Three-Dimensional Echocardiographic Guidance of Right Heart Catheterization Decreases Radiation Exposure in Atrial Septal Defect Closures

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Background: Radiation reduction is desirable in children undergoing cardiac catheterization. Three-dimensional (3D) transesophageal echocardiographic (3D TEE) imaging obviates the need for mental reconstruction of 3D structures from two-dimensional images. Three-dimensional TEE imaging is used in atrial septal defect (ASD) closures. Three-dimensional TEE guidance of right heart catheterization (RHC) without fluoroscopy for ASD closures has not been demonstrated. The aim of this study was to evaluate the feasibility of 3D TEE guidance of RHC in ASD closures and radiation reduction compared with historical control subjects.

Methods: Twenty-two patients underwent 3D TEE guidance of RHC and ASD closures and were compared with 44 control subjects. RHC time, total fluoroscopy time, radiation dose, and procedural time were compared. Fluoroscopy time during RHC was recorded in patients undergoing 3D TEE guidance.

Results: There was a 54% reduction in total fluoroscopy time and a 78% radiation reduction demonstrated with 3D TEE guidance of patients with ASDs compared with control subjects. Although there were no statistically significant differences in the RHC time compared with control subjects, the fluoroscopy time (mean, 0.06 ± 0.23 min) for RHC guidance using 3D TEE imaging was almost zero. There was decreased RHC time as we progressed through the learning curve of performing 3D TEE guidance of RHC ($r = -0.63$, $P < .01$). There were no statistically significant differences in total procedural time.

Conclusions: Three-dimensional TEE guidance in RHC is feasible without the use of fluoroscopy and reduces radiation exposure in percutaneous ASD closures. Three-dimensional TEE guidance may be used in other interventional procedures in the future to further reduce radiation exposure and facilitate catheter interventions. (J Am Soc Echocardiogr 2018;■:■-■.)

Keywords: Three-dimensional transesophageal echocardiography, Atrial septal defect, Right heart catheterization, Catheter guidance

Radiation reduction is desirable in children with congenital heart disease undergoing cardiac catheterization. Children have developing brain and immature structures that, when exposed to radiation, may be at increased lifetime risk for cancer.[1-3] Previous studies have shown that by raising provider awareness and making technical changes to x-ray fluoroscopy systems, patient radiation exposure can be reduced.[4-7] There is radiation exposure not only to patients but also to the staff members performing the procedures. The cumulative lifetime exposure to staff members can also be minimized by demonstrating the philosophy of radiation safety through implementing a collection of sustained practice and radiographic system changes.[4] Although these changes have decreased radiation exposure, the use of other imaging modalities, such as three-dimensional (3D) transesophageal echocardiographic (TEE) imaging, could further reduce fluoroscopy time and radiation exposure.

Three-dimensional TEE imaging provides depth (with elevation plane) of cardiac structures beyond what can be seen on two-dimensional (2D) echocardiography and obviates the need for mental reconstruction of multiple 2D planes. It provides the spatial relationship in detail of many of the cardiac structures accessed during right heart catheterization (RHC), which has traditionally relied on fluoroscopy for guidance. Three-dimensional TEE imaging is already being used in atrial septal defect (ASD) closure and other interventions.[8-13] Furthermore, we have previously demonstrated that using fusion imaging (fusion of echocardiography and fluoroscopy) has helped us decrease radiation exposure in percutaneous ASD closure.[14] However, the utility of 3D TEE imaging to guide RHC without fluoroscopy for ASD closures has not been demonstrated. In this study, we hypothesized that (1) 3D TEE guidance is feasible in RHC without

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Conflicts of Interest: None.

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Abbreviations

2D = Two-dimensional

3D = Three-dimensional

ASD = Atrial septal defect

GL = Goodale-Lubin

RHC = Right heart catheterization

TEE = Transesophageal echocardiographic

the use of fluoroscopy, and (2) 3D TEE guidance of ASD closures may help reduce radiation in children undergoing cardiac catheterization for ASD closures.

METHODS

Study Population

We retrospectively evaluated patients with ASDs from December 2015 to September 2017 using 3D TEE imaging for percutaneous ASD device closures. Three-dimensional TEE guidance of RHC and ASD closure was performed in children who were of adequate size to pass the X7-2t 3D TEE probe (iE33; Philips Medical Systems, Andover, MA) without causing injury. Inclusion criteria were secundum ASD without other associated congenital heart disease, age $<$ 18 years, and adequate body size to pass the X7-2t 3D TEE probe. Exclusion criteria were body size too small for 3D TEE probe placement and esophageal abnormalities. We compared 22 patients who underwent ASD closure with 3D TEE guidance (cases) with 44 patients who underwent ASD closure without 3D TEE guidance (historical control subjects). Two historical control subjects were matched to one study subject. They were matched by ASD device size $\pm$ 2 mm, weight $\pm$ 10 kg, and age $\pm$ 5 years. RHC time, fluoroscopy time for the entire procedure, radiation dose, and procedural time for the entire procedure were compared between the two groups. Fluoroscopy time during RHC time was recorded in patients undergoing 3D TEE guidance. Residual ASDs after device closures and the success rate of ASD closures without residual ASDs were compared between the two groups. All procedures were performed under general anesthesia with mechanical ventilation. The study was approved by the institutional review board.

