Deltex
medical

TrueVue Monitoring System Workbook

Contents

1. Introduction

Welcome to the Deltex Medical TrueVue Monitoring System Workbook. This workbook is designed to introduce the user to oesophageal Doppler monitoring using the TrueVue monitor.

Fluid management using oesophageal Doppler monitoring in operating theatres and intensive care units, has been shown to reduce patient complications and length of stay, as it allows for rapid assessment and early intervention to a patient's haemodynamic status (including the use of inotropes and vasoactive drugs). The TrueVue System is easy and quick to set up, and therefore monitoring can start early, thus promoting a fuller, faster recovery.

The workbook is split into the following sections:

1. **Introduction**
2. **Anatomy and Physiology**
3. **Oesophageal Doppler Probes**
4. **The TrueVue Monitor**
5. **Analysis and Management of TrueVue Data**
6. **Screenshots**
7. **FAQs**
8. **Bibliography**

Deltex Medical recommends that users work through sections 2-7 in order, answering the questions for each section before moving on to the next section.

A basic understanding of oesophageal Doppler monitoring is recommended before starting the workbook and is available from your local Deltex Medical representative. Alternatively visit the Deltex Medical academy using the QR code below for additional information.

It would help to have an oesophageal Doppler probe and TrueVue monitor to hand, to become familiar with the equipment. Further useful information can be found in the TrueVue operating handbook and a relevant anatomy and physiology textbook.

For further information or help with any part of the workbook, please contact the local Deltex Medical representative who will be happy to help. Deltex Medical can also offer a certificate on completion of the workbook. Send completed questions together with contact details to customer.services@deltexmedical.com and a reply will be given as soon as possible.

Deltex also has a learning Academy available on its website, offering a wide range of resources designed to support your professional development. The Academy can be accessed using the link or URL below.

Enjoy the workbook.

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www.deltexmedical.com/academy

Deltex Medical, Terminus Road, Chichester, West Sussex, PO19 8TX www.deltexmedical.com
Phone: +44(0)1243 774837. Fax: +44(0)1243 532534.

2. Cardiac Anatomy and Physiology

This section briefly describes the structures of the heart and key cardiodynamic definitions.

2.1. Anatomy of the Heart

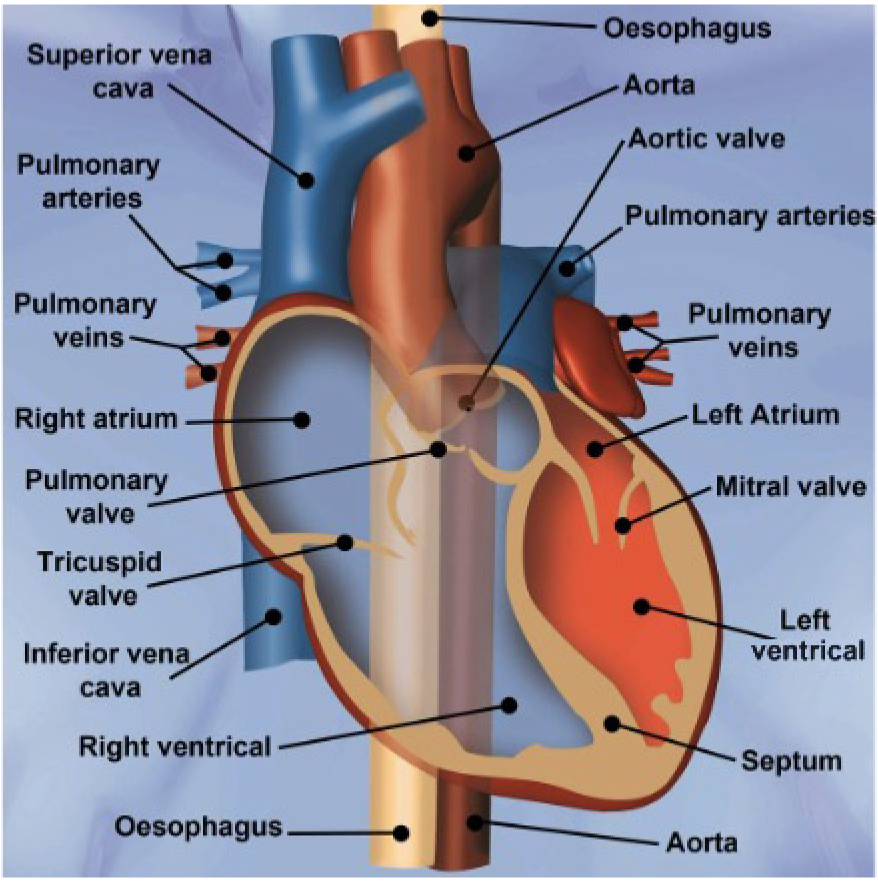


Figure 2.1. The Heart

The heart consists of four chambers: two atria and two ventricles. However, it is better to refer to the functions of the left- or right-sided heart.

Between the two chambers on each of the left and right sides of the heart are valves, which, in a healthy heart will prevent back flow of blood.

The deoxygenated blood flows from the vena cava into the right atrium, then into the right ventricle. It continues to the lungs via the pulmonary circulation where it is oxygenated, and CO2 is removed.

Oxygenated blood returns to the left atrium, then the left ventricle, and is finally ejected into the aorta and around the body via the systemic circulation.

2.2 Physiology of the Cardiovascular System

It is essential that the organs and tissues be adequately perfused with blood, so that they receive the oxygen and nutrients that they require to function. Some of the important concepts relating to cardiovascular physiology are described below.

Systole

- Systole is the contraction phase of the cardiac cycle.
- As the left ventricle contracts, blood is ejected into the aorta.
- The oesophageal Doppler monitor will detect blood flow in the descending aorta as it passes the probe tip during the systolic phase. This will be converted by the TrueVue monitor into an audible & visual waveform.

Diastole

- Diastole is the relaxation phase of the cardiac cycle.
- During ventricular diastole, the ventricles relax and fill with blood.
- At the end of diastole, the volume of blood that fills the ventricle is called the end-diastolic volume.
- Minimal or no blood flow in the descending aorta will be detected by the oesophageal Doppler probe during diastole.

Stroke Volume

- The Stroke Volume is the volume of blood that is ejected from each ventricle with each contraction. It is measured in millilitres (mL).
- Stroke Volume = end-diastolic volume minus end-systolic volume.
- Cardiac Output = Stroke Volume × Heart Rate.
- Factors that affect Stroke Volume are preload, contractility, afterload, and heart rate.

Cardiac Output

- Cardiac Output is the amount of blood that is ejected from the left ventricle each minute. It is measured in litres/min (L/min).

Preload

- Preload is the stretch of cardiac muscle fibres related to filling.
- This is dependent on the end diastolic volume - the greater the volume, the greater the stretch on the muscle fibre.
- Stroke Volume will be low if the patient's preload is inadequate, e.g., hypovolaemia. It will also be low if the afterload is increased (most common cause is hypovolaemia, but also then consider for example if the patient is cold, responding to pain or on vasoconstricting drugs etc.).

Contractility

- Contractility is the strength of the contraction for a given preload.
- Patients with poor left ventricular function may have a reduced contractility.

Afterload

- Afterload is the opposing force that the heart must overcome to eject blood. During systole, the pressure in the left ventricle must exceed that in the aorta. This high pressure causes blood to press against the aortic valve, opening it and ejecting the blood into the aorta.
- Vascular resistance affects the afterload.
- Vascular resistance depends on the diameter of systemic blood vessels.
- The diameter of the systemic blood vessels is affected by vasoconstