Advanced Troubleshooting - VAD
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1. Ventricular Assist Device (VAD)
   a. What is a VAD?
      i. A VAD is a mechanical circulatory device that is used to partially or completely replace the function of a failing heart
      ii. Goal of device: to direct blood away from the failing ventricle (Left and/or Right) and provide flow to the circulation (Systemic and/or Pulmonary)

2. When are VADs used?
   a. Bridge to Recovery (BTR)
   b. Bridge to Transplant (BTT)
      i. Non-reversible left heart failure
      ii. Imminent risk of death
      iii. Candidate for cardiac transplantation
   c. Destination Therapy (DT)
      i. NYHA Class IIIB or IV heart failure
      ii. OMM 45 out of last 60 days
      iii. Not a candidate for cardiac transplantation

3. The many classifications of VADs
   a. Axial Flow vs. Centrifugal Flow
   b. First Generation
      i. HeartMate XVE, PVAD, IVAD
         1. Pulsatile pumps mimic the natural pulsing action of the heart. These pumps are also known as displacement pumps
   c. Second Generation
      i. HeartMate II
         1. Continuous flow devices have a rotor containing permanent magnets that are controlled with electric currents applying force on the magnets which in turn rotate the rotors
   d. Third Generation
      i. HeartWare, DuraHeart

4. First Generation
   a. Displacement pumps that mimicked the human heart.
   b. Fill and ejection phases similar to your own heart
   c. Provides pulsatile pressure
   d. Early versions had a diaphragm that pushed with compressed air
   e. Mechanical valves provided one way blood flow

5. First Generation Downfalls
   a. Difficult to discharge home – it is done in some facilities
   b. Issues with site infections
   c. Bulky equipment – even portable equipment

6. First Generation Advancements
a. Implantable design.
b. Smaller exit wound
c. Reduced infection
d. More mobility
e. Electronic motor with pusher-plate design.
f. More efficient
g. Battery and system controller wearable by patient

7. HeartMate XVE
8. XVE downfalls
   a. Large size – many men and women are too small for such a big device
   b. Difficult operation/implant
c. Durability – device wears out in 18 months
d. Percutaneous driveline site - problem for infection

9. Second Generation - A Pulseless Heart
   a. Heart Mate II only FDA approved continuous flow device for both destination therapy and bridge to transplant therapy.
   b. Electrically powered continuous flow pump with spinning axial impeller
   c. Valveless pump design
d. Continuous blood flow translates to damped pulse pressure – no pulse on palpation.

10. Third Generation
    a. Same continuous flow design as second generation
    b. Magnetically suspended rotor, no bearings - Greater than 10 year pump lifespan?
    c. Smaller, easier to implant
d. Lower energy consumption, longer battery life
e. Long-term advantages are unknown-trials ongoing

11. HeartMate II®
    Clinical Operation and Patient Management

12. HeartMate II LVAS
    System Components
       a. Implantable titanium blood pump
       b. System Controller
       c. Shared Components:
       d. System Monitor
       e. Display Module
       f. Power Sources
       g. Power Module
       h. Batteries & Clips
       i. Emergency Power Pack
       j. Accessories

13. HeartMate II LVAS – Key Design Features
    a. Relatively Simple Design
    b. Valveless
    c. Only one moving part, the rotor
d. Blood immersed bearings designed for minimization of blood damage
e. All motor drive and control electronics are outside of the implanted blood pump
f. Speed range: 6,000 to 15,000 rpm
   g. Flow range: 3 – 10 L/min
15. Intraoperative concerns
   a. Aortic Insufficiency
   b. PFO/ASD
   c. Inflow cannula
   d. Outflow
   e. Right heart function and protection

16. Pump Power
   a. Measured in watts
   b. Related to pump speed and flow
   c. Under normal patient conditions, power should remain within a certain range for a specified speed
   d. \( \uparrow \text{Speed} \rightarrow \uparrow \text{Power} \)
   e. Note baseline power for later diagnostic use

17. Flow Estimator Design
   a. Flow measurement does not use a sensor or flow probe
   b. Derived from motor power and speed providing an estimate of pump flow
   c. \( \downarrow \text{Power} \rightarrow \downarrow \text{Flow} \)
   d. \( \uparrow \text{Power} \rightarrow \uparrow \text{Flow} \)
   e. For a given speed, pump flow is linearly related to power (over a limited range)

