NONINVASIVE HEMODYNAMIC MONITORING: IMPEDANCE CARDIOGRAPHY

1. Provide a general overview of impedance cardiography (ICG).

   - ICG is a safe, non-invasive hemodynamic monitoring tool that measures and monitors the cardiac cycle and provides specific measurements which include: cardiac output, stroke volume, systemic vascular resistance, contractility, and fluid status. Data are analyzed, and displayed graphically as an impedance waveform (similar to an arterial pressure waveform, but based on volume and velocity of aortic blood flow, rather than pressure) and an ECG waveform.

   - ICG detects and records changes in cardiac hemodynamic function using thoracic electrical bioimpedance (TEB) technology. ICG is a safe, accurate, reproducible, technology that provides a cost effective alternative for hemodynamic evaluation and continuous monitoring.

   - The accuracy, precision, and reproducibility of ICG measures of hemodynamics have been documented in clinical studies. ICG has been used effectively in a variety of acute care and ambulatory care settings for patient assessment, selecting pharmacological agents and adjusting dosages, optimizing pacemaker settings, and monitoring patients' responses to therapy. In addition, ICG monitoring facilitates patient education and increases patient involvement in and co-operation with the treatment program, all of which contribute to quality patient care.

   - ICG measures electrical resistance changes in the thorax. Corresponding changes in impedance are used with the ECG to measure and calculate hemodynamic parameters. This is how it works:
     - An alternating current is transmitted through the chest.
     - The current seeks the path of least resistance: the blood filled aorta.
     - Baseline impedance to current is measured.
     - Blood volume and velocity in aorta change with each heartbeat.

2. Describe how impedance cardiography reveals problems.

   - ICG works by measuring changes in thoracic electrical bioimpedance over changes in time in relation to the cardiac cycle. A harmless, low voltage, high amplitude, alternating current is introduced through the outermost sensors of paired electrodes placed on the root of the neck and at the base of the thorax. The conducted voltage is sensed through the innermost sensor pads and the drop in voltage (difference between what is introduced and what is sensed) is used to determine resistance (or impedance) to the current.

   - If there is a change in impedance, over changes in time, when the current is held constant, there must be a change in the properties of the conducting medium. These properties include the inherent resistance of the conducting medium (thoracic contents), the length, and the cross sectional area of the conducting medium.

   - With each heartbeat, changes in conductivity occur as blood distends, and then leaves the aorta. These changes are measured and recorded as impedance waveform, similar to the arterial pressure waveform but based on volume rather than pressure.

   - The ECG is recorded and the timing of changes in impedance are simultaneously measured and recorded. Algorithms are used to calculate or derive heart rate, stroke volume, cardiac output, indices of contractility, and indices of workload that are displayed on a monitor screen.

3. Discuss the indications and clinical applications of impedance cardiography.

Indications:

- Patients with suspected or known cardiovascular disease
- Differentiation of cardiogenic from pulmonary causes of acute dyspnea
- Optimization of atrioventricular interval for patients with AV sequential cardiac pacemakers
- Patients with need of determination for intravenous inotropic therapy
- Patients with the need for fluid management

Applications:

- ***Critical Care***
  - Quickly assess baseline hemodynamic status with any patient
  - Trend and detect hemodynamic changes for earlier intervention
  - Monitor drug titration and fluid management to evaluate and optimize treatment
  - Assist in invasive line management and determine need
  - Provide a noninvasive bridge
  - Enable earlier removal of invasive lines
  - Provide hemodynamics in patients where invasive procedures are contraindicated or not routinely used:
    - Unavailability of invasive placement staff
    - Right heart valve dysfunction
    - Thrombolytic therapy
    - Endocardial pacemakers
    - High risk for infection
  - Some studies show that the monitoring of cardiac output by invasive catheter is not only expensive, but it also has a high infection risk for the patient. ICG can often replace the catheter and is a more economical, safe and comfortable.

