Diagnostic catheterization for valvular heart disease

OCL Catheterization and Interventional Cardiology in Adult Patients
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Key points

- Echocardiography is most frequently used for the diagnosis of valvular heart disease.
- Cardiac catheterization is indicated to visualize coronary anatomy and/or to answer any discrepancy between the clinical and echocardiographic findings.
- Transvalvular pressure gradient is not precise to estimate the significance of stenosis in low or high cardiac output states.
- Stenosis severity is most precisely assessed by valvular orifice area index.
- Valvular regurgitation is evaluated usually only semiquantitatively based on angiography.
For most patients diagnosed with valve disease nowadays, severity and prognosis can be evaluated on the basis of patient history, physical examination, and echocardiography. According to the most recent guidelines, cardiac catheterization should be performed only in selected cases where data obtained from echocardiography are inadequate or inconsistent, which is rare. Cardiac catheterization can have several roles in patients with valve disease such as assessment of pressures at rest and on exercise, cardiac output, valve area, pulmonary and systemic valve resistances, measurement of regurgitant volumes, left ventricular function, and performance of angiography. Thus, even if catheterization is seldom performed, it is necessary to summarize the general principles, in particular those which are necessary for percutaneous valve interventions.

2.1 Aortic stenosis (AS)

Catheterization protocol in AS: (1) right heart pressures, (2) cardiac output, (3) left heart pressures, (4) simultaneous registration of left ventricular + aortic root systolic pressures with cardiac output, heart rate, and systolic ejection period, (5) careful manual injection left ventriculography (not with automated pump injector!), and (6) coronary angiography. Simultaneous pressure recording from the left ventricle (LV) and aortic root requires the use of special techniques: either a double-lumen pigtail catheter (e.g. Cook Instruments) or a combination of left Amplatz coronary diagnostic catheter (for aortic root measurement) with 0.014” coronary pressure wire (RADI, for left ventricular measurement). The use of femoral artery pressure (via sheath) is not precise and should not be used.

The invasive evaluation of the severity of AS requires catheterization of the LV, which could be performed either using the retrograde approach from the femoral, radial, or brachial artery, or using the transseptal approach.

In the retrograde approach, vascular access is performed using the usual technique. Crossing of the aortic valve is an important step, which requires specific training. It is advised to use the left anterior oblique 40° or the anteroposterior view. The preferred catheter is an Amplatz left 1 or Amplatz left 2, according to the size of the aorta. Alternatives are the use of a right Judkins, or a multi-purpose catheter. Straight-tipped guide wires, 0.035 inch, are usually preferred over their J-tipped counterparts. The catheter is advanced until it reaches the edge of the leaflet and then carefully pulled back applying a counter-clockwise rotation while an attempt is made to direct the guide wire towards the valve plane and across the valve by moving it gently backwards and forwards. Attempts should not take longer than 1 or 2 min. When the guide wire has crossed the valve, the catheter is gently pushed over the wire into the left ventricular cavity, trying to avoid a too distal position, which would create extrasystolic beats.

When the LV pressure is obtained, the mean gradient is calculated by averaging the values measured during several cycles (five in patients in sinus rhythm and ten in those with atrial fibrillation). To avoid a pressure recovery phenomenon, the catheter recording the aortic pressure should be immediately adjacent to the valve. Pull-back from LV to the aorta (Figure 1.1) allows for a quick estimate of the transvalvular gradient measured as the difference between peak LV and peak aortic pressure; however, due to the quality of curves, changes in frequency, and extrasystolic beats, superposition of curves may be difficult and lead to erroneous conclusions in cases of moderate or mild stenosis, when gradient is low, or when using a multiple hole catheter. Finally, the pull-back from the apex to the valve should be
performed in order to diagnose the presence of any intra-ventricular gradient.

Retrograde crossing is not without risk, in particular cerebral embolization, and thus heparin (40 units/kg) should be given. A small number of vascular complications have been reported, particularly in patients under anticoagulant treatment, and it should not be performed if the international normalized ratio (INR) is >2.

