

قيمة التصوير الدوراني الثلاثي الأبعاد للأوعية الدموية في أمراض القلب الخلقية

رسالة

توطئة للحصول على درجة الدكتوراة في تخصص أمراض القلب
والأوعية الدموية

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2018

Value of 3D Rotational Angiography in Congenital Heart Diseases

Thesis

Submitted for Partial Fulfillment of MD
degree in Cardiology

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INTRODUCTION

Despite all the recent progress with new diagnostic modalities for congenital heart diseases (CHDs) including magnetic resonance imaging (MRI), computed tomography (CT), and transesophageal echocardiography (TEE), cardiac catheterization continues to be the gold standard in this field because of its diagnostic accuracy and therapeutic advantages⁽¹⁾.

For a long time, fixed projection angiography (FPA) has been the mainstay for guiding congenital cardiovascular interventions. However, FPA has limitations in soft tissue visualization and precise characterization of complex structures such as segmental branch pulmonary arteries, coronary arteries, and pulmonary veins (PVs). These limitations can be attributed in part to simultaneous opacification of overlying structures and foreshortening of structures if the projection is not perfectly aligned⁽²⁾.

Integration of 3-dimensional (3D) image data sets with fluoroscopy can potentially overcome limitations of 2-dimensional (2D) angiography for visualizing complex vascular structures and can facilitate accurate diagnosis as well as guide interventional procedures⁽³⁾.

Rotational angiography (RA) and 3D rotational angiography (3DRA) have emerged as promising modalities

applicable in congenital cardiac diagnosis. Additionally, integrated 3D images from 3DRA, CT, and MRI overlaid onto live fluoroscopy are now being used for roadmaps to guide interventional procedures ⁽⁴⁾. The potential benefits of integrating 3D images into fluoroscopic procedures for CHD are many, including: improved diagnostic and interventional efficacy, reduced overall radiation exposure, reduced contrast dose, and reduced procedural time ^(5,6). All of these are particularly advantageous in the pediatric population.

The use of 3DRA to assess patients with CHD appears to be a promising technique despite the scarce literature available⁽⁷⁾.

In Ain Shams University, we have a large reference center for congenital and structural heart diseases performing an average of 20 cases per week whether diagnostic or interventional.

Recently, the cath lab unit in our institute was equipped with 2 devices capable of rotational angiography; these devices were equipped with the software for 3D reconstruction. However, since the installation of these 2 devices, this new technique was still not explored.

AIM OF THE WORK

The primary goal is to describe our initial experience with rotational angiography at Ain Shams University and propose a written protocol for our institution to effectively use and master such technique.

The secondary goal is to compare between conventional and rotational angiography in terms of contrast, radiation and procedure time.

Chapter 1

CARDIAC CATHETERIZATION IN CHDS

The reported birth prevalence of all CHDs increased significantly over the last century, reaching a stable estimate of 9 per 1,000 live births in the last 15 years. This corresponds to 1.35 million newborns with CHD every year, representing a major global health burden. ⁽⁸⁾

Cardiac catheterization (whether diagnostic or interventional) is currently one of the most important tools in CHD. It has evolved from balloon atrial septostomy performed by Rashkind in the early 1970s to a wide range of procedures including device closure of various defects, percutaneous valve implantation and hybrid techniques. ⁽⁹⁾

Advances in the imaging techniques in the last 10 years have been associated with recent advances in cardiac catheterization; this includes the development of intracardiac echocardiography, 3D TEE, cardiac CT and MRI, rotational angiography with 3D roadmap, and EchoNavigator and VesselNavigator systems. ⁽¹⁰⁾

Among the important aspects while performing cath in the pediatric population are the radiation exposure, contrast media and access sites. And hence we will rapidly pass by these topics before proceeding to specific procedures.