Three-Dimensional TEE Guidance

RHC was performed using 3D TEE guidance. Live 3D imaging, in the midesophageal view at 90°, was used to guide the catheter from the inferior vena cava to the superior vena cava (Figure 1, Video 1 available at www.onlinejase.com). Using live 3D imaging at the midesophageal view at 0° with increased maximal lateral width, the right atrium and right ventricle were visualized (Figure 2, Video 2 available at www.onlinejase.com). The catheter was guided from the right atrium to the right ventricle, then at the midesophageal view at 60° with increased maximal lateral width, the catheter is guided into the main pulmonary artery (Figure 3, Video 3 available at www.onlinejase.com). Then the catheter was pulled back to the right atrium to cross the ASD. Using 3D zoom mode, the ASD was seen from the right atrial view (Figure 4, Video 4 available at www.onlinejase.com), and the catheter could be seen crossing the ASD into the left atrium. Last, using live 3D imaging at the midesophageal view at 0° to 30° and rotation of the 3D probe to a left pulmonary vein, the catheter was guided into the left pulmonary vein (Video 5 available at www.onlinejase.com). ASD closure was performed with 2D and 3D (x-plane or live 3D) TEE guidance. One echocardiographer guided one interventionalist in this study to limit the amount of variability between operators.

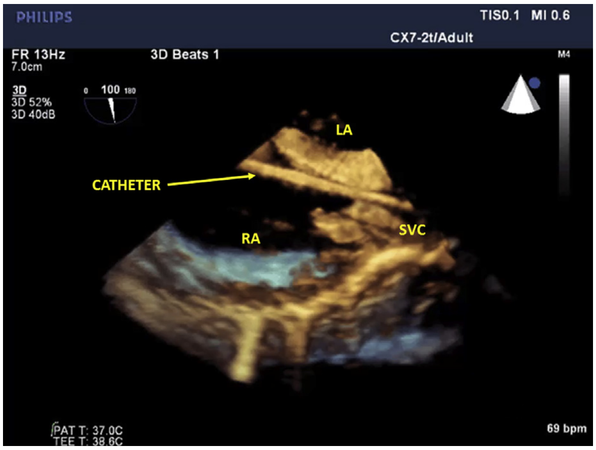

Figure 1 Three-dimensional echocardiographic guidance showing the catheter into the superior vena cava (SVC). *LA*, Left atrium; *RA*, right atrium.

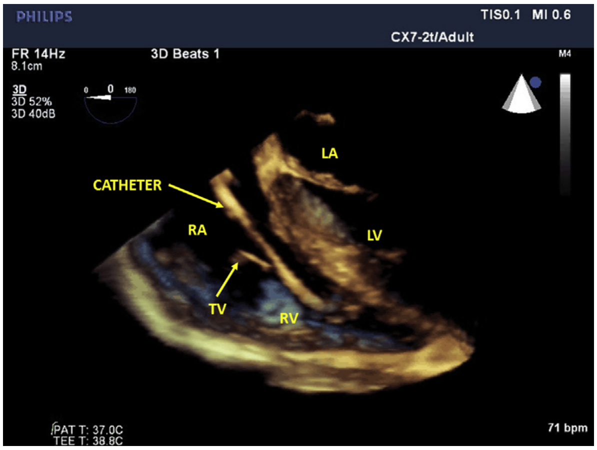

Figure 2 Three-dimensional echocardiographic guidance showing the catheter into the right ventricle (RV). *LA*, Left atrium; *LV*, left ventricle; *RA*, right atrium; *TV*, tricuspid valve.

Cardiac Catheterization of ASD Closures

Access was obtained in the right or left femoral vein, and an 8-Fr sheath was placed. A Goodale-Lubin (GL) 7-Fr catheter was used to perform RHC under 3D TEE guidance. The catheter was chosen because it is echogenic compared with other diagnostic catheters available and can be easily seen and tracked on 3D TEE imaging. Before inserting into the patient's femoral vein, a tip-deflecting catheter is advanced just to the distal tip of the catheter and the position marked by securing an elastic band (Figure 5). This is to prevent perforation of the atrium from the tip-deflecting wire going beyond the GL catheter during the procedure. This also allows non-fluoroscopy-guided advancement of the tip deflector wire into the catheter later in the procedure. The catheterization procedure begins with the GL catheter inserting into the femoral vein once femoral vein access is obtained. The tip of the GL catheter is identified at the inferior vena cava to the right atrium by 3D TEE imaging. While maintaining the tip of the GL catheter in the ultrasound field of view, it can be guided with a counterclockwise motion posteriorly and directed into the superior vena cava (Figure 1). After oxygen saturation in the superior vena cava is obtained, the GL catheter is pulled back into the right atrium for pressure assessment. Then the tip-deflecting wire is