the manuscript: Manica JLL, Rossi Filho RI; Critical revision of the manuscript for intellectual content: Manica JLL, Rossi Filho RI, Borges MS.

#### Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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#### Study Association

This study is not associated with any thesis or dissertation work.

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