Radiation exposure in the cath lab:

Radiation results in both deterministic and stochastic effects;

- **Deterministic effects:**

These are related to the radiation dose. The threshold for mild transient skin erythema is about 2 Gray, telangiectasis occurs with 10–15 Gray, and skin ulcerations occur with 16–18 Gray.⁽¹¹⁾ Higher doses of radiation can damage the conjunctiva, iris, sclera, and blood vessels of the retina. The lens is a critical site as it may sustain irreversible damage from a relatively low dose of radiation with high likelihood of cataract formation.⁽¹²⁾

- **Stochastic effects:**

These have no clear exposure threshold for development. Most radiation-induced damage is rapidly repaired, however, occasional misrepair of DNA breaks can result in point mutations, chromosomal translocations, and gene fusions linked to induction of cancer. Brain, skin, and thyroid are at greater risk than other organs.⁽¹³⁾

Females are at higher risk than males and younger patients have higher risk as shown in figure 1. ⁽¹⁴⁾

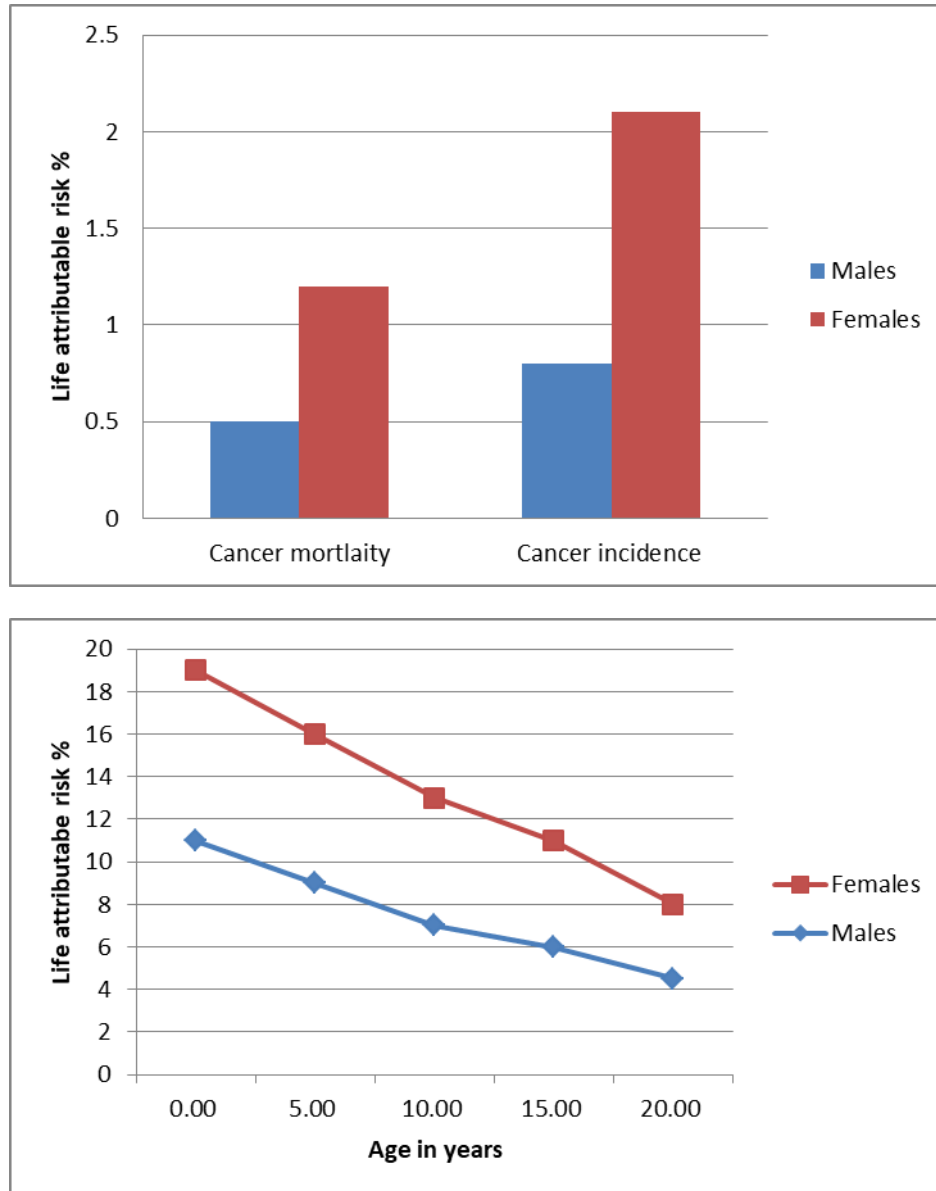


Figure (1): The estimated lifetime attributable risk of cancer mortality and incidence by a single cardiac catheterization in the study by Beels et al in 2009 ⁽¹⁴⁾

Why should we focus on radiation exposure in patients with CHD?