Transseptal catheterization is seldom used for diagnostic purpose only. This relatively complex technique has had a revival with the introduction of the new percutaneous electrophysiological and valvular interventions. Contraindications are left atrial thrombi, bleeding disorders (including INR > 1.5 or activated partial thromboplastin time (APTT) > 50 s), kyphoscoliosis, complex congenital diseases, obstruction, or agenesis of the vena cava (associated with azygos return). Extreme right and/or left atrial enlargement restricts the performance of the procedure to experienced operators, possibly under echographic guidance. As regards the technique, the most commonly used transseptal needle is the Brockenbrough needle, which is 70-cm long, has a curved tip and tapers distally. A hub arrow on the proximal part indicates the direction of the needle. The catheter used most often is the Mullins sheath, which comprises a dilator and a sheath, and is also 8 Fr. Figures 2.1 to 2.3 show the transseptal technique.

Figure 2.2
Transseptal catheterization–transseptal puncture. (a) Right anterior oblique (RAO) 30° view. The position of the transseptal needle is checked. (b) AP view. When the left atrial (LA) pressure is recorded the transseptal needle and the catheter are advanced into the LA.
Figure 2.1
Transseptal catheterization–transseptal puncture. Anteroposterior view. The transseptal catheter is at the level of the fossa ovale. The needle is inside the catheter. The pigtail catheter is positioned at the level of the aortic cusps.

Figure 2.3
Transseptal catheterization–transseptal puncture. AP view. The transseptal needle is withdrawn and the catheter is positioned in the LA

The rare, but feared complication is perforation of the free wall (right atrium, left atrium, or aorta). It mostly occurs when the operator is less experienced, in severe atrial enlargement, or
in thoracic deformity. The perforation of the heart may result in mild pericardial effusion without clinical consequences but haemopericardium usually has immediate clinical consequences resulting in tamponade. Its incidence is around 1% but may be as high as 4% in centres with limited experience. It should always be suspected when hypotension occurs during transseptal catheterization. If haemopericardium is suspected, echocardiography should be performed urgently before deterioration occurs. In most cases, haemopericardium due to transseptal catheterization can be managed by pericardiocentesis, especially when it results from only a puncture by the transseptal needle. Rarely, embolism due to a pre-existing atrial thrombus may result in a stroke. ST segment elevation in the inferior leads accompanied by diaphoresis, hypotension, and chest discomfort with normal coronary angiogram has been occasionally observed after transseptal catheterization as is also the case after other intra-cardiac manipulation. They may be neurally mediated as Bezold–Jarish-like reflex and are responsive to atropine.

**Assessment of stenosis severity.** After catheterization of both the LV (by retrograde or transseptal approach) and the aorta, the calculation of valve area requires simultaneous measurement of transvalvular gradient and cardiac output. Valve area is calculated using the Gorlin formula (Table 2.1). It has several pitfalls particularly in cases of regurgitation, low output, or unstable haemodynamic condition. Despite these limitations, valve area is the most precise invasive parameter of stenosis severity. The symptoms usually occur when aortic valve area falls below 1 cm². Correcting the valve area for body surface area (BSA) (valve area index) is more precise: aortic valve area index <0.6 cm²/m² is generally considered to support the indication for surgery. The normal aortic valve area index should be >1.5 cm²/m². Transvalvular gradient is popular, but is not precise; it is largely influenced by cardiac output, left ventricular function, arrhythmias, and so on. In severe AS the gradient exceeds 50 mmHg (sometimes even 100 mmHg), in mild stenosis it is <20 mmHg. Values 20 to 50 mmHg are difficult to interpret without additional informations and especially with these gradients the calculation of valve area index should be a priority. Fluoroscopic evidence of valvular calcifications is an additional sign supporting stenosis severity.

**Table 2.1 Calculation of valve area using the Gorlin formula**

<table>
<thead>
<tr>
<th>Valve Type</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic valve</td>
<td>( \frac{SV}{SEP} \times \frac{1}{44.3 \sqrt{\Delta P_{mean}}} )</td>
</tr>
<tr>
<td>Mitral valve</td>
<td>( \frac{SV}{DFP} \times \frac{1}{37.7 \sqrt{\Delta P_{mean}}} )</td>
</tr>
</tbody>
</table>

\( SV = \) stroke volume; \( SEP = \) systolic ejection period; \( DFP = \) diastolic filling period; \( \Delta P_{mean} = \) mean pressure gradient.

Indications for aortic valve surgery (ESC guidelines): (1) symptomatic AS, (2) asymptomatic severe AS with left ventricular ejection fraction (LVEF) <50%, (3) asymptomatic moderate–severe AS undergoing other type of cardiac surgery, (4) asymptomatic AS with abnormal
exercise stress test, (5) asymptomatic AS with calcified aortic valve and progressive increase of gradient during follow-up, (6) asymptomatic AS with severe LV hypertrophy.