- ***Surgery / Anesthesia***
  - Pre-operative: Establish baseline hemodynamics on high-risk surgical patient
  - Peri-operative:
    - Assess hemodynamic status during thoracic, vascular, orthopedic general surgery
    - Establish differential diagnosis between fluid status and cardiac dysfunction
    - Monitor drug titration and fluid management to evaluate and optimize treatment
    - Trend and detect hemodynamic changes for earlier intervention
  - Post-operative
    - Evaluate hemodynamics for transfer to appropriate care unit
    - Detect compromised hemodynamics to guide therapeutic options

- ***Emergency Care***
  - Establish baseline status on any patient with potentially unstable hemodynamics:
    - Heart Failure
    - COPD
    - Hypo / Hypertension
    - Myocardial infarction
    - Cardiac arrhythmia
    - Trauma
    - Early Sepsis
    - Cardiogenic /Non-Cardiogenic shock

    - High risk pregnancy
  - Guide differential diagnosis and treatment options:
    - Monitor drug titration and fluid management to evaluate and optimize treatment
    - Trend and detect hemodynamic changes for earlier intervention
    - Triage patients to appropriate level of care

- ***Congestive Heart Failure***

  - ICG monitoring provides:
    - A quantifiable measurement of the effects of cardiac medications on both SVR and cardiac output.
    - The added benefit that it does not require the patient to be hospitalized
      - Easy to perform in the outpatient clinic.
  - For Class III - IV heart failure patients requiring outpatient inotrope infusions, ICG monitoring assists in determining an adequate dosage regimen through immediate noninvasive display of cardiac output.

- ***Pacemaker Optimization***

  - Various parameters (AV-delay, maximum pacing rate) of pacemakers require individual adjustment (which can be a time consuming process achieved by trial and error that may not reach the true optimum).
  - The ICG enables easily optimized pacemaker settings by measuring cardiac output and examining the changes in curve shape.
  - In patients with dual-chamber pacemakers, cardiac output can vary significantly by altering the AV delay. With the beat-to-beat stroke volume monitoring available with ICG, cardiac outputs can be evaluated at a wide range of AV delays within minutes.

- ***Heart Transplant***

  - Decreased myocardial contractility is one of the first signs of early heart rejection.
  - ICG monitoring can serve as a valuable noninvasive adjunct in postoperative monitoring for early rejection.

- ***Hypertension***
  - Assessing baseline hemodynamics and the interaction between blood pressure, flow, resistance, and fluid status assists in the selection and dosing of therapy.
  - Because hemodynamic information is not available, many times patients are diuresed or beta-blocked to the benefit of blood pressure but at the expense of overall vascular resistance. ICG data can be used to verify a balanced treatment regimen by providing data on LV contractility (beta-blockers), Systemic Vascular Resistance (vasodilators), and fluid status (diuretics), to target therapy for each patient's unique needs.

- ***Dialysis***
  - Assessing hemodynamic status during dialysis to evaluate and optimize patient condition and identify optimum fluid status and customize therapy for each patient.
  - ICG prevents hemodynamic crisis by trending and detecting changes in hemodynamics for earlier intervention

4. Identify precautions in patient populations that may produce unreliable ICG data.

Precautions:

- Severe aortic regurgitation
- Minute ventilation driven pacemakers

- o Note: The ICG monitor should not be used for patients with impedance-driven pacemakers that calculate minute ventilation to regulate pulse generator pacing rate. The ICG impedance current interferes with the pacemaker impedance current and may cause pacemaker rate acceleration.
- ❖ Severe septic shock
- ❖ Weight < 67 > 341 pounds
- ❖ Height < 4’0’’ > 7’5”
- ❖ HR < 40 > 250

5. Describe patient assessment parameters and preparation prior to initiation of impedance cardiography.

- Provide preprocedure teaching; explain the purpose of monitoring thoracic fluid and hemodynamic status
- Obtain the patient's VS and complete a cardiovascular assessment

