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REVIEW ARTICLE

The Role of Right Heart Catheterization in Volume Overload – A Narrative Review

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ABSTRACT

Right heart catheterization (RHC) plays an important role in the diagnosis and management of heart conditions, such as heart failure and pulmonary hypertension. RHC monitors pressure parameters and oxygen levels within the heart and lungs. The understanding of RHC is less common among non-cardiologists despite its significant role and widespread applications in diagnosing and managing life-threatening diseases.

Physicians other than cardiologists, including those in critical care and internal medicine, may find it invaluable to understand RHC, especially in the context of volume overload. Knowledge of the implication of RHC findings, especially in critical care settings where prompt decisions are vital, can help improve patient management techniques by providing comprehensive patient evaluation.

Moreover, non-cardiologists who are aware of the indications and implications of RHC can work together more effectively with cardiologists in managing patients with complex cardiovascular diseases. This review aims to enhance the understanding of right heart catheterization's role in cardiovascular conditions, especially volume overload, particularly among non – cardiologists.

1. Introduction

Right heart catheterization (RHC) is an invasive tool that monitors oxygen levels and hemodynamic measurements within the pulmonary artery and chambers of the heart. These pressure parameters help with diagnosis, management and, monitoring of diseases such as heart failure, pulmonary hypertension, cardiomyopathy, cardiogenic shock, and heart valve diseases. Among its diverse applications, RHC provides reliable and precise information in assessing volume overload. Volume overload – characterized by excessive fluid accumulation within the circulatory system, is commonly observed in a variety of clinical scenarios, including heart failure, renal dysfunction, and liver disease. Its complex pathophysiology and multifactorial etiology pose significant diagnostic and management challenges.[1,2]

In addition to evaluating hemodynamics in patients with heart failure, RHC provides critical information for advanced therapeutic options as well as diagnosis. RHC is an important tool in advanced heart failure due to its frequent use in the implantation of a left ventricular assist device or either before or after organ transplantation.[3]

This review provides a comprehensive overview of the role of RHC in diagnosing volume overload, especially identifying its role in optimizing patient outcomes and guiding clinical decision-making. In this review, we will address the methodology of right heart catheterization, the rationale of utilizing RHC as a diagnostic modality, and its clinical implications. This review aims to offer a clear and concise understanding of the role of RHC in volume overload, with attention paid to both specialists in the field and healthcare professionals.

2. Methodology of Right Heart Catheterization (RHC)

The detailed overview of the methodology of RHC includes:

A. Preparation

1. Patient Evaluation: A detailed patient evaluation is conducted to determine clinical indications for RHC and to identify patients who might be at risk of performing this procedure. Patient assessment includes the review of the patient's history, current medications, and allergies.

2. Informed Consent: Patients are provided with information related to benefits, risks, and complications of RHC to make an informed decisions and obtain consent.

3. Pre-Procedural Testing: Selective blood testing and investigations, including ECG, chest X-ray and others, might be required to obtain baseline data and to identify existing comorbidities that require treatment as a prerequisite to performance of RHC procedure.

B. Procedure

1. Access Site Preparation: The access site is sterilized to avoid infection and anesthetized to avoid discomfort. Common access sites for RHC include, the internal jugular vein in the neck, the femoral vein in the groin, or the antecubital vein in the arm.

2. Catheter Insertion: A small incision is made and thin, flexible catheter is carefully guided into the heart under fluoroscopic X-ray guidance, for accurate placement.

3. Hemodynamic and Oxygen Levels Measurements: Pressure parameters and oxygen levels are measured once the catheter is positioned in the heart chamber or the pulmonary artery. Hemodynamic and oxygen levels data gathered during RHC for diagnosing and managing volume overload in heart failure include:

I. Right Atrial Pressure (RAP): Right atrial pressure is an important hemodynamic parameter for evaluating volume overload. RAP represents venous return and the ability of the heart to pump blood into the arterial system. Normal right atrial pressure (RAP) values typically range from 2 to 6 mmHg. Elevated right atrial pressure indicates increased pressure in the right atrium, which suggests fluid overload. Heart failure and pulmonary hypertension are frequently linked to volume overload.

