Chapter 63

Anesthesia for Cardiac Catheterization

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> A 17-day-old, full-term male with Trisomy 21, transitional atrioventricular canal defect (TAVC), secundum atrial septal defect (ASD), and aortic arch hypoplasia presents for hemodynamic cardiac catheterization. This infant is currently in the neonatal intensive care unit, tachypneic and saturating 92% on room air. His echocardiogram is suggestive of pulmonary hypertension. His Hgb is 10.7 g/dl and his assumed oxygen consumption is 170 mL/min/m^2. His catheterization diagram is shown in Figure 63.1.

What Is a Transitional Atrioventricular Canal Defect?

An atrioventricular canal (AVC) defect, also known as an atrioventricular septal defect, is a defect involving the endocardial cushions. These defects are categorized into partial, transitional, and complete AVC defects (Table 63.1).

What Are the Rastelli Classifications for Complete Atrioventricular Canal Defects?

The normal AV valves (mitral and tricuspid) form one valve referred to as the common AV valve. This valve straddles the ventricular septal defect with varying choral attachments. The leaflets that overlie the septate are referred to as "bridging leaflets." The variations of the attachments determine the Rastelli classification which is helpful in surgical planning.

What Is the Natural History of AVC Defect Physiology?

Atrioventricular canal defects begin as a left-to-right shunt at the atrial (ASD) and ventricular (VSD) levels. In this patient, only an inlet (type III) VSD is present. With the normal age-related decline in pulmonary vascular resistance, nadir around two months of age, the left-to-right shunt increases and pulmonary over-circulation develops. Infants develop congestive heart failure and failure to thrive. Surgical correction is undertaken in infancy, often around four months of age. If surgical correction is deferred, longstanding pulmonary over-circulation can lead to pulmonary hypertension, Eisenmenger's syndrome, and arterial oxygen desaturation.

Is This Patient's Presentation Consistent with the Natural History of AVC?

No. This patient has a left-to-right shunting lesion. He should not have arterial oxygen desaturation nor echocardiographic evidence of pulmonary hypertension at age 17 days.

What Echocardiographic Findings May Suggest Pulmonary Hypertension?

Pulmonary arterial hemodynamics cannot be directly measured using echocardiography. However, several echo findings are suggestive of pulmonary hypertension. Flattening of the interventricular septum during systole, tricuspid regurgitation, and right ventricular hypertrophy may all indicate a hypertensive right ventricle and could suggest pulmonary hypertension depending on the rest of the clinical and echo features.

Is Cardiac Catheterization Routinely Performed Prior to Surgical Repair of AVC?

No. This patient has echo findings of pulmonary hypertension which is unexpected, therefore catheterization is indicated to clarify hemodynamics and assess for suitability of complete repair (or medical optimization prior to complete repair). Angiograms are also taken to determine anatomic relationships and morphology as needed.

Table 63.1 Description of the types of AV canal type defects.

Canal defect type	Defect location	Associated issues
Partial canal	Primum ASD Cleft anterior mitral valve leaflet	tricuspid valve (TV) often abnormal Mitral regurgitation due to cleft leaflet
Transitional canal	Primum ASD AV valve anomaly VSD (restrictive) Cleft anterior mitral valve leaflet	Mitral regurgitation due to cleft leaflet
Complete canal	Primum ASD Common AV valve VSD (non-restrictive)	Mitral regurgitation due to cleft leaflet Classified according to Rastelli types A,B,C

What Measurements Are Taken during a Hemodynamic Catheterization? What Ventilation Strategy Is Helpful to Ensure Accuracy of Catheterization Measurements?

Oxygen saturations and pressure measurements are obtained in sequence from the superior vena cava (SVC), right atrium (RA), right ventricle (RV), pulmonary artery (PA), and pulmonary capillary wedge (PCW) during a right heart cath eterization. This is followed by a left heart catheterization in which measurements are taken from the descending, transverse and ascending aorta, left ventricle (LV), and left atrium (LA).