Radiation is of particular concern in the pediatric age group. This is attributed to the increased radiation dose needed in such patients owing to the higher heart rates, smaller cardiovascular structures, smaller body size, and the presence of wide complex anatomical variants making catheterization lengthier. In addition, the long life span ahead of these children together with increased radio sensitivity and the possibility of future cardiac catheterizations poses greater risk from radiation in children. ⁽¹⁵⁾

This led to the introduction of the concept of As Low As Reasonably Achievable (ALARA) in the CHD cath lab which was highlighted in an article proposed by Justino in 2006. The ALARA rests on 3 main principles (Time, distance and shielding). ⁽¹⁶⁾

Trying to apply the ALARA concept necessitates the application of many tactics to reduce radiation exposure; such tactics were proposed by many authors including Justino, Mullins, Lock and others. ^(16–18)

Among the proposed tactics to reduce radiation exposure are: accurate non-invasive diagnosis before cath (to minimize angiograms), proper patient positioning in the isocenter of the field and removal of unnecessary body parts and instruments

before starting, use of shields, use of the least accepted frame rate and the least magnification, use of roadmaps, image overlay and reference images, use of proper catheters and use of adequate contrast dose with test dose before cine loops.

Contrast use in the cath lab:

Going back to earlier eras of pediatric catheterization in the 1980s, hyperosmolar ionic, contrast agents were associated with many adverse events including arrhythmias, pulmonary edema, hemodynamic alterations, cerebral and renal complications. ^(19, 20)

Later the invention of nonionic, hypo-osmolar and iso-osmolar contrast agents gave equivalent angiographic results with less hemodynamic response following contrast administration. Using these agents, adverse consequences related to contrast use appear uncommon. ⁽²¹⁾

So, what is the upper limit of contrast injection in the pediatric population?

Studies addressing contrast administration in the pediatric population appear to be exiguous and hence safe limits of contrast administration is still controversial.

One of the leading studies in this field was that conducted by Senthilnathan and colleagues in 2009, who collected 2321 cases presenting to the cath lab in Boston's

children hospital over 3 years, with median contrast injection of 3.9 ml/kg. Among these patients only 2 patients had contrast related adverse events (transient renal impairment and acute neurological deficit), and more surprisingly, none of the 50 cases receiving the most contrast (more than 6 ml/kg and up to 10 ml/kg), showed adverse events attributed to contrast use. Needless to say that Senthilnathan recommended the use of minimum required dose for a full conclusive study with some reassurance regarding doses above 6 ml/kg. ⁽²²⁾

On the other hand, Niboshi and colleagues stressed that attention should be made to doses exceeding 5 ml/kg especially in neonates and younger age groups. ⁽²⁰⁾

Vascular access in cardiac catheterization for CHD:

In cardiac catheterization, the most frequently used access to the heart is via the femoral artery and/or vein as shown in figure 2. This is followed by the subclavian vein, internal jugular vein, umbilical vein and artery and radial artery. ⁽²³⁾

It is worth mentioning that ultrasound guided access adds a higher success rate from the first attempt, fewer overall attempts, a higher overall success rate, fewer complications and a reduced time to successful cannulation. ⁽²⁴⁾

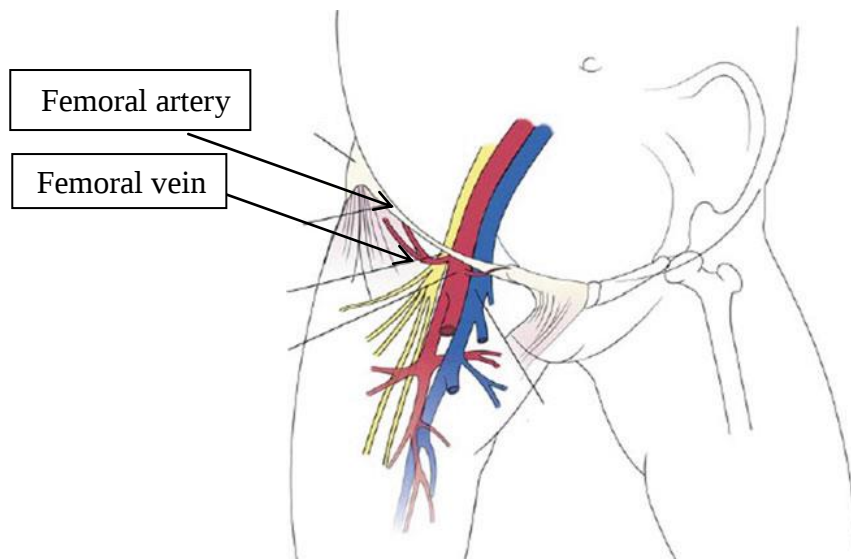


Figure (2): Femoral access site. ⁽²³⁾

Alternative vascular access sites do exist and include: transhepatic venous access ⁽²⁵⁾ paravertebral access for access of venovenous collaterals after Fontan procedure ⁽²⁶⁾, iliac vein access in cases of femoral vein stenosis or thrombosis and most recently aortic access through the IVC for transcatheter aortic valve replacement (TAVR) ⁽²⁷⁾.

One should be aware that complications related to vascular access are the most common after cardiac catheterization and include arterial or venous thrombosis, pseudoaneurysm, hematoma, arteriovenous fistula, dissection and retroperitoneal hemorrhage.

Next we shall discuss some of the frequent cardiac catheterizations done in patients with CHD:

- Diagnostic catheterization for tetralogy of Fallot (TOF) and patients with cavopulmonary shunts.
- Patent ductus arteriosus (PDA) closure
- Balloon pulmonary valvuloplasty (BPV)
- Aortic Coarctation (CoA) balloon/stenting

A. Cardiac catheterization in patients with TOF and cavopulmonary shunts:

Does diagnostic cath have a place in the current era?

In earlier years of pediatric cardiology, cardiac catheterization was the major diagnostic tool but in recent years, the use of catheterization for the diagnosis of CHD has greatly decreased. ⁽²⁸⁾

TEE, MRI, Radionuclide angiography and spiral CT have been employed in defining the structural heart lesions. However these non-invasive techniques don't provide full hemodynamic assessment of flows, pressures and saturations. ⁽²⁹⁾

Although cardiac MRI provided great image resolution and is comparable to cardiac cath, its high cost and need for trained personnel make its use somehow limited especially in developing countries.

To solve this dilemma, Echocardiography and CT angiography may be regarded as complimentary non-invasive imaging tests for preoperative evaluation of TOF patients, the former being most suited for intracardiac anatomy and hemodynamic evaluation, and the latter for assessment of extracardiac structures. Cardiac catheterization still remains the gold standard for diagnosis and for answering any missing questions by non-invasive techniques. ⁽³⁰⁾

Patient with TOF:

Cardiac catheterization indications include ⁽³¹⁾:

- ✓ Assessment of pulmonary artery anatomy in terms of size using McGoon's and Nakata indices, confluence, any stenosis at origin or any peripheral pulmonary stenosis.
- ✓ Assessment of pulmonary artery pressures.
- ✓ Assessment of aorto-pulmonary collaterals.
- ✓ Assessment of coronary arteries.

Patients with cavopulmonary shunts:

Diagnostic cardiac catheterization includes:

- Measurement of PAP and PCWP/LVEDP: Completion of univentricular repair requires PAP less than 15 mmHg and PVR less than 2 Woods' units. ⁽³²⁾
- Assessment of the aorta to exclude coarctation and aorto-pulmonary collaterals.

- Assessment of the pulmonary tree anatomy and exclusion of pulmonary AV fistulae. ⁽³³⁾
- Looking for bilateral SVC, bilateral Glenn shunts.
- Exclusion of veno-venous collaterals.
- It is important to look thoroughly for confounding factors that either lower PAP (presence of venovenous collaterals and pulmonary fistulae) or increase PAP (obstruction to pulmonary venous return, restrictive ASD, ventricular dysfunction, CoA, additional flow to the lungs, peripheral PS).

Interventions in patients with cavopulmonary shunts:

- Balloon dilatation/stenting of the Glenn, Fontan shunts, SVC, RPA, LPA, PVs and/or CoA. ⁽³⁴⁾
- Occlusion of venovenous collaterals, MAPCAs, PDA, previous MBT shunt, pulmonary AV fistulae.
- Balloon dilatation of a restrictive ASD. ⁽³⁵⁾

B. Cardiac catheterization for PDA closure:

Isolated PDA in a full-term infant is one of the common CHD. Its incidence ranges from 5 to 10% of all CHD. PDA has been classified angiographically by Krichenko et al. into five types (Figure 3). The most common is type A. ⁽³⁶⁾