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Right Heart Catheterisation: How To Do It

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Right heart catheterisation (RHC) is a minimally invasive procedure that provides direct haemodynamic measurement of intracardiac and pulmonary pressures. It is the gold standard investigation for the diagnosis and management of pulmonary hypertension. This article will describe how to perform right heart catheterisation, indications and contraindications.

Keywords Right heart catheterisation • Pulmonary hypertension

Introduction

Accurate measurements of cardiac and pulmonary haemodynamics are critical in the diagnosis, management and prognostication of various cardiovascular and pulmonary disease states. Although modern day echocardiography has revolutionised the ability to assess and estimate haemodynamics non-invasively, direct invasive haemodynamics using right heart catheterisation (RHC) remains central in critical decision-making in selected clinical scenarios, and is often under-utilised. We aimed to provide an overview of the indications, best practices, common pitfalls and potential limitations of this procedure.

Indications, Contraindications and Risks

Right heart catheterisation is a minimally invasive procedure, and is the gold standard investigation for the diagnosis and management of pulmonary hypertension (PH) [1–3]. In addition, RHC is necessary for differentiations between haemodynamics in constrictive pericardial disease and restrictive cardiomyopathy, and allows qualification of intracardiac left-to-right shunts [1–4]. Indications, contraindications and risks in RHC are outlined in Table 1.

Patient Preparation and Venous Access

Patients must be euvolaemic prior to the procedure and fasted for at least 2 hours as volume status can impact haemodynamic measurement. Hypervolaemia may lead to overestimation of pulmonary artery (PA) pressure by causing a higher oscillatory load for a given static afterload, driving up PA pulse pressure, leading to potential misclassification of PH (e.g. misclassified pulmonary venous hypertension as mixed, pre- and post-capillary PH). Sedation with benzodiazepines and opioids is typically avoided as they can cause artefactual reduction in intracardiac pressures, and reduction in oxygen saturation from induced hypoventilation.

Once the patient is on the table and the sterile field established, venous access should be obtained. Jugular, brachial or femoral venous routes can be utilised depending on operator and patient preference. The relative advantages and disadvantages of each access route are provided in Table 2.

For femoral access, a 7Fr sheath (Terumo, Tokyo, Japan) is inserted via the femoral vein under ultrasound guidance. Brachial access can be obtained under ultrasound guidance with a 7Fr sheath, or a 6Fr sheath for individuals <60 kg. A large medial vein in the antebrachial fossa can also be used, if present.

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Table 1 **Indications, contraindications and risks in right heart catheterisation.**

Indications	Contraindications	Risks
- Evaluation of the breathless patient and diagnosis of: • Pulmonary hypertension • Constrictive pericardial disease • Restrictive cardiomyopathy • Heart failure with preserved ejection fraction - Intracardiac left-to-right shunt quantification - Adult congenital heart disease (e.g. baffle and conduit gradient quantification) - Work-up for cardiac transplantation [5] - Ventricular assist devices: • Pre-implantation assessment • Post-implantation optimisation	Absolute - Infection at access site Relative - Thrombocytopaenia - Severe electrolyte or acid-base disturbances	Common - Bleeding/Haematoma at access site - Pneumothorax (jugular access) Uncommon - Induced arrhythmias - Pericardial/pulmonary haemorrhage

Internal jugular vein (IJV) access can be safely obtained using a double Seldinger technique, which is associated with lower risk of bleeding complications due to unintentional carotid artery or posterior IJV penetration. A 21 gauge micropuncture needle (Micropuncture ®, Cook Medical, Bloomington, IN, USA) is used to cannulate the IJV under ultrasound guidance, followed by a 0.0018" 40 cm fine wire. Once venous placement is confirmed, a 5Fr, 10 cm catheter is inserted, through which a 0.035" wire can be advanced and a 7Fr sheath inserted.

Choice of Catheter

Once access has been obtained, a Swan-Ganz balloon tipped catheter (Edwards Lifesciences, Irvine, CA, USA) or other flexible catheter can be used to conduct the study, with relative advantages outlined in Table 3.

Procedural Approach

Care must be taken to ensure the pressure transducer is appropriately placed in relation to the patient's position and a reference or 'zero' obtained. The pressure transducer should be zeroed at the mid-thoracic level (midpoint between anterior sternum and bed surface) with the patient supine, which best approximates the level of the right atrium (RA). These references should be maintained for the duration of the procedure.

Balloon inflation allows for ease of 'flotation' of the catheter tip, with reduced perforation risk. The catheter is advanced without a wire unless there is difficulty with manipulation. From the femoral vein position the catheter tip is advanced superiorly through the inferior vena cava (IVC) until it reaches the RA. Deviation away from midline may be a consequence of entry into a renal or hepatic vein, resolved by slight withdrawal and rotation of the catheter prior to secondary advancement. Once in the RA, the catheter should be advanced into the SVC to obtain oxygen saturation for calculation of mixed venous oxygen saturation (MVO_2).

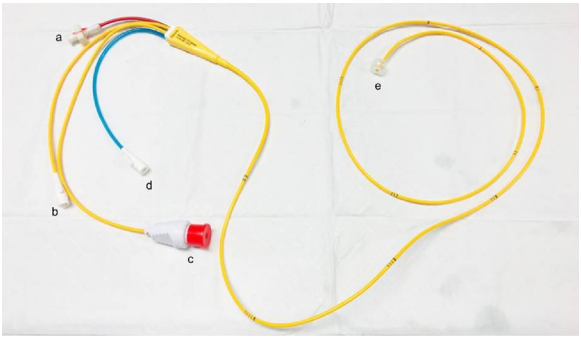
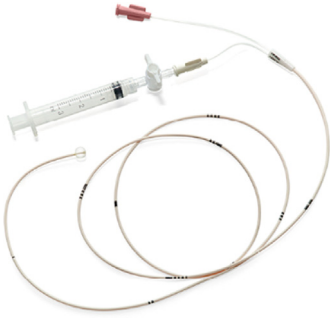
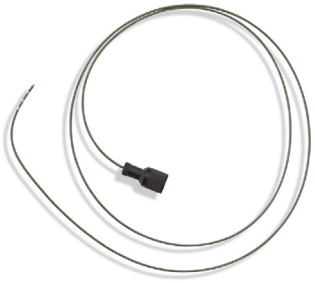
Manipulation of the catheter within the RA to manoeuvre through the right ventricle (RV) and PA differs depending on whether a IJV or femoral approach was taken. Both techniques are outlined in Figure 1. If brachial access is chosen

Table 2 **Advantages and disadvantages of potential right heart catheterisation access sites.**

Access site	Advantages	Disadvantages
Femoral	- Easy access - Conventional cath lab set-up - Less radiation to operator	- More difficult catheter manipulation from RA to PA
Brachial	- Easier Swan-Ganz catheter manipulation into the PA - More comfortable for patients - Decreased risk of bleeding/haematoma	- More radiation to operator - Cannot perform thermodilution to assess cardiac output
Internal jugular	- Easier Swan-Ganz catheter manipulation into the PA	- Most institutions use micropuncture with ultrasound guidance - Non-conventional cath lab set-up - More radiation to operator

Abbreviations: PA, pulmonary artery; RA, right atrium.

Table 3 catheter types, advantages and disadvantages.

Catheter	Advantages	Disadvantages
 ***Swan-Ganz Catheter*** *(Edwards Lifesciences, Irvine, CA, USA)* *a* - balloon inflation port, *b* - pulmonary artery port (distal), *c* - computer connection, *d* - proximal injectate, *e* - balloon/tip	- Mitigates vessel perforation risk with balloon tip - Can measure PAWP - Can use thermodilution to measure CO	- Curve may deform minutes within the venous system
 ***Arrow ®Balloon Wedge-Pressure Catheter*** *(Teleflex, Wayne, PA, USA)*	- Mitigates vessel perforation risk with balloon tip - Can measure PAWP - Easier entry into wedge position	- Cannot measure CO
 ***Cournand Catheter*** *(Boston Scientific, MA, USA)*	- Superior manipulation with stiff tip that does not deform - Can make a pre-formed bend in catheter to assist entry into PA - Use of 0.35" guidewire can improve manipulation	- Stiffer tip increases risk of perforation - Cannot perform thermodilution CO assessment

Abbreviations: PAWP, pulmonary arterial wedge pressure; PA, pulmonary artery; CO, cardiac output.

manipulation of the catheter occurs in a similar fashion to IJV access.