RAP provides valuable information regarding the extent of volume overload and the severity of heart failure. It also helps assess the response to treatment and guides therapy adjustments in the setting of volume overload. Overall, RAP aids in the diagnosis, monitoring, and treatment of volume overload.[4]

II. Pulmonary Artery Pressure (PAP): PAP can be directly measured by a right heart catheterization, which can help distinguish between different acute heart failure phenotypes and direct the escalation or de-escalation of therapy. Normal PAP ranges from 11 to 20 mm Hg at rest.[5] Elevated PAP, especially the systolic component, can indicate pulmonary hypertension, which might be related to left heart failure or volume overload conditions. This strategy is particularly relevant for patients getting mechanical circulatory support or experiencing cardiogenic shock because stabilizing the patient and enhancing results depend heavily on a precise hemodynamic assessment.[6]

III. Pulmonary Capillary Wedge Pressure (PCWP): PCWP provides an estimated inference on left ventricular end-diastolic pressure (LVEDP). LVEDP is a surrogate measure of left atrial pressure. The normal range of PCWP/ LVEDP is between 6 and 12mmHg. Elevated PCWP implies volume overload or left ventricular dysfunction. Elevated PCWP may necessitate therapeutic interventions such as diuretics to manage pulmonary edema and other related complications. [7]

IV. Cardiac Output (CO) and Cardiac Index (CI): Cardiac output (CO) is the volume of blood the heart ejects per minute, whereas cardiac index (CI) is CO related to body surface area. The normal ranges for CO and CI are around 5 to 6 liters at rest and 2.5 to 4 L/min/m², respectively. Initially, as the heart compensates for increased volume in volume overload, CO may be normal or high. However, in chronic overload or heart failure, CO can decrease. A study conducted by Ibe et al. highlighted the need to maintain sufficient cardiac output and cardiac index in heart failure as the study showed that patients with a preserved CI (≥2.5 L/min/m²) had better outcomes compared to those with reduced CI (<2.5 L/min/m²)8.In that study, reduced CI is associated with increased readmission due to heart failure, cardiac death, and left ventricular assist device (LVAD) implantation.

V. Right Ventricular Systolic Pressure (RVSP): Right heart catheterization (RHC) assesses Right Ventricular Systolic Pressure (RVSP) which is a key parameter used to evaluate the pressure in the right ventricle during systole. RVSP can be elevated in conditions like pulmonary hypertension, a common consequence of left-sided heart failure leading to volume overload on the right side of the heart.[9]

VI. Oxygen Saturation Measurements: This measure reflects the balance between oxygen delivery and consumption throughout the body. Oxygen saturation levels provide information on shunts and oxygen extraction, which might be altered due to volume overload. This information can guide treatment decisions, helping to optimize patient outcomes in heart failure management. The normal SVO2 ranges between 60-80%. In volume overload states, the heart may struggle to pump effectively, leading to changes in oxygen extraction by tissues and consequently decreasing SVO2 levels. By assessing oxygen saturation levels and pressure within the heart and pulmonary artery, RHC provides valuable information that can guide the management of patients with volume overload, helping to tailor treatments such as diuretics, vasodilators, or inotropic agents to optimize cardiac output and reduce excess fluid.[10]

5. Cardiac Output Measurement: Right heart catheterization measures cardiac output by using thermodilution and Fick principle methods.[13]

(I) **Thermodilution:** A predetermined amount of indicator material is injected into the right atrium or pulmonary artery. After mixing the indicator with the blood, the indicator is circulated through the pulmonary system, and a thermistor in the pulmonary artery catheter detects temperature changes. Cardiac output is calculated by examining the temperature curve. The magnitude and the rate of temperature changes are inversely correlated with cardiac output.[14]

(II) **Fick Principle:** Fick principle uses oxygen content differences in the arteriovenous system to determine cardiac output. According to the Fick principle, cardiac output is the amount of oxygen taken up by an organ that equals the blood flow to that organ and the product of the difference in the arteriovenous concentration of oxygen. Consequently, the following formula can be used to determine cardiac output.[15]

$$CO = \frac{VO_2}{C(a-v)O_2}$$

Where:

- CO = Cardiac Output
- VO2 = Oxygen consumption
- C(a-v)O2 = Arteriovenous oxygen content difference

Both thermodilution and the Fick principle have their benefits and drawbacks. Factors that control the selection of methods include the patient's condition, the level of expertise of health care team, and the patient's condition.[15]

C. Post-Procedural Care

1. Monitoring: Patients are monitored for complications such as bleeding or arrhythmias.

2. Discharge instructions: Discharge instructions include avoiding exertional activates for a short period after the procedure, observing for possible complications such as catheter insertion site hematoma and infections, and signs to seek medical attention.

D. Safety Considerations and Complications

RHC poses potential risks, such as bleeding, infection, arrhythmias, or damage to the heart or blood vessels, even though it is generally thought to be safe. Advanced imaging techniques and experienced operators help minimize these risks.

3. Right Heart Catheterization (RHC) versus other diagnostic tools

Right Heart Catheterization (RHC) remains a critical tool in diagnosing and evaluating intracardiac shunts, pulmonary hypertension, valve dysfunction, monitoring the effects of treatments and assessing patients before lung and heart transplantation.[11] The invasive nature of RHC limits its use to more critical cases or when precise data is crucial for clinical decisions.

Conversely, Doppler echocardiography (DE) is a non-invasive alternative for initial screening pulmonary hypertension by estimating pulmonary artery systolic pressure and considering parameters derived from tricuspid regurgitation velocity and right atrial pressure. The tight ventricular wall thickness and the quality of the Doppler signal influence the accuracy of DE. Although DE is a valuable non-invasive tool due to its high correlation with RHC results, however DE has some limitation in accuracy particularly at extreme values of pulmonary artery pressure.[12]

RHC and Dopper echocardiography (DE) have their own benefit and setbacks and the choice between these tools depends on the risk-benefit balance of invasiveness versus non-invasiveness, the need for precision, and clinical context.

4. Clinical Applications of RHC in Volume Overload

Right Heart Catheterization (RHC) has wide-ranging applications in the clinical setting, particularly for patients experiencing volume overload.

A. Diagnosing and Differentiating Heart Failure: RHC provides information on parameters like Pulmonary artery wedge pressure (PAWP), Cardiac output (CO), Cardiac index (CI), and systemic vascular resistance (SVR), which assist in diagnosing and differentiating heart failure with reduced ejection fraction (HFrEF) from heart failure with preserved ejection fraction (HFpEF). This distinction is essential for tailoring treatment strategies to specific types of heart failure.[16]

B. Managing Acute Decompensated Heart Failure: RHC offers real-time cardiac filling pressure and output data, which is essential for modifying therapies to maximize myocardial contractility, preload and afterload. This improves cardiac output and alleviates symptoms associated with volume overload.[17]

C. Guiding Therapy in Pulmonary Hypertension: RHC is the gold standard for the diagnosis of pulmonary hypertension (PH), a common consequence of left-sided heart failure that can worsen volume overload. RHC helps in classifying the etiology and severity of pulmonary hypertension by measuring pulmonary artery pressures. Making this distinction is crucial for choosing the right PH-specific treatments, which can have a big influence on patient outcomes.[18]

D. Assessing Volume Status in Renal and Liver Disease: Volume overload is a common outcome of fluid retention in patients with severe liver or renal dysfunction. RHC can assess the impact of this fluid accumulation on hemodynamics, guiding the administration of diuretics and other volume-control measures.

Particularly in situations of cirrhosis with ascites, RHC measurements help determine the risk and acceptability of procedures like trans jugular intrahepatic portosystemic shunt (TIPS) implantation. TIPS is considered contraindicated in cases of coexisting portal hypertension, pulmonary hypertension, or heart failure. By using fluid to challenge the pulmonary circulation-heart unit during a right heart catheterization, we may accurately identify patients who are most at risk of developing heart failure symptoms due to elevated left ventricular filling pressure (PAWP) following TIPS implantation.[19]

E. **Risk Stratification and Prognosis in Cardiovascular Diseases:** RHC offers prognostic data for various cardiovascular disorders linked to volume overload. Reduced outcomes in heart failure and other cardiovascular disorders are related to hemodynamic characteristics like high filling pressures or decreased cardiac output. Consequently, RHC data can aid in risk categorization, directing more intensive interventions or setting priorities for cutting-edge treatments like transplantation or mechanical circulatory support.[20,21]

F. **Monitoring Response to Treatment:** RHC is very helpful in monitoring the hemodynamic response to therapeutic measures in patients with volume overload, even beyond diagnosis and initial care. Treatments such as vasodilators or diuretics can be modified in real time to enhance patient outcomes by measuring their effectiveness repeatedly.[1]

5. Benefits and Limitations of Right Heart Catheterization (RHC)

A vital diagnostic technique for managing volume overload is right heart catheterization (RHC), which provides unique insights into the hemodynamic condition of the cardiovascular system. Like any medical technique, RHC has advantages and disadvantages that affect how useful it is in practical settings.[22]

A. Benefits of Right heart catheterization (RHC) in Volume Overload

1. **Direct Hemodynamic measures:** RHC offers precise and direct measures of the pressures inside the pulmonary arteries and heart chambers, which are crucial for treating and diagnosing disorders related to volume overload.

2. **Guidance for Guided Therapeutic Decisions:** The data gathered from RHC can help optimize fluid management and medication adjustments, especially in complex heart failure situations or pulmonary hypertension where clinical assessment alone may not be sufficient.

3. **Differentiation of Heart Failure Types:** RHC differentiates and, in turn, best course of action for treating heart failure with preserved ejection fraction (HFpEF) versus heart failure with reduced ejection fraction (HFrEF).

4. **Risk Stratification and Prognosis:** RHC provides information on disease prognostication and risk stratification, such as pulmonary capillary wedge pressure and cardiac output.

5. **Evaluation of Treatment Efficacy:** RHC can also be used for the hemodynamic response to therapy. It gives clinicians real-time feedback to modify their interventions for the best possible control of volume overload.

B. Limitations of Right heart catheterization (RHC) in Volume Overload

1. **Invasiveness and Associated Risks:** The invasiveness of radiofrequency catheterization

(RHC) entails certain dangers, including bleeding, infection, arrhythmia, and, in rare cases, more severe problems such as pulmonary artery rupture. Because of these hazards, selecting patients carefully and performing procedures skilfully are required.

2. **Interpretation Requires Expertise:** A great deal of knowledge and expertise are needed to analyze RHC data accurately. Management decisions that are not appropriate can result from misinterpreting hemodynamic data.

3. **Potential for Hemodynamic Instability:** The technique itself may result in momentary hemodynamic alterations, especially in patients who are very sick. This could have an impact on patient safety and measurement accuracy.

4. **Cost and Resource Intensity:** RHC requires many resources, including workers and specialized equipment. In some locations, its availability may be restricted due to the related costs and requirements for a catheterization lab.

In summary, RHC provides unmatched insights into the hemodynamic status of patients experiencing volume overload, assisting in the diagnosis and treatment planning of intricate clinical situations. However, several factors are to be considered, including its invasiveness, related hazards, and the requirement for specific knowledge and resources. To maximize patient outcomes in the treatment of volume overload, it is imperative to weigh the advantages and disadvantages of RHC.

6. Emerging Trends and Future Directions

The field of right heart catheterization (RHC) in the setting of volume overload is changing; new approaches and trends aim to improve the applicability, safety, and efficacy of RHC. These developments seek to maximize patient outcomes through increased diagnostic precision, decreased procedural risks, and the integration of RHC with other diagnostic modalities.[23]

A. Technological Advancements

1. **Miniaturized and Advanced Sensors:** It is anticipated that the creation of smaller catheters fitted with more sophisticated sensors will increase the accuracy of hemodynamic measures while lowering the dangers associated with the procedure. These sensors improve the monitoring capabilities during and after RHC by offering continuous, real-time data on flow and pressure.[24]

2. **Imaging Integration:** RHC, in combination with cutting-edge imaging modalities like computed tomography (CT), magnetic resonance imaging (MRI), or echocardiogram (ECHO), would be helpful in a thorough understanding of the structure and function of the heart. The evaluation of therapy efficacy and diagnosis accuracy may both be enhanced by this synergy.[25]

B. Enhanced Safety Protocols

1. **Improved Procedural Methods:** Constant investigation into procedural methods seeks to reduce the risks connected with RHC. Lowering the risk of vascular injury or arrhythmias involves creating safer access points, better catheter designs, and real-time imaging guidance.

2. **Predictive Analytics for Risk Assessment:** By analyzing outcomes from large patient cohorts using machine learning algorithms

and big data, it is possible to find predictors of procedure risk, allowing for individualized risk assessment before receiving radical heart transplantation

C. Expanding Indications and Applications

Precision medicine: By improving the prediction power of RHC data through genomic and biomarker advancements, more individualized treatment plans may be possible depending on patient risk profiles and hemodynamic responses.

D. Integrating RHC Data with Clinical Decision Support Systems

1. Advanced Analytics and AI: RHC data integration with clinical decision support systems driven by AI and machine learning will help optimize treatment regimens for patients experiencing volume overload.[26]

2. Telemedicine and Remote Consultation: The digitization of RHC data makes it easier to conduct remote consultations and obtain second opinions. This increases access to professional care and team-based management strategies, particularly in underprivileged areas.

E. Ethical and Regulatory Considerations

Ethical and regulatory concerns will be critical as these new trends develop, especially concerning patient privacy, standardizing new technology, and guaranteeing fair access to cutting-edge diagnostic techniques.

7. Conclusion

RHC is a detailed, step-by-step procedure that provides invaluable insights into the heart's and lungs' hemodynamics. Through careful preparation, execution, and post-procedural care, it serves as a critical diagnostic and management tool in cardiac conditions, particularly for conditions involving altered hemodynamic states like volume overload.[11]

In volume overload, RHC analyzes and diagnoses underlying issues to guide short- and long-term management approaches. Its capacity to deliver accurate, in-the-moment hemodynamic data and its advancement in patient safety and personalized treatment makes it a vital tool in the individualized treatment of patients with complicated fluid management problems.

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References:

1. Del Rio-Pertuz G, Nugent K, Argueta-Sosa E. Right heart catheterization in clinical practice: a review of basic physiology and important issues relevant to interpretation. *Am J Cardiovasc Dis.* 2023;13(3):122-37.

2. Ruge M, Fischman DL, Rajapreyar I, Brailovsky Y. The Value of Right Heart Catheterization: Case Series Showing Benefits in a Variety of Diagnoses. *JACC Case Rep.* 2023;21:101959.

3. Ranka S, Mastoris I, Kapur NK, et al. Right Heart Catheterization in Cardiogenic Shock Is Associated With Improved Outcomes: Insights From the Nationwide Readmissions Database. *J Am Heart Assoc.* 2021;10(17):e019843.

4. Nagata R, Harada T, Omote K, et al. Right atrial pressure represents cumulative cardiac burden in heart failure with preserved ejection fraction. *ESC Heart Fail.* 2022;9(2):1454-62.

5. Kumar V, Walia I. Recording of birthweight range by traditional birth attendants (dais) in villages in Northern India. *J Trop Pediatr.* 1986;32(2):66-8.

6. Marini M, Manfredi R, Battistoni I, et al. Acute heart failure: differential diagnosis and treatment. *Eur Heart J Suppl.* 2023;25(Suppl C):C276-C282.

7. Schwam SJ. Pulmonary capillary wedge pressure. *Anesth Analg.* 1982;61(9):805.

8. Ibe T, Wada H, Sakakura K, et al. Cardiac index predicts long-term outcomes in patients with heart failure. *PLoS One.* 2021;16(6):e0252833.

9. He Q, Lin Y, Zhu Y, et al. Clinical Usefulness of Right Ventricle-Pulmonary Artery Coupling in Cardiovascular Disease. *J Clin Med.* 2023; 12(7):2526.