Ventilation with room air and measurements taken at end expiration help to ensure consistency and accuracy of hemodynamic catheterization data. Ideally, positive pressure ventilation is minimized or

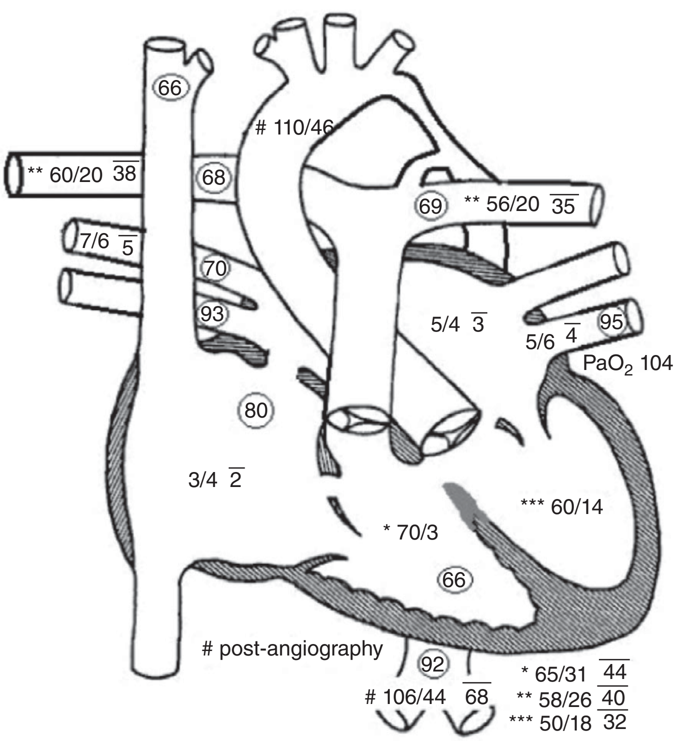

Figure 63.1 Cardiac catheterization diagram. Encircled values represent oxygen saturation, pressures are denoted as systolic / diastolic, mean pressures are overlined. Courtesy of Adam C. Adler, MD.

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avoided completely as is excess positive end-expiratory pressure (PEEP). Similarly, obstruction during spontaneous ventilation may result in abnormally high intracardiac pressure measurements.

What Calculations Are Made from the Hemodynamic Data?

Oxygen saturations are used to calculate oxygen carrying capacity, oxygen content, and cardiac output. In patients with shunt lesions such as this patient, the ratio of pulmonary to systemic blood flow, Qp:Qs, can be calculated. Pressure measurements are used to calculate pulmonary and systemic vascular resistances, transpulmonary gradient, and peak-to-peak gradient.

Oxygen Saturation in the SVC Is 66%, in the RA Is 80%, and in the RV Is 66%. Would These Values Be Expected in a Patient with a Structurally Normal Heart?

No. Oxygen saturations on the systemic venous (right) side of the heart should decline slightly as blood progresses toward the pulmonary artery. In this case, the saturation in the right atrium exceeds the SVC. This implies the existence of a left-to-right shunt at the atrial level. This is consistent with the patient's known ASD.

The RV saturation of 66% is much less than the RA saturation of 80%. This is inconsistent with left-to-right shunting through his VSD. This is concerning for flow reversal through the VSD, e.g., bidirectional or right-to-left at some point in the cardiac cycle. Ventricular pressure measurements and/or ventriculograms are helpful to clarify this.

What Can Be Concluded from the Right Upper Pulmonary Vein Saturation of 70%?

Normally, pulmonary vein saturation should approach 100%. Pulmonary vein desaturation indicates pulmonary pathology at least in a segmental lung section.

What Is the Expected Qp/Qs in a Patient with a Left-to-Right Shunt (Such as Most Patients with TAVC)? <1, =1, or >1?