2.2 Mitral stenosis (MS)

Catheterization protocol in MS: (1) right heart pressures, (2) cardiac output, (3) left heart pressures, (4) simultaneous registration of LV + pulmonary capillary wedge (PCW) diastolic pressures with cardiac output, heart rate, and diastolic filling period, (5) simultaneous registration of the mean pressures in the pulmonary artery and PCW with cardiac output measurement (for the calculation of pulmonary vascular resistance), (6) simultaneous registration of the right ventricular and right atrial pressures for the diagnosis of any concomitant tricuspid valve disease, (7) automated pump injection left ventriculography (to diagnose any mitral regurgitation (MR)), (8) coronary angiography.

The invasive estimation of the severity of MS is also based on the valve area index calculation and thus includes simultaneous measurement of pressures allowing for the calculation of transvalvular gradient and simultaneous performance of cardiac output. This can usually be obtained using retrograde catheterization of the LV and simultaneous recording of the pulmonary wedge pressure (Figure 1.5). Although this approach can provide a reasonable approximation of left atrial pressure in many cases, several technical and physiological factors can affect the relationship between the measured wedge pressure and actual left atrial pressure. If an accurate measurement of the transmitral gradient is needed, direct measurement of left atrial pressure can be obtained using the transseptal technique.

The measurement of cardiac output using thermodilution may be wrong in cases of tricuspid regurgitation which is often associated with MS. Mitral valve area can be calculated using the Gorlin formula with the same limitations as in AS (Table 2.1).

It is also important to calculate pulmonary vascular resistances, even if irreversible elevation of pulmonary resistance is more rarely observed currently due to early diagnosis. In addition, the degree of reversibility of pulmonary hypertension is difficult to predict.

As a general principle in MS, as in other valve diseases, complete evaluation is necessary because valve disease is often multifocal. LV angiography is far less sensitive than echography in evaluating associated MR.

Assessment of stenosis severity. Normal mitral valve area index is >2.5 cm²/m², while in severe MS it is <1 cm²/m². Transvalvular pressure gradient is less precise. In severe MS, it usually exceeds 15 to 20 mmHg. High pulmonary vascular resistance (normal values < 130 dyn/s/cm⁵) is a marker of advanced MS and carries increased risk for cardiac surgery.

Indications for mitral commissurotomy or surgery in symptomatic MS: (1) valve area <1.5 cm² or valve area index <0.9 cm²/m² and favourable characteristics for commissurotomy, (2) valve area <1.5 cm² or valve area index <0.9 cm²/m² and high thromboembolic risk (history of embolism, spontaneous contrast, atrial fibrillation), (3) valve area <1.5 cm² or valve area index <0.9 cm²/m² and pulmonary hypertension (systemic pulmonary artery pressure > 50 mmHg).

2.3 Aortic regurgitation (AR)
2.3 Aortic regurgitation (AR)

Catheterization protocol in AR: (1) right heart pressures, (2) cardiac output, (3) left heart pressures, (4) aortography, (5) left ventriculography (when LV was not sufficiently opacified by regurgitant aortic flow), and (6) coronary angiography.

Regurgitant orifice area in severe AR is usually >0.5 cm²/m² and regurgitant fraction (percentage of regurgitant volume from overall systolic left ventricular discharge) is >50%. However, cardiac catheterization is rarely necessary and is not more precise than echocardiography in calculation of these parameters. The most important is aortography, which is detailed in Chapter 10. Angiographic grading of regurgitant severity using aortography is shown in Table 2.2.

Table 2.2 Angiographic grading of regurgitant severity

<table>
<thead>
<tr>
<th>Grade</th>
<th>Aortic regurgitation</th>
<th>Mitral regurgitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1+</td>
<td>Contrast refluxes from the aortic root into the LV but clears on each beat.</td>
<td>Contrast refluxes into the left atrium but clears on each beat.</td>
</tr>
<tr>
<td>2+</td>
<td>Contrast refluxes into the LV with a gradually increasing density of contrast in the LV that never equals contrast intensity in the aortic root.</td>
<td>Left atrial contrast density gradually increases but never equals LV density.</td>
</tr>
<tr>
<td>3+</td>
<td>Contrast refluxes into the LV with a gradually increasing density such that LV and aortic root density are equal after several beats.</td>
<td>The density of contrast in the atrium and ventricle equalize after several beats.</td>
</tr>
<tr>
<td>4+</td>
<td>Contrast fills the LV rapidly resulting in an equivalent radiographic density in the LV and aortic roots on the first beat.</td>
<td>The left atrium becomes as dense as the LV on the first beat and the contrast is seen refluxing into the pulmonary veins.</td>
</tr>
</tbody>
</table>

LV = Left ventricle.