18. Pump Flow Principles
   a. Pump flow is a function of:
   b. The speed of the rotor
      1. \( \uparrow \text{Speed} \rightarrow \uparrow \text{Flow} \)
      2. \( \downarrow \text{Speed} \rightarrow \downarrow \text{Flow} \)
   c. The difference in pressure across the pump
      i. \( \uparrow \text{Pressure gradient} \rightarrow \downarrow \text{Flow} \)
      1. \( \downarrow \text{Pressure gradient} \rightarrow \uparrow \text{Flow} \)

19. Pressure-Flow Curves
20. Pump Flow Waveform
21. Flow Estimator – “Green Zone”
22. Pulsatility Index
   a. The Pulsatility Index (PI) is a measurement of flow pulse through the pump
   b. It is determined by the degree of native LV contractility and pump speed
   c. Pump speed determines the amount of LV unloading
   d. As speed increases the PI goes down
   e. As speed decreases the PI goes up
   f. PI is a dimensionless value where:
      g. \( \text{PI} = \frac{[\text{power max} - \text{power min}]}{\text{power average}} \times 10 \)

23. Pulsatility Index
   a. PI relates to amount of unloading provided by the pump & therefore the amount of native heart function
   b. The lower the PI \( \rightarrow \) the greater the amount of support/unloading being provided by the pump
   c. The higher the PI \( \rightarrow \) the less the amount of support/unloading being provided by the pump (more native heart function)
   d. PI will naturally vary by patient
24. PI Events
   a. The HM-2 incorporates a suction detection algorithm to help reduce the risk of unwanted events.
   b. The system monitors sudden changes in pump flow pulsatility (a PI event)
   c. If a PI event is detected, the pump speed is automatically reduced to the auto speed low limit setting to avoid suction.
   d. Immediately following an event the operating speed displayed on the monitor will be lower than the set speed and then slowly return to the set speed.

25. PI/Suction Event
   a. Management
   b. Volume status
      i. Correct bleeding
   c. Treat RV failure, arrhythmias
      i. Adjust fixed speed setting
   d. Reposition inflow conduit

26. Alarms and troubleshooting
   a. Advisory, Hazard and Battery Alarms
      i. Advisory Alarms
         1. Power Lead Disconnected
         2. SC Battery Module Low
         3. Replace System Controller
         4. Low Speed Operation
         5. Low voltage
      ii. Hazard Alarms
         1. Low voltage
         2. PERCUTANEOUS LEAD DISCONNECTED
         3. LOW FLOW
         4. LOSS OF POWER

27. Causes of Low Flow:
   a. Decreased preload (right heart failure, tamponade, hypovolemia, bleeding, etc)
   b. Obstruction of pump inflow or outflow
   c. Systemic hypertension
   d. Pump off or perc lead disconnected
      i. Action:
         1. Assess patient
         2. ECHO to assess RV, LV function, inlet cannula obstruction
         3. If persist, seek additional help immediately

28. Patient management
   a. Defibrillation / Cardioversion
      i. External defibrillation or cardioversion
         1. Do not stop the pump
      ii. Internal defibrillation or cardioversion
         1. Disconnect the percutaneous lead from the controller
            a. Consider clamping the outflow graft to prevent retrograde flow
   b. Unique Treatment Issues-pulse and B/P
      i. Close surveillance for changes in afterload (SVR) or preload (filling) is required
      ii. Under stable physiologic conditions:
1. Automated B/P may not be accurate
2. Manual B/P recommended
3. Invasive B/P when indicated – when flow is pulse less
   iii. When in doubt, ECHO
      1. Helps decide on LV volume
      2. RV function
      3. Appropriate Speed
      4. Aortic valve opening
      5. Tamponade
      6. Mixed venous oxygen saturation

29. HeartWare HVAD® Guidelines
   a. Recommended speed: 2400-3200 RPM
   b. Flow Trough >2L/min
   c. Flow Pulsatility 2 to 4 L/min
   d. Expected power range: 3-7 watts
   e. Set high power alarm at 2 watts above average power
   f. Set low flow alarm at 2 L/min below average flow

30. Post-Operative Management
   a. Fluids are given to maintain pump flow index at greater than 2.0 L/min/m² with central venous pressure and left atrial pressure less than 20 mmHg
   b. Vasopressors and/or vasodilators can be used as required to adjust vascular tone
   c. Patients may require inotropic assistance of right ventricular function
   d. Control hypertension – maintain MAP < 90mmHg

31. Arrhythmias/Emergency Procedures
   a. OK to defibrillate HeartWare® System patients
   b. Anti-arrhythmic drugs, pacemakers, and ICDs are compatible with the HeartWare® System
   c. Institute appropriate ACLS protocols
      i. If chest compressions have been administered, confirm function and positioning of HVAD® pump

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