Left-to-right shunt physiology produces excessive pulmonary blood flow. When pulmonary blood flow exceeds systemic blood flow, Qp/Qs is > 1.

What Is the Qp:Qs Ratio?

The Qp:Qs is a ratio of pulmonary (Qp) to systemic (Qs) blood flow (or cardiac output).

How Is Qp:Qs Calculated?

To calculate the pulmonary or systemic blood flow, oxygen consumption is divided by the absolute value of the difference in oxygen content between arterial and venous blood. In general, flow = oxygen consumption / (difference in arterial and venous oxygen content).

Pulmonary flow (Qp):

$$\begin{aligned} Qp &= VO_2/[Hb \text{ x } 1.34 \text{ x } 10 \text{ x } (SpvO_2 - SpaO_2)] \\ &= 4.6 \text{ L/ min /m}^2 \end{aligned}$$

Systemic flow (Qs):

$$\begin{aligned} Qs &= VO_2/[Hb \text{ x } 1.34 \text{ x } 10 \text{ x } (SaO_2 - SvO_2)] \\ &= 4.6 \text{ L/ min /m}^2 \end{aligned}$$

Because the right and left sides of the heart each have the same hemoglobin and oxygen consumption, a rearrangement and simplification of this calculation can be made:

$$Qp : Qs = (SaO_2 - SvO_2)/(SpvO_2 - SpaO_2)$$

In our patient, the oxygen saturations are SaO_2 = 92%, SvO_2 is usually taken from the SVC and = 66%, $SpvO_2$ = 93–95%; use 95% for calculations, $SpaO_2$ = 69%.

Using the above formula, Qp:Qs = 1.

This patient is ventilated with room air, so any contribution of dissolved oxygen to oxygen content is negligible.

Is a Qp:Qs of 1 to Be Expected in This Patient? What Can Be Concluded from This Value?

Patients with AVC defects are expected to have left-to-right shunts with Qp:Qs >1. Our patient's Qp:Qs equals 1. This finding, along with a desaturated right ventricle (compared to the right atrium), and

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suprasystemic right ventricular pressure suggests some pulmonary obstruction such as pulmonary hypertension.

How Can Pulmonary Obstruction Due to Pulmonary Valve Pathology Be Differentiated from Pulmonary Hypertension by Catheterization?

Certainly, echo images of the pulmonic valve may adequately rule out pulmonary valvular obstruction or stenosis. Without echo findings of pulmonary stenosis, pulmonary hypertension can be strongly suspected in this patient. Catheterization calculations of elevated pulmonary vascular resistance could be used to confirm a diagnosis of pulmonary hypertension.

How Is Pulmonary Vascular Resistance Calculated?

Reminiscent of Ohm's Law in physics (V = IR), vascular resistances can be calculated. Resistance equals change in pressure divided by flow. In the case of pulmonary vascular resistance (PVR), the change in pressure driving blood from the pulmonary artery to the left atrium is divided by pulmonary flow (or right-sided cardiac output).

$$\text{PVR} = (\text{mean PA pressure} - \text{mean LA pressure})/\text{Qp}$$

For our patient, mean PA pressure is approximately 36 torr and mean LA pressure is approximately 3 torr. Qp is 4.6 L/min/m^2 from the previous calculation. PVR = 7.17 Wood units/m^2.

Are Outcomes Following Congenital Heart Surgery in Children with Down Syndrome any Different than Other Children?

From a large retrospective cohort study, patients with Down Syndrome had similar mortality following cardiac surgery compared to their euchromosomal counterparts. The Down syndrome cohort did, however, have increased length of hospital stay if they underwent ASD, VSD or tetralogy of Fallot repair. Patients who underwent VSD closure also had higher rates of heart block.

Suggested Reading

Fudge JC Jr, Li S, Jaggers J, et al. Congenital heart surgery outcomes in Down syndrome: analysis of a national clinical database. *Pediatrics*. 2010;126(2):315–22. PMID: 20624800.

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