6. Demonstrate the placement of sensors.

Lead Placement

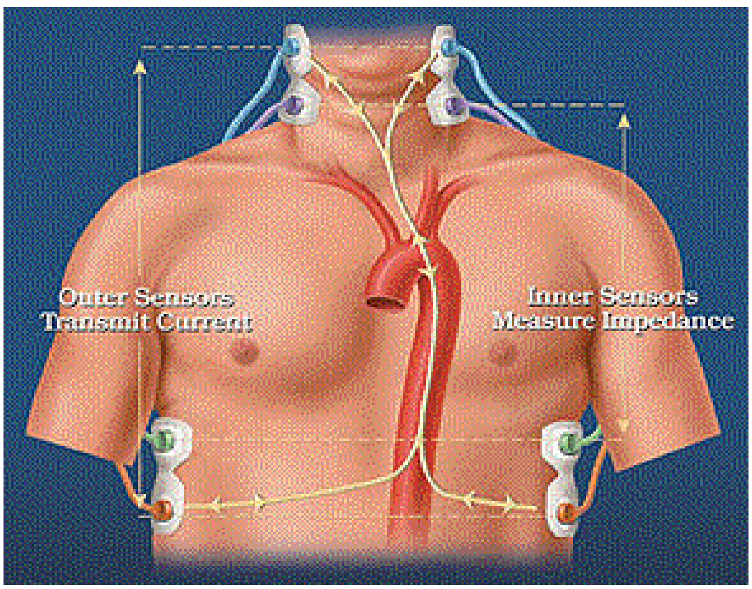


Figure 1 (Reprinted from CardioDynamics, The ICG Company website)

- Prepare skin for sensor placement to clean and dry hairless skin.

- Do not use alcohol or benzoin as sensing will be impaired.

- Landmarks are identified for placement of the upper and lower sensors (Figure 1 Lead Placement). Proper sensor placement is essential for acquisition of accurate hemodynamic and thoracic fluid status data.

- Attach 4 dual sensors to patient.

  - ➢ Use the root of the neck as a reference for vertically locating the rectangular shaped detecting sensor being positioned directly superior and inline with the ear lobe.
    - ▪ Heart symbol faces down
    - ▪ Avoid trachea and bone

  - ➢ Use the xiphoid process as a reference for vertically locating the rectangular shaped detecting sensor with the corresponding circular shaped transmitting sensor.
    - Position directly inferior and along the mid-axillary line
    - Heart symbol faces up

- Identify left and right branches of the patient cable (with respect to the patient) as indicated on the patient cable yoke diagram and connect the respective leads in order from top to bottom: blue, purple, green and orange.

- Verify a secure patient cable connection to the BioZ.

7. Demonstrate the skills required to perform ICG: noninvasive hemodynamic monitoring.

- Leave monitor and printer on and plugged in to avoid warm up delays.

- Press 'Start Monitor', and enter patient data: ID, Name, Gender, Height, Weight, Age, BP (manual entry or ICG), CVP (or use default CVP value), PAOP (or use default CVP value).

- View default parameters. Adjust as needed.

- Ensure the patient is in the supine position with the head of the bed less than 30 degrees

  Note: If HOB > 30 degrees, perform consistently at same level documenting same on report.

- Place the ECG electrodes in a lead that produces an upright R wave.
  - ➢ BioZ needs to sense 30 similar beats
  - ➢ Set average lower in Afib, Pacers, LBBB

- A low-amplitude, high frequency alternating electrical current is applied to the thorax via the most superior neck and inferior thorax sensors (blue and orange leads respectively). Pulsatile blood volume changes emanating predominantly from the aorta result in pulsatile impedance changes to the current flow thus producing a waveform (termed the delta Z, impedance, or ICG waveform). ICG measures the voltage drop, and calculates the impedance (Z) to the applied electrical current.
  - ➢ Observe ICG waveform and ECG displayed on monitor.
  - ➢ Hemodynamic calculations depend on artifact-free ICG and ECG waveforms.
  - ➢ Baseline impedance (Zo), the amount of impedance/conductivity of all of the conductive matter in the thorax, is measured.

- Changes in impedance over changes in time are calculated and displayed numerically and graphically as the ICG waveform to reflect the dynamic state of fluid in the thorax (Figure 2: ECG and ICG Waveforms).
  - ➢ The changes in resistance are used to measure and calculate hemodynamic parameters.
  - ➢ Changes in thoracic impedance reflect changes in the pulsatile volume of blood flow through the aorta in response to electrical and mechanical events in the myocardium.

