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Pulmonary Hypertension and Right Ventricle: All You Need to Know

ANESTHESIOLOGY UPDATE 2022

NOTHING TO DISCLOSE
A Patient presenting for Cholecystectomy has a hx of Pulmonary Hypertension. Most important information you would like to know about his heart?

A. Left ventricular function

B. Severity of mitral regurgitation

C. Dilation of the right atrium

D. Right ventricular Function

E. Severity of tricuspid regurgitation
3. Which of the following vasodilators would you use to lower the PVR during induction?

A. Nitroglycerine
B. Nitroprusside
C. Milrinone
D. None of the above
4. Which of the following is not consistent with RV failure?

A. Increased right atrial pressure.
B. Increased right ventricular end diastolic pressure.
C. Decreased cardiac output.
D. Tricuspid regurgitation
E. Increased Cardiac Index
A 65-year-old woman for laparoscopic Cholecystectomy

- Heavy smoker
- Severe COPD
- Pulmonary hypertension.
- Essential hypertension.
- Medications: beta-blocker, ACE inhibitor, inhaled steroid/beta-agonist and aspirin.
Pre-operative Transthoracic Echocardiography

- Right ventricle is enlarged with depressed systolic function
- Normal left ventricular size and systolic function
- Severe tricuspid regurgitation
- Severely enlarged right atrium
- Paradoxical septal motion
Right and Left Heart Catheterization

**Cardiac Output (CO):** 3.5 L/min

**Cardiac Index (CI):** 1.6 L/min

**Wedge Pressure:** 17 mmHg

**Right Ventricular Afterload:** 937 dynes*s/cm^5
OMG
OUTLINE

- Classification of Pulmonary Hypertension (PH)
- Definition of Pulmonary Hypertension
- Pathophysiology of PH and RV Failure
- Goals for perioperative management of PH.
Classifications of Pulmonary Hypertension

- **Group I**: PAH based on etiology e.g. Idiopathic PHT, heritable, drugs & toxins
- **Group II**: Left ventricular disease, including congenital heart
- **Group III**: Chronic lung disease
- **Group IV**: Pulmonary arterial obstruction, chronic thromboembolic disease (CTEPH)
- **Group IV**: Encompasses PH associated with unclear and/or multifactorial mechanisms.

Condon D, Nickel N, Anderson R, et al. The 6th World Symposium on Pulmonary Hypertension:
NORMAL PUL ARTERY PRESSURES

• The normal systolic, diastolic, and mean pulmonary artery pressure (PAP) are 22 mmHg/10 mmHg, and 15 mmHg, respectively.

• The pulmonary vascular resistance (PVR) ranges between 90 to about 120 dynes.sec.cm-5.
Hemodynamic definitions for PH

- The first World symposium on PH defined PH as \( mPAP > 25 \) mmHg at rest.
- In 2018, PH was redefined as an \( mPAP > 20 \) mmHg in normal adults and \( PVR > 300 \) dynes/sec/cm²
- **SEVERE PH** Mean PAP > 50 mmHg, PVR > 600 dynes/sec/cm²

### Hemodynamic Definitions of Pulmonary Hypertension Based on Right-Heart Catheterization

<table>
<thead>
<tr>
<th>Condition</th>
<th>mPAP (mmHg)</th>
<th>PCWP (mmHg)</th>
<th>PVR (WU)</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precapillary pulmonary hypertension</td>
<td>( mPAP \geq 20 )</td>
<td>( \leq 15 )</td>
<td>( \geq 3 )</td>
<td>1, 3, 4, 5</td>
</tr>
<tr>
<td>Isolated postcapillary pulmonary hypertension</td>
<td>( mPAP \geq 20 )</td>
<td>( &gt; 15 )</td>
<td>( &lt; 3 )</td>
<td>2, 5</td>
</tr>
<tr>
<td>Combined pre- and postcapillary pulmonary hypertension</td>
<td>( mPAP \geq 20 )</td>
<td>( &gt; 15 )</td>
<td>( \geq 3 )</td>
<td>2, 5</td>
</tr>
</tbody>
</table>

Abbreviations: mPAP, mean pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; PVR, pulmonary vascular resistance; WU, Woods units.
The pathophysiology of PH is multifactorial

- Increase in vascular stiffness
- Reduction of the cross-sectional area
- Imbalance of pulmonary vascular vasodilators and vasoconstrictors
- Localized thrombosis & plexiform lesions

Leading to increase in both pulmonary vascular resistance and right ventricular afterload
Pulmonary Hypertension

\[
PVR = \frac{(mPAP - LAP) \times 80}{C.O.}
\]

\[
mPAP = LAP + \frac{(C.O. \times PVR)}{80}
\]

Three factors account for Pulmonary HTN

↑ LAP
↑ PVR
↑ C.O.

Once PH exists from any factor, the effects on the right heart are the same
\[
\text{PAP} = \text{LAP} + \frac{(\text{CO} \times \text{PVR})}{80}
\]

\[\uparrow\text{LAP}\]
- LV failure
  - Systolic / Diastolic
  - Valvular disease

\[\uparrow\text{CO}\]
- Congenital heart disease
- Pregnancy
- Hyperthyroidism
- Beri-beri
- Sepsis
- Cirrhosis
- Anemia

\[\uparrow\text{PVR}\]

**Acute**
- Hypoxia
- Hypercapnia
- Acidosis
- \(\uparrow\)Sympathetic tone
- Exogenous or endogenous pulmonary vasoconstrictors
- Pulmonary embolism

**Chronic**
- Parenchymal lung disease eg. COPD, ILD
- Hypoxia without parenchymal lung disease eg. hypoventilation, high altitude
- Pulmonary arterial obstruction eg. PE
- Pulmonary arterial hypertension
Hemodynamics Over Time

Adapted from Harrison's Principles of internal Medicine
RV CHANGES DUE TO PUL HTN

The Right Ventricle and Its Load in Pulmonary Hypertension

- Pulmonary vessel narrowing leads to increased vascular load on right ventricle (RV)
- RV adapts by increasing muscle contractility and wall thickness (“coupling”)
- To maintain cardiac output, RV dilates and heart rate increases
  Increase in wall stress and oxygen consumption per gram follow
  Leftward septal bowing results
- Final stage: Uncoupling occurs with high metabolic demand and reduced output
RHC provides very important data prior to induction

- Confirms diagnosis
- Provides critical prognostic information
- Follow-up treatment
“Honeymoon Period”

- The honeymoon period is the time in which Pul HTN exists but very few symptoms.

- It is during this time that *compensatory hypertrophy* of the right ventricle occurs in an effort to maintain cardiac output in the presence of increased PVR.
Regardless of the primary pathologic mechanisms, once PH exists, the effects on the right heart and pulmonary arteries are similar.

The right ventricle is an important therapeutic target in the perioperative management of PH.

Pathophysiology of the RT Ventricle

- **Lower** oxygen consumption.
- **Thin-walled** chamber, function at low O₂ demands.
- The ability to *increase its O₂ extraction* with increase demand.
- *Perfused throughout* the cardiac cycle.
Response to Afterload and Preload

Afterload

Preload

Braunwald E. Pathophysiology of heart failure 1984, p 1573
Right Ventricular Pressure Volume Loop

Phases
1. Start of Ejection
2. Onset of Relaxation
3. End of Ejection

Normal RV
- IVC is not well defined
- Ejection is continued during pressure decline

RV changes due to afterload
- Well defined IVC
- No ejection during pressure decline
Ventricular Interdependence

- VENTRICULAR INTERDEPENDENCE ELEMINATES THE SEPTUM’S ROLE IN RV CONTRACTILITY

- LV (SEPTUM) CONTRIBUTION TO RV EJECTION= 40%

- COMPETTION FOR SPACE BECAUSE OF PERICARDIAL CONSTRAINT

- ANY CHANGE IN ONE CHAMBER IS TRANSMITTED TO THE ADJACENT

Pathophysiologic changes seen in RV failure resulting from increased afterload. Adapted with permission from *Chest* 2005;128:1836-1852.
Principles of Perioperative Management

- Prevention of Systemic Hypotension (risk of RV ischemia)
- Prevention of Acute Elevations in Pulmonary Arterial Pressure (risk of RV failure)
Original Article

Outcomes After Noncardiac Surgery for Patients with Pulmonary Hypertension: A Historical Cohort Study

Atousa Deljou, MD*,2, Moldovan Sabov, MD*,2, Garvan C. Kane, MD, PhD†, Robert P. Frantz, MD†, Hilary M. DuBrock, MD†, David P. Martin, MD, PhD*, Darrell R. Schroeder, MS§, Madeline Q. Johnson, BS§, Toby N. Weingarten, MD*, Juraj Sprung, MD, PhD*†

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‡Division of Pulmonary and Critical Care Medicine, Mayo Clinic, Rochester, MN
§Division of Biomedical Statistics and Informatics, Mayo Clinic, Rochester, MN
• Retrospective study
• PH and surgical databases were reviewed from 2010 to 2017
• They looked at 196 pt with PH undergoing noncardiac surgery under GA.