10. Bhende VV, Sharma TS, Sharma AS, et al. Detecting and Quantifying Residual Intracardiac Shunts Using Oximetric Step-Up Methods: A Prospective Observational Study. *Cureus.* 2023;15(1):e33942.

11. Grymuza M, Małaczyńska-Rajpold K, Jankiewicz S, et al. Right heart catheterization procedures in patients with suspicion of pulmonary hypertension - experiences of a tertiary center. *Postepy Kardiol Interwencyjnej.* 2017;13(4):295-301.

12. Augustine DX, Coates-Bradshaw LD, Willis J, et al. Echocardiographic assessment of pulmonary hypertension: a guideline protocol from the British Society of Echocardiography. *Echo Res Pract.* 2018;5(3):G11-G24.

13. Volodarsky I, Kerzhner K, Haberman D, et al. Comparison between Cardiac Output and Pulmonary Vascular Pressure Measured by Indirect Fick and Thermodilution Methods. *J Pers Med.* 2023;13(3):559.

14. Heerdt PM, Pond CG, Blessios GA, Rosenbloom M. Inaccuracy of cardiac output by thermodilution during acute tricuspid regurgitation. *Ann Thorac Surg.* 1992;53(4):706-8.

15. Opotowsky AR, Hess E, Maron BA, et al. Thermodilution vs Estimated Fick Cardiac Output Measurement in Clinical Practice: An Analysis of Mortality From the Veterans Affairs Clinical Assessment, Reporting, and Tracking (VA CART) Program and Vanderbilt University. *JAMA Cardiol.* 2017;2(10):1090-9.

16. Manzi L, Sperandeo L, Forzano I, et al. Contemporary Evidence and Practice on Right Heart Catheterization in Patients with Acute or Chronic Heart Failure. *Diagnostics (Basel).* 2024;14(2):136.

17. Njoroge JN, Teerlink JR. Pathophysiology and Therapeutic Approaches to Acute

Decompensated Heart Failure. *Circ Res.* 2021;128(10):1468-86.

18. Constantinescu T, Magda SL, Niculescu R, et al. New Echocardiographic Tehniques in Pulmonary Arterial Hypertension vs. Right Heart Catheterization - A Pilot Study. *Maedica (Bucur).* 2013;8(2):116-23.

19. Manguso G, Vignone A, Merli M, et al. Hemodynamic Evaluation of the Right Heart-Pulmonary Circulation Unit in Patients Candidate to Transjugular Intrahepatic Portosystemic Shunt. *J Clin Med.* 2022;11 (2):461.

20. Craig M, Pereira NL. Right heart catheterization and risk stratification in advanced heart failure. *Curr Heart Fail Rep.* 2006;3(3):143-52.

21. Krishnan A, Markham R, Savage M, Wong YW, Walters D. Right Heart Catheterisation: How To Do It. *Heart Lung Circ.* 2019;28(4): e71-e78.

22. Rier SC, Vreemann S, Nijhof WH, van Driel VJHM, van der Bilt IAC. Interventional cardiac magnetic resonance imaging: current applications, technology readiness level, and future perspectives. *Ther Adv Cardiovasc Dis.* 2022;16:17539447221119624.

23. Michard F. Hemodynamic monitoring in the era of digital health. *Ann Intensive Care.* 2016;6(1):15.

24. Dogan O, Schierbaum N, Weidenmuller J, et al. Miniaturized Multi Sensor Implant for Monitoring of Hemodynamic Parameters. *Annu Int Conf IEEE Eng Med Biol Soc.* 2019;2019:3823-6.

25. Fagan TE, Truong UT, Jone PN, et al. Multimodality 3-dimensional image integration for congenital cardiac catheterization. *Methodist Debakey Cardiovasc J.* 2014;10(2):68-76.

26. Alabed S, Alandejani F, Dwivedi K, et al. Validation of Artificial Intelligence Cardiac MRI Measurements: Relationship to Heart Catheterization and Mortality Prediction. *Radiology.* 2022;305(1):68-79.