- To print report, make sure printer is on. Press [PRINT] hardkey.

- Select the [STATUS REPORT] softkey followed by the [COMPLETE STATUS] softkey to print the report.

- When finished monitoring, press [STOP MONITORING] hardkey.

- Remove sensors from patient (if one time monitoring event only)

8. Describe important concepts and waveforms in ICG analysis including patient monitoring and care.

- Assess hemodynamic parameters and TFC for trends every 1 to 2 hours, following interventions, and as needed. Recognizable landmarks on the impedance waveform correlate with landmarks on the electrocardiogram.

ECG and Normal ICG Waveform

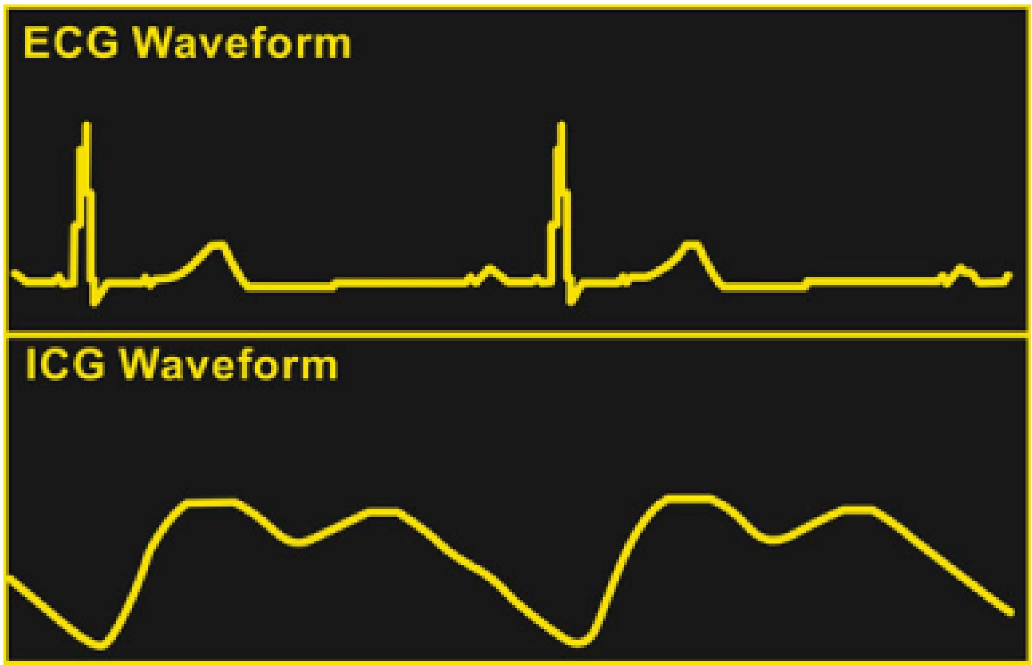


Figure 2
(BioZ.com display of ECG and ICG Waveforms. CardioDynamics, The ICG Company)

- Assess baseline and trends in thoracic fluid status (TFC). Normal values:
  - Men 30-20
  - Women 21-37

- Assess baseline and trends in continuously displayed cardiac output (CO) or cardiac index (CI)
  - Normal: CO 4 -8 L/min
  - Normal: CI 2.5 - 4.2 L/min/m2

- Assess baseline and changes in preload by evaluating stroke volume (SV) response to physiologic fluid challenge:
  - Measure and note SV with head of bed elevated
  - Place patient supine or lift legs for 'physiologic fluid bolus.'
  - Measure and note SV change
    - Normal: SV 60 - 100 mL
    - Normal: SI: 35 - 65 mL/beat/m2
    - Formula: CardioDynamics' proprietary ZMARCâ algorithm

- Assess baseline and trends in afterload:
  - Systemic vascular resistance (SVR)
  - SVR normal: 742 - 1378 dyne sec cm-5
  - SVR index normal: 1337 - 2483 dyne sec cm-5 m2

- Formula: $SVR = \frac{(MAP – CVP)}{C0*}$ X 80   * Use CI for SVR index calculation

- Assess baseline and trends in thoracic fluid content:
  - Normal: 30-50/1000/ohms (males) 21-37/1000/ohms (females)
  - Should decrease with position changes (supine to standing)
  - Note: Thoracic fluid content TFC does not correlate to pulmonary artery wedge pressure

Figure 3: Monitoring Screen

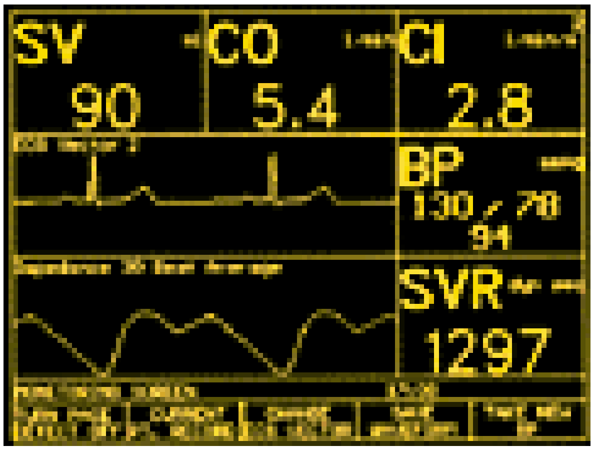
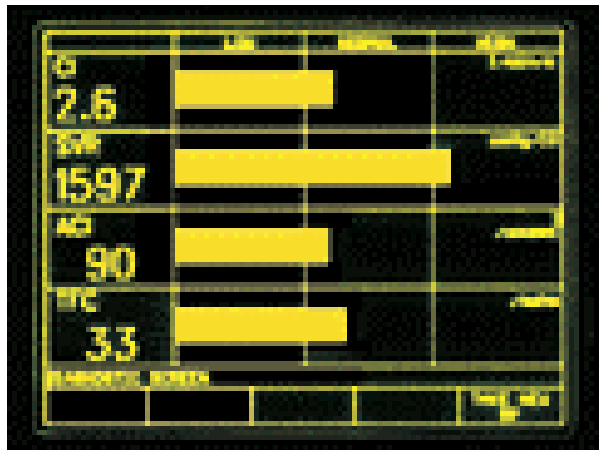


Figure 4: Diagnostic Screen



(BioZ.com displays of monitoring and diagnostic screens. CardioDynamics, The ICG Company)

9. Discuss the hemodynamic parameters measured by or derived from ICG.

- ***Stroke Volume (SV):***
  SV is the amount of blood the left ventricle ejects in one beat, measured in milliliters per minute (ml/min). SV can be indexed to a patient's body size by dividing by Body Surface Area (BSA) to yield Stroke Index (SI).

- ***Cardiac Output (CO):***
  CO is the amount of blood the left ventricle ejects into the systemic circulation in one minute, measured in liters per minute (l/min). To get CO, multiply Stroke Volume (SV) by Heart Rate (HR). CO can be indexed to a patient's body size by dividing by Body Surface Area (BSA) to yield Cardiac Index (CI).

- ***Systemic Vascular Resistance (SVR):***
  SVR is representative of the force that the left heart must pump against in order to deliver the stroke volume into the periphery. SVR is directly proportional to blood pressure and indirectly proportional to blood flow (CO).

  SVR can be indexed to a patient's body size by dividing by Body Surface Area (BSA) to yield Systemic Vascular Resistance Index (SVRI).

  SVR is determined by the following equation:

  $$SVR = [(MAP - CVP) / CO] \times 80$$

  Mean Arterial Pressure (MAP): MAP is measured in mmHg. Outside of direct measurement, it is determined by the following equation:

MAP = (SBP - DBP)*KP) + DBP

- ***Velocity Index (VI) and Acceleration Index (ACI):***
  These two indices are both BioZ specific parameters. VI is the maximum rate of impedance change, and is representative of aortic blood velocity. ACI is the maximum rate of change of blood velocity and representative of aortic blood acceleration.

- ***Thoracic Fluid Content (TFC):***
  TFC is a BioZ-specific parameter that is representative of total fluid volume in the chest, comprised of both intra-vascular and extra-vascular fluid. TFC is calculated as the inverse of the baseline impedance measurement. Baseline impedance is directly proportional to the amount of conductive material (i.e. blood, lung water) in the chest.