• The main predictors of peri operative morbidity included:
  • Poor baseline functional status
  • Increased serum NT-proBNP
  • Higher-risk surgeries
Perioperative management of patients with pulmonary hypertension undergoing non-cardiothoracic, non-obstetric surgery: a systematic review and expert consensus statement

Laura C. Price\textsuperscript{1,2,*}, Guillermo Martinez\textsuperscript{3,†}, Aimee Brame\textsuperscript{1,4}, Thomas Pickworth\textsuperscript{5}, Chinthaka Samaranayake\textsuperscript{1}, David Alexander\textsuperscript{5}, Benjamin Garfield\textsuperscript{1,6}, Tuan-ChenAw\textsuperscript{5}, Colm McCabe\textsuperscript{1,2}, Bhashkar Mukherjee\textsuperscript{1,4}, Carl Harries\textsuperscript{1}, Aleksander Kempny\textsuperscript{1,2}, Michael Gatzoulis\textsuperscript{1,2}, Philip Marino\textsuperscript{4}, David G. Kiely\textsuperscript{7}, Robin Condliffe\textsuperscript{7}, Luke Howard\textsuperscript{8}, Rachel Davies\textsuperscript{8}, Gerry Coghlan\textsuperscript{9}, Benjamin E. Schreiber\textsuperscript{9}, James Lordan\textsuperscript{10}, Dolores Taboada\textsuperscript{11}, Sean Gaine\textsuperscript{12}, Martin Johnson\textsuperscript{13}, Colin Church\textsuperscript{13}, Samuel V. Kemp\textsuperscript{14}, Davina Wong\textsuperscript{4}, Andrew Curry\textsuperscript{15}, Denny Levett\textsuperscript{16,17}, Susanna Price\textsuperscript{6}, Stephane Ledot\textsuperscript{6}, Anna Reed\textsuperscript{2,18}, Konstantinos Dimopoulos\textsuperscript{1,2,†} and Stephen John Wort\textsuperscript{1,2,†}

6518 publications identified through database and references

- 1787 duplicates removed

4731 titles screened

- 2931 records excluded

1801 abstracts screened

- 1759 records excluded (not relevant)

Included in the review:
- 13 Clinical studies of adult patients with PH undergoing surgery
- 8 studies for patients with PH undergoing endoscopy
- 16 selected review articles
- 5 case reports
Conclusion

- Reported 30 day mortality after non-cardiac and non-obstetric surgery ranges between 2% and 18% in patients with PH undergoing elective procedures.

- Risk increases to 15-50% for emergency surgery, with complications and death usually relating to acute right ventricular failure.
Conclusion

- With an increasing number of PUL HTN patients requiring surgery in specialized and non-specialized PH centers

- Adequate risk stratification and a tailored-individualized perioperative plan is paramount
Risk factors for mortality include:

- Procedure-specific
- Patient-related factor
- PH severity
  - Pulmonary hemodynamics
  - Poor exercise performance
  - Right ventricular dysfunction
Preoperative questions to consider for patients with pulmonary hypertension undergoing surgery

- Who leads the team and who are the MDT members?
- Do we need to operate, risks vs benefits vs expected survival.
  - What information do we need to make the decision?
  - Are there non-surgical alternatives?
- Is this procedural sedation? Risk assessment is necessary
- Have we optimized the PH preoperatively?
- Do we need an updated RHC? (BNP, 6MW, echo)
Preoperative questions to consider for patients with pulmonary hypertension

- Risk assessment and consent for mortality. Family to be informed too
- Is the patient suitable for ECMO, transplant if needed
- Where to operate? PH center; General or cardiac OR?
- Anesthetic factor: GA vs Regional? Do we need to modify the technique?
- Surgical approach: laparoscopic vs open surgery
Preoperative questions to consider for patients with pulmonary hypertension