Once in the PA, a pressure recording is obtained to confirm position, with the pulmonary artery pressure (PAP) waveform characterised by the presence of a clear dichrotic notch, representing pulmonary valve closure. All pressure recordings should be recorded at end expiration, when intrathoracic pressure is closest to zero, as changing intrathoracic pressure through the respiratory cycle is transmitted to the pulmonary vasculature. If there is significant respiratory variation, averaging pulmonary artery pressure PAP over several respiratory cycles can be performed to better approximate true PAP. Normal intracardiac pressure ranges and common equations and reference ranges are listed in Table 5. Saturations should be obtained from the PA and RA simultaneously to calculate cardiac output using the Fick equation (Table 5). Once PA pressure is recorded it should be advanced with balloon tip inflated to obtain a pulmonary arterial wedge pressure (PAWP). PAWP is confirmed by measuring the oxygen saturation as >95%, in combination

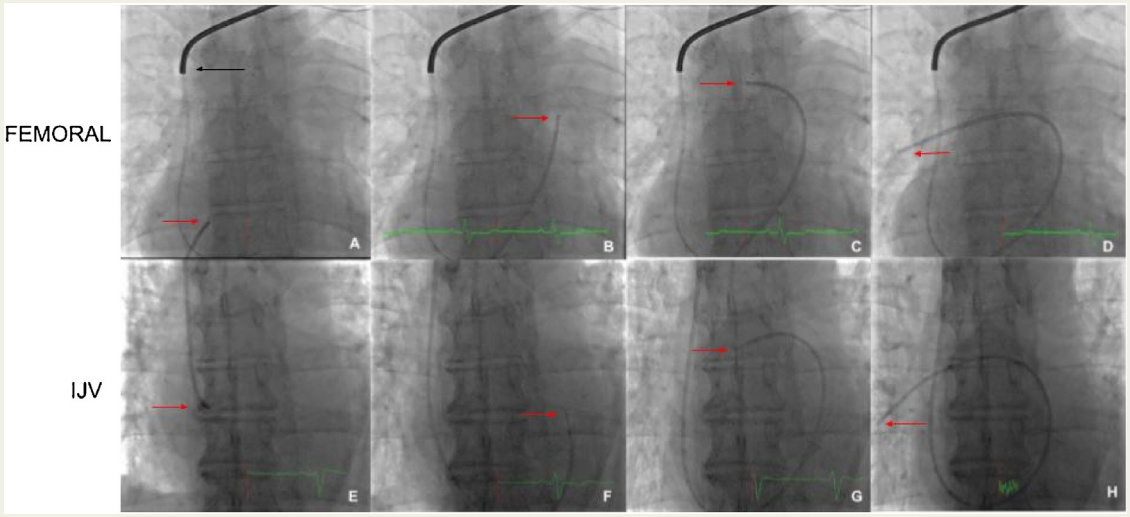


Figure 1 *A-D* - Femoral approach, *E-H* - Internal jugular vein (IJV) approach; *red arrow* - catheter tip, *black arrow* - central venous line. *A.* Right atrium to Right ventricle – turn the catheter tip to face 3 o'clock, then push forward. If RV position is not achieved, then turn catheter tip to 9 o'clock, against the wall of the RA and push until it forms a loop to then enter the RV. *B.* RV to Pulmonary artery – position the catheter oriented to 3 o'clock then apply slight traction and clockwise torque on the catheter until it flicks up into the PA then push. *C.* PA to Pulmonary arterial wedge pressure – once in the PA, push the catheter with the balloon inflated to get into the wedge position. *E-H* – the natural U-shaped curve of the Swan-Ganz ensures that a simple push from the RA should get the catheter into the RV, then the PA and finally the PAWP.
Abbreviations: RA, right atrial; RV, right ventricular; PA, pulmonary artery; PAWP, pulmonary arterial wedge pressure.

with fluoroscopy and waveform analysis. The typical waveform of PAWP is provided in Figure 2. The PAWP tracing is characterised by prominent 'a' and 'v' waves, with an absent 'c' wave that is typical of atrial pressure waveforms, secondary to damping. Three consecutive 'a' wave pressures must be averaged to best estimate PAWP. Repeated inflation and deflation of the balloon tip during the procedure should be avoided to reduce the risk of vessel perforation. Withdrawal from the wedge position should have the balloon partially inflated for the same reason.

Thermodilution cardiac output can be performed when the catheter tip (and distal thermosistor) are in the PA and is preferred for estimation of cardiac output compared with the Fick method, as it better predicts mortality [6]. Sources of error common to both methods are provided below (Table 4). Three measurements within 10% are obtained in this position. The catheter is then withdrawn to the RV and RA sequentially to record pressures and take blood samples for oxygenation levels if required for shunt evaluation. This should not be done with the balloon inflated.

Pulmonary Hypertension

The European Society of Cardiology (ESC) and World Health Organization (WHO) have suggested classification of

Table 4 Sources of error in Thermodilution and Fick's Method for determining cardiac output.

Thermodilution	Fick's Method
- No infusions should be entering the RA from central or peripheral lines	- 'Assumed' O_2 consumption a source of error
- Bolus injection must be delivered with a consistent rate (as rapidly as possible without generating turbulence)	- Measuring and calculating O_2 consumption too time consuming (rarely performed)
- Injection must be delivered without making contact with syringe barrel (can warm injectate)	- MVO_2 and arterial blood samples ideally sampled simultaneously (not always done)
- Patient must not talk or cough during measurement (can alter intrathoracic temperature)	- Drifting of the catheter closer to a wedge position can falsely elevate MVO_2
- Can overestimate CO presence of intracardiac shunts, low cardiac output states and severe tricuspid regurgitation	

Abbreviations: RA, right atrium; CO, cardiac output; O_2, oxygen; MVO_2, mixed venous oxygen saturation.

Table 5 Common equations used during right heart catheterisation (from Department of Cardiology, The Prince Charles Hospital, Brisbane, Qld, Australia).

Cardiac output (Fick) (L/min)	$\frac{BSA\times125\times10}{(SaO_2-PAO_2)\times1.36\times10}$	4.0–8.0
Cardiac index (L/min/m^2)	$\frac{CO}{BSA}$	2.5–4.0
Stroke volume (mL/beat)	$\frac{CO}{HR}\times1000$	60–100
TPG (mmHg)	$PAP-PCWP$	<12
DPG (mmHg)	$PAP_{dias}-PCWP$	<7
PVR (dyne.s.cm^{-5})	$\frac{TPG}{CO}\times80$	<250
Pulmonary flow (mL/min)	$\frac{O_2 consumption}{PVO_2-PAO_2}$	
Systemic flow (mL/min)	$\frac{O_2 consumption}{SaO_2-MVO_2}$	
Qp:Qs shunt	$\frac{Ao-\frac{3SVC+IVC}{4}}{PV-PA}$	1:1
RA (mmHg) (sys and dias)	*direct*	0–7
RV (mmHg) (sys/dias)	*direct*	15–30/0–6
PA (mmHg) (sys/dias)	*direct*	15–30/6–12
PAWP (mmHg) (sys and dias)	*direct*	4–12
Valve area (mitral) (Gorlin) (cm^2)	$\frac{CO\times1000}{44.3^{*}\times HR\times Diastolicfillingperiod\times\sqrt{meangradient}}$	4–6
Valve area (aortic) (Hakki) (cm^2)	$\frac{CO}{\sqrt{PeaktoPeakgradient}}$	3–4

Abbreviations: BSA, body surface area; SaO_2, oxygen saturation; MVO_2, mixed venous oxygen saturation; CO, cardiac output; HR, heart rate; TPG, transpulmonary gradient; PAP, pulmonary artery pressure; PAWP, pulmonary arterial wedge pressure; DPG, diastolic pressure gradient; PAP_{dias}, pulmonary artery pressure during diastole; PVR, pulmonary vascular resistance; PVO_2, pulmonary venous oxygen saturation; PAO_2, pulmonary arterial oxygen saturation; RA, right atrium; RV, right ventricle; PA, pulmonary artery. *mitral valve constant.

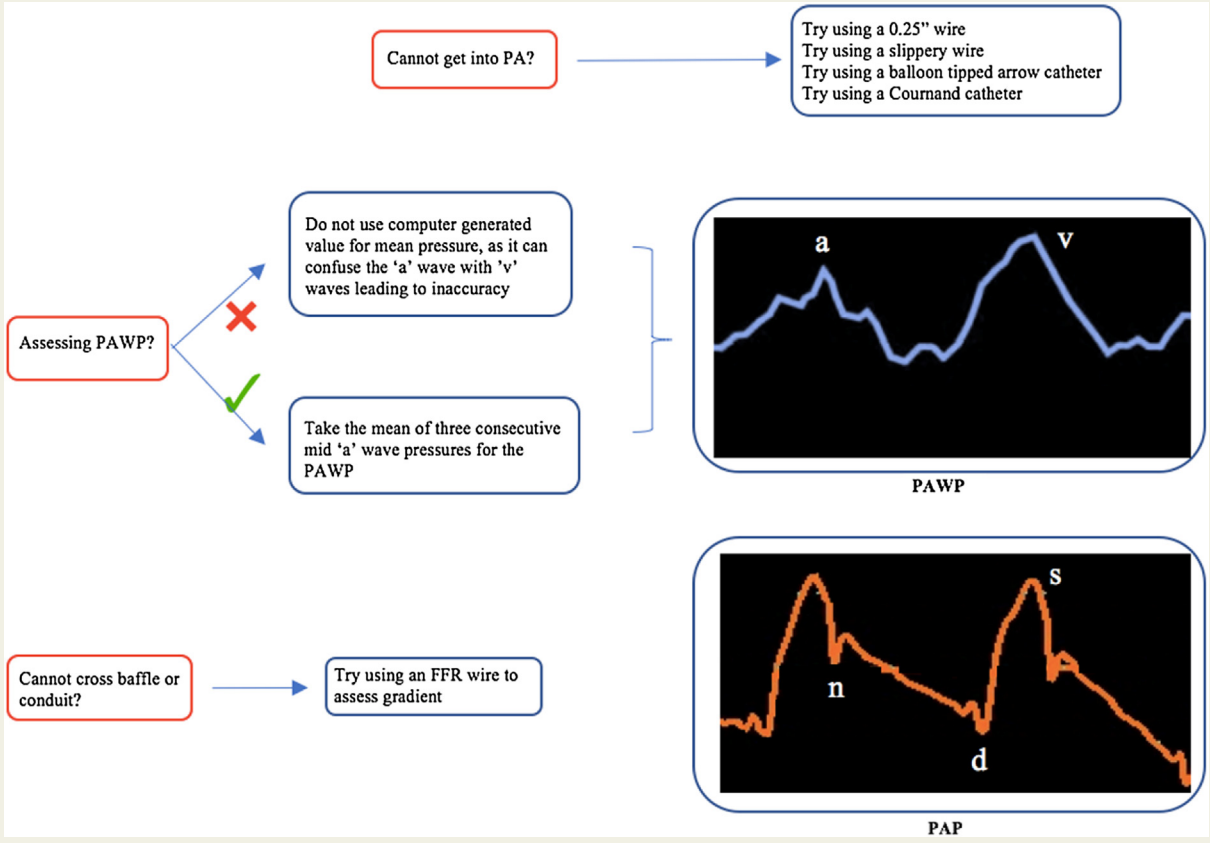


Figure 2 Tips and tricks for RHC, including typical pulmonary artery wedge pressure and pulmonary artery pressure waveforms. Abbreviations: PA, pulmonary artery; PAWP, pulmonary artery wedge pressure; PAP, pulmonary artery pressure; FFR, fractional flow reserve; a, 'a' wave of atrial contraction; v, 'v' wave of ventricular contraction; n, dichrotic notch; d, diastole; *s*, systole.

Table 6 Haemodynamic definitions of pulmonary hypertension (From 2015 ESC/ERS Guidelines for the diagnosis and treatment of pulmonary hypertension and 2013 WHO Updated Clinical Classification of Pulmonary Hypertension [2,3]).

Definition	Characteristics	WHO Clinical group(s)
PH	mPAP $\geq$ 25 mmHg	All
Pre-capillary PH	mPAP $\geq$ 25 mmHg PAWP $\leq$ 15 mmHg	- Pulmonary arterial hypertension (class I) - PH due to lung diseases - (class III) - Chronic thromboembolic PH (class IV) - PH with unclear and/or multifactorial mechanisms - (class V)
Post-capillary PH- Isolated post-capillary PH - Combined post-capillary and pre-capillary PH	mPAP $\geq$ 25 mmHg PAWP $>$ 15 mmHg DPG $<$ 7 mmHg and/or PVR $\leq$ 3 WU DPG $\geq$ 7 mmHg and/or PVR $>$ 3WU	- PH due to left heart disease (class II) - PH with unclear and/or multifactorial mechanisms - (class V)

Abbreviations: PH, pulmonary hypertension; mPAP, mean pulmonary arterial pressure; PAWP, pulmonary arterial wedge pressure; DPG, diastolic pressure gradient; PVR, pulmonary vascular resistance; WU, Wood units.

pulmonary hypertension by haemodynamic parameters obtained from RHC (Table 6).

Right heart catheratisation has a class I level of recommendation for diagnosis of pulmonary arterial hypertension (PAH) and for evaluation of PH in patients being considered for cardiac transplantation [2]. Since PAP is affected by flow, resistance and left heart filling pressure, the PAP during diastole is often substituted for the purposes of classification, where the difference between diastolic PAP and PAWP defines the diastolic pulmonary gradient (DPG). A DPG <7 mmHg suggests post-capillary PH [7].

Although sometimes used interchangeably PAWP is not equivalent to left-ventricular end-diastolic pressure (LVEDP). Using PAWP as a marker for LV dysfunction may result in misclassification [8]. The occlusion of a balloon in the wedge position creates a column of blood between the catheter tip and the LA, allowing for sensitive pressure recordings and so functional analysis of LA operating compliance. Although LA dysfunction can occur secondary to LV dysfunction, there are situations in which LA dysfunction is 'out of proportion' to LV dysfunction, such as in mitral stenosis or atrial fibrillation [9]. In these situations, PAWP is not the best marker for LV function. If LV dysfunction is suspected, dedicated LV catheterisation must be performed to assess LV operating compliance. LVEDP and PAWP are not interchangeable. This has IIa level of recommendation from the ESC [2].

Constriction and Restriction Studies

There is often diagnostic overlap between restrictive cardiomyopathy and constrictive pericardial disease, but differentiation is necessary as pericardial resection is the cornerstone of management of the latter but not the former. Fundamental to diagnosis of pericardial constriction is a reduction in LV systolic pressure with an increase in RV systolic pressure during inspiration. Here, the constricting pericardium does not allow for movement of the RV free wall to accommodate an increased venous return, instead compressing the intraventricular septum into the LV, reducing LV end-diastolic volume and so LV systolic pressure [10].

The haemodynamic characteristics to describe each condition are offered in Table 7.

In a constriction study, to diagnose constrictive pericarditis, RA pressures are taken during exaggerated breathing, before a pigtail catheter is advanced into the LV and simultaneous pressure readings are recorded from the RV and LV. Simultaneous RV/LV pressures are taken during normal and exaggerated breathing cycles. If RA pressure is less than 15 mmHg, 1 L normal saline is given over 10 minutes and the process outlined above is repeated.

A number of the characteristic findings on a constriction study waveform are highlighted in Figure 3.

Shunt Calculation

Using RHC to evaluate the haemodynamic impact of cardiac shunts has a class I level of recommendation from the ESC [2]. Saturations before and after the shunt are measured and input with aortic saturations to complete a shunt flow calculation (Table 5). A difference of 8% between the SVC and main PA saturations is suggestive of a left-to-right shunt and is followed by a full saturation run in all areas of heart and great vessels for specific localisation. The calculations for shunt qualification (Qp:Qs) are shown in Table 5.

Table 7 Haemodynamic characteristics revealed by catheterisation in constrictive pericarditis vs. restrictive cardiomyopathy.

Constrictive Pericardial Disease	Restrictive Cardiomyopathy
- Reduction in LV systolic pressure with an increase in RV systolic pressure during inspiration - Square-root sign of RV/LV filling phase - Equalisation of end-diastolic RV/LV pressures - RVEDP >1/3 RV systolic pressure - RA pressure decrease <5 mmHg - Systolic area index > 1.1*	- Filling pressures >25 mmHg - RVEDP >1/3 RV systolic pressure - Variable presence of square-root sign and early rapid 'y' descent of early diastolic filling

Abbreviations: RVEDP, right ventricular end-diastolic pressure; RV, right ventricular; LV, left ventricular.
*Numerical value with highest sensitivity and specificity [4].

Congenital Heart Disease Assessment

Right heart catheterisation can evaluate gradients across baffles and other conduits in ACHD patients. Pressures are compared in the proximal and distal baffle across the stenosis whilst radiographic images are obtained using a pig-tail or multipurpose angiographic catheter to fully characterise the patency and flow through a conduit.