- ***Pre-Ejection Period (PEP):***
  PEP is the measured interval from the onset of ventricular depolarization (Q-wave in an ECG) to the beginning of mechanical contraction (first upslope of the impedance waveform, B point).

- ***Left Ventricular Ejection Time (LVET):***
  LVET is the time from aortic valve opening (B point on the impedance waveform) to aortic valve closing (X point on the impedance waveform).

- ***Systolic Time Ratio (STR):***
  STR is inversely proportional to left ventricular function, and is calculated as the Pre-Ejection Period (PEP) divided by the Left Ventricular Ejection Time (LVET).

- ***Left Cardiac Work (LCW):***
  LCW parallels myocardial oxygen consumption, and It is the product of blood pressure and blood flow. LCW is determined with the following equation:

  LCW = (MAP - PAOP) x SV x 0.0144

  MAP is Mean Arterial Pressure, measured in mmHg. Outside of direct measurement, it is determined by the following equation:

  MAP = (SBP - DBP)*KP) + DBP

  PAOP is Pulmonary Artery Occluded Pressure, or wedge pressure. Outside of direct measurement with a Pulmonary Artery Catheter, a default value of 12 mm Hg can be used because of PAOP's minimal effect on LCW determination.

  LCW can be indexed to a patient's body size by dividing by Body Surface Area (BSA), to yield Left Cardiac Work Index (LCWI).

- ***Heart Rate (HR):***
  The number of heart beats per minute, measured from the ECG (R wave to R wave).

- ***Mean Arterial Pressure (MAP):***
  MAP is measured directly in mmHg with an automatic noninvasive BP cuff. Outside of direct measurement, it is determined by the following equation:

  MAP = (SBP - DBP)*KP) + DBP

BioZ.com Parameters

Parameter	Abbrev.	Definition	Normal Range	Derivation/Formula
Heart Rate	HR	Number of heart beats each minute	58 - 86 bpm (beats per minute)	Measurement of the R-R interval on the ECG and extrapolation to bpm.
Mean Arterial Pressure (SBP & DBP)	MAP	Average pressure exerted by the blood on the arterial walls.	84 – 100 mmHg	1. If SBP and DBP values manually entered, the formula for MAP = (SBP – DBP)*KP) + DBP 2. If automatic BP (oscillometric method is used), MAP is measured directly and SBP and DBP are derived.
Cardiac Output	CO	Amount of blood pumped by the left ventricle each minute	4.5 – 8.5 l/min (liters per minute)	CO = SV x HR
Cardiac Index	CI	Cardiac Output normalized for body surface area	2.5 - 4.7 l/min/m^2 (liters per minute per meter squared)	CI = CO / BSA
Stroke Volume	SV	Amount of blood pumped by the left ventricle each heartbeat	60 – 130 ml (milliliters)	Z MARC Algorithm: $SV = VEPT \cdot LVET \cdot VI$
Stroke Index	SI	Stroke volume normalized for body surface area	35 - 65 ml/beat/m^2 (milliliters per heart beat per meter squared)	$SI = \frac{SV}{BSA}$
Systemic Vascular Resistance	SVR	The resistance to the flow of blood in the arterial system (often referred to as "Afterload")	742 – 1378 dynes sec / cm^5 (dynes second per centimeter to the fifth power)	$SVR = 80 \cdot \frac{(MAP - CVP)}{CO}$
Systemic Vascular Resistance Index	SVRI	The resistance to the flow of blood in the arterial system normalized for body surface area	1337 – 2483 dynes sec m^2 / cm^5 (dynes second meters squared per centimeter to the fifth power)	$SVRI = 80 \cdot \frac{(MAP - CVP)}{CI}$
Acceleration Index	ACI	Initial acceleration of blood flow in the aorta, which occurs within the first 10 - 20 milliseconds after the opening of the aortic valve	Males: 70 – 150 / 100 sec^2 Females: 90 – 170 / 100 sec^2 (per 100 seconds squared)	$ACI = \frac{d^2Z/dt^2{}_{MAX}}{TFI}$