- PAH therapies around GA/surgery
- Anticoagulation around surgery

Preoperative checklist:
- PAH meds (IV epoprostenol, inhaled NO, iloprost)
- Plan for PH crisis (vasopressors, PH meds, inotropes, ECMO)
- Intraoperative monitoring (e.g. Echo, A-line, PAC)
- ICU beds booked for 48-72 h postop care
Perioperative risk assessment:

Perioperative risk assessment should take into account:

- Type of surgery
- Patient’s functional capacity
- Hemodynamic severity of the PAH
- RV function
- Any comorbid conditions
Type of Surgery Predicts Perioperative Risk

- Procedures with rapid blood loss → fatal hypotension
- Orthopedic surgeries pose special risk e.g., pulmonary embolization of air, bone marrow, and cement during joint replacement surgery.
- Pneumoperitoneum may compromise cardiovascular hemodynamic status.
- Pregnancy is poorly tolerated in patients with PAH and is contraindicated.
- Mortality rate, was 24% in one study of patients with Eisenmenger syndrome and pregnancy

Progressive or acute increases in PAP leading to acute RV failure are the major complications of anesthesia and surgery in patients with PH.
Preoperative assessment

- Evidence of significant RV dysfunction should prompt re-evaluation of the need for surgery.
- Patients receiving chronic therapy for PH should continue therapy throughout the perioperative period.
- Patients on chronic prostacyclin (epoprostenol) infusions should continue infusion.
- Intraop management of hypotension should be with vasopressor therapy rather than decreasing the infusion.
Perioperative Monitoring

- Arterial catheterization
- Central venous pressure
- Transesophageal Echocardiography
- Pulmonary artery catheter
- Non-invasive CO flowtrack (Vigileo)
Choice of Anesthetic Technique

- General anesthesia method of choice for major surgery
- Peripheral nerve blocks when appropriate
- Neuraxial regional techniques (spinal or epidural block)
- Sedation (avoid excessive sedation)
Inhalational Anesthetics

- Isoflurane, sevoflurane and desflurane may result in pulmonary vasodilation with less effect on contractility.

- Nitrous oxide increase PVR and decrease contractility.
Intravenous Anesthetics

- **Etomidate** maintains systemic hemodynamics without affecting PVR
- **Propofol** can adversely affect contractility and SVR, causing hypotension (careful)
- **Ketamine** has little effect on systemic hemodynamics
- **Narcotic-oxygen technique**, provides hemodynamic stability
- **Dexmedetomidine**
Right and Left Heart Catheterization

CO = 3.5

CI = 1.6 L/min

Wedge 17 mmHg

937 dynes*s/cm^5 = RV afterload
Induction Goals

- Based on Right heart cath
- Based on RV function

- Vasopressor to maintain perfusion pressure to RV
  - Diastolic Perfusion only
  - The RV blood/oxygen supply is proportional to the systemic pressure and inversely proportional to the RV pressure.

- Inotropes if RV failure evident
  - RVEDP > 15mmHg
  - Cardiac Index < 2 l/min/m²
Anesthetic Induction

- Extensive preoxygenation **(avoid sedation)**

- Fentanyl, midazolam, etomidate used in varying doses, with muscle relaxant. Propofol (caution)

- Titration of narcotics should take place after control of ventilation to avoid chest rigidity, hypoventilation
Consider hemodynamic support (e.g. dopamine, epinephrine, phenylephrine)

Do **NOT** attempt to lower PVR pharmacologically (e.g. nitroglycerin, NTP) - lowers CPP

**Hyperventilate, Hyperventilate, Hyperventilate**

Avoid exacerbating PVR – avoid hypoxia, hypercarbia, acidosis

Be careful with volume

Check an ABG

iNO typically not helpful (PVR fixed)
Intraoperative Management Summary

Depressed Contractility

- Hypotension
  - CPP
  - vasopressors
  - RV Ischemia
  - RV dysfunction
  - RV output

Hypervolemia

- Hypertension
- Hypoxia, Hypothermia, Hypercarbia, Pain, Hypo/Hyperventilation, Acidosis
  - FiO₂ warm, RR, ventilate at FRC, pain meds

RV Dilation

- RV output
- LV Preload
- LV Output

CARDIOGENIC SHOCK

- PAP
- RV afterload
- Inotropes and PA dilators
Thank You Thank You