LV angiography and simultaneous measurement of cardiac output allow for the calculation of regurgitant volumes and fraction, but reliable non-invasive measures supersede the complexity of angiographic haemodynamic measurements.

Aortography can also assess the morphology of the ascending aorta. However it is agreed that non-invasive evaluation, using echocardiography or MRI, provides this information in most cases.

Indications for aortic valve surgery (ESC guidelines): (1) symptomatic AR, (2) asymptomatic AR with LV EF <50%, (3) asymptomatic AR in patients undergoing other types of cardiac surgery (e.g. coronary artery bypass grafting (CABG) or thoracic aorta), (4) asymptomatic AR with
severe LV dilatation, (5) asymptomatic AR with aortic root dilatation.

2.4 MR

Catheterization protocol in MR: (1) right heart pressures, (2) cardiac output, (3) left heart pressures, (4) left ventriculography, (5) coronary angiography.

MR results in an increase in LA pressure that peaks in the late systolic ‘v’ wave. The left atrial pressure is transmitted variably to pulmonary wedge tracing, which is the measurement recorded in practice. Although the ‘v’ wave is often considered the hallmark of MR, this finding is not sensitive for the diagnosis of MR nor is it an absolute value as a reliable predictor of regurgitant severity, because it may be affected by several factors such as the level of systemic pressure, the presence of atrial fibrillation, and so on.

Calculation of the severity of regurgitation by catheterization has the same pitfalls in MR as in AR and is now largely superseded by echocardiography. Angiographic grading of regurgitant severity is shown in Table 2.2.

Very important findings in severe MR are: (a) left ventricular end-diastolic pressure is much lower than the left atrial or PCW pressure (‘pseudostenosis’ on the mitral level) and (b) systolic (and thus also mean) pulmonary artery pressure (PAP) is increased more than diastolic PAP, resulting in an increased (>10 mmHg) transpulmonary pressure gradient even in the absence of active (pre-capillary) pulmonary hypertension. Thus, in severe MR the evaluation of any potential pulmonary arterial (pre-capillary) hypertension should be based on the comparison of PCW mean and PAP diastolic pressures. Under normal circumstances, these two pressures are equal and PAP diastolic pressure should not exceed PCW mean by more than 5 mmHg.

Indications for surgery in severe chronic organic (non-ischemic) MR (ESC guidelines): (1) symptomatic severe MR with LVEF >30%, (2) symptomatic severe MR with LVEF <30% with high likelihood of durable repair and low co-morbidities, (3) asymptomatic severe MR with LVEF <60%, (4) asymptomatic severe MR with pulmonary hypertension (systolic PAP >50 mmHg), (5) asymptomatic severe MR with atrial fibrillation.

Indications for surgery in ischemic MR (ESC guidelines): (1) severe MR in patients primarily indicated for CABG, (2) moderate MR in patients undergoing CABG if repair is feasible.

2.5 Tricuspid regurgitation and stenosis

The haemodynamic changes in patients with tricuspid regurgitation include elevated right atrial mean pressure and systolic ‘v’ wave and also decreased cardiac output at rest. The haemodynamic changes depend on the acuteness as well as the severity of valve lesions. Measurement of cardiac output should not use thermodilution in such cases. Right ventricular angiography is rarely helpful diagnostically because of the presence of the catheter across the valve, which induces further regurgitation.

Tricuspid stenosis can be evaluated by the measurement of transvalvular pressure gradient and calculation of valve area, which would require the use of two catheters and very careful recording of pressure tracing because of low pressures. In addition, the almost constant
presence of tricuspid regurgitation can lead to erroneous calculation of cardiac output. Early studies indicate that tricuspid valve area less than 1.5 cm² is associated with symptoms.

2.6 Pulmonary stenosis

Typically cardiac catheterization is not needed in patients with pulmonary stenosis, unless the clinical picture and echocardiographic data are discordant.

Cardiac catheterization is only minimally helpful in the diagnosis of pulmonary regurgitation since angiography must be performed with the catheter across the pulmonary valve. However, catheterization is essential for the calculation of pulmonary vascular resistance in patients with pulmonary regurgitation due to pulmonary hypertension.

Key reading