Parameter	Abbrev.	Definition	Normal Range	Derivation/Formula
Velocity Index	VI	Peak velocity of blood flow in the aorta	33 - 65 / 1000 sec (per 1000 seconds)	$VI = \frac{dZ/dt_{MAX}}{TFI}$
Thoracic Fluid Content	TFC	The electrical conductivity of the chest cavity, which is primarily determined by the intravascular, intraalveolar, and interstitial fluids in the thorax	Males: 30 – 50 / kohm Females: 21 - 37 / kohm	$TFC = \frac{1}{TFI}$
Left Cardiac Work	LCW	An indicator of the amount of work the left ventricle must perform to pump blood each minute	5.4 - 10 kg m (kilogram meter)	$LCW = (MAP - PAOP) \cdot CO$
Left Cardiac Work Index	LCWI	LCW normalized for body surface area	3.0 - 5.5 kg m / m^2 (kilogram meter per meter squared)	$LCWI = (MAP - PAOP) \cdot CI$
Systolic Time Ratio	STR	The ratio of the electrical and mechanical systole	0.3 – 0.5	$STR = \frac{PEP}{LVET}$
Pre Ejection Period	PEP	The time interval from the beginning of electrical stimulation of the ventricles to the opening of the aortic valve (electrical systole)	Depends on HR, preload, and contractility	Time interval from the beginning of the Q wave on the ECG to the B point on the dZ/dt waveform
Left Ventricular Ejection Time	LVET	The time interval from the opening to the closing of the aortic valve (mechanical systole)	Depends on HR, preload, and contractility	Time interval from the B point to the X point on the dZ/dt waveform

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VEPT	Volume of Electrically Participating Tissue (volume conductor for size of thorax affected by height, weight, and sex)
TFI	Thoracic Fluid Index, which is the baseline thoracic impedance, Z_0
SBP/DBP	Systolic Blood Pressure/Diastolic Blood Pressure
KP	A variable which is dependant on pulse pressure ratio, usually varying between 0.25 – 0.33
BSA	Body Surface Area
dZ/dt_{MAX}	Maximum of the first time derivative of delta Z
d^2Z/dt^2_{MAX}	Maximum of the second derivative of delta Z
CVP	Central Venous Pressure, the BP in the thoracic vena cava and right atrium (default value of 6 mm Hg)
PAOP	Pulmonary Artery Occlusion Pressure or “wedge” pressure (default value of 10 mm Hg)

10. Identify the steps taken when troubleshooting ICG monitoring system to ensure accurate ICG results.

- Display screen does not show ECG or ICG waveforms
  - Ensure 'power' or 'on' switches are activated
  - Ensure sensors are in direct contact with skin
  - Ensure leads are properly connected to sensors and ICG monitor

- There is excessive noise or 60-cycle interference on ECG or ICG waveforms
  - Ensure sensors are in direct contact with skin

- ➢ Ensure leads are properly connected to sensors and monitoring cable
- ➢ Ask patient to momentarily lay still to eliminate possible motion artifact as a cause of interference

- ICG data does not correspond to patient clinical presentation.
  - ➢ Verify correct sensor placement
  - ➢ Ensure good sensor contact with skin.
  - ➢ Ensure that leads are properly connected to all sensors.
  - ➢ Validate that correct patient height, weight, and other data have been entered.
  - ➢ Update blood pressure or means arterial pressure to update the SVR calculation
  - ➢ Update the CVP pressure in the ICG monitor if large changes (e.g., > 10 mm Hg) have occurred in the CVP or the patient has become hypotensive.
  - ➢ Verify BioZ and Patient Cable operation with the BioZ.sim.

11. Describe documentation requirements including patient response, waveform measurements and analysis, and therapeutic effects.

- Patient and family education
- Initiation of ICG hemodynamic monitoring
- Head-of-bed elevation for initial and subsequent documentation of hemodynamic and thoracic fluid status parameters
- Initial ICG parameters and SV response to physiologic fluid challenge
- ICG parameters and trends every 1 to 2 hours, if routine
- Hemodynamic responses to therapeutic interventions
- Printout of ICG report
- Unexpected outcomes
- Additional interventions

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