Emerging Utilities of RHC

After left-ventricular assist device (LVAD) implantation, patient and pump settings variation can lead to variance in the haemodynamic performance of devices, contributing to varying benefit to patient morbidity and mortality. A haemodynamic 'ramp' protocol using RHC has been described and, used in combination with simultaneous echocardiography, has the potential to guide improved management of patients with LVAD's [11]. This represents a novel

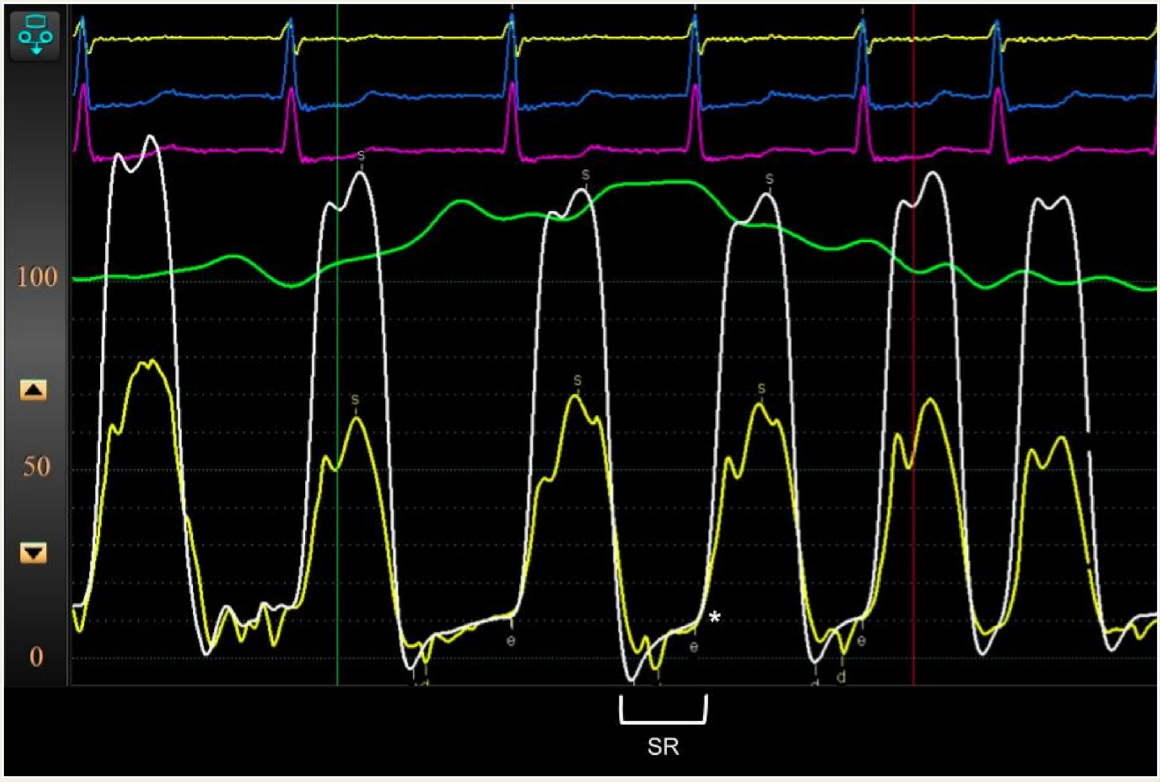


Figure 3 *A.* LV (white) and RV (yellow) waveforms in constrictive pericarditis. The characteristic square root sign, or dip and plateau of the RV waveform is shown (SR). Equalisation of the LV and RV end-diastolic pressures is shown (*). Abbreviations: LV, left ventricular; RV, right ventricular.

indication for RHC in a growing area of advanced heart failure therapy.

Exercise RHC, using a recumbent bike, has been increasingly used to clarify haemodynamics derangements among patients with unexplained dyspnoea with exercise intolerance, including patients with heart failure with preserved ejection fraction. With increasing exercise workload values (e.g. 20 W, 40 W, 60 W, and 80 W), abnormal rise in PAP and/or PAWP may unmask significant diastolic impairment of the LV or exercise induced pulmonary hypertension [12]. Nonetheless, there's currently lack of consensus agreement in regards to the appropriate normal ranges and standardised protocol for exercise invasive haemodynamics.

Conclusion

Invasive haemodynamics provides fundamental diagnostic information in a number of common cardiovascular disorders, but is often under-utilised and limited to a few key subspecialties. With appropriate training and experience, the procedure can be done with exceptionally low risk to patients, while providing critical parameters that may clarify diagnosis and guide therapeutics options. Despite the rapid advancement in non-invasive cardiac imaging, invasive haemodynamics with RHC will remain an important evaluation tool for clinicians and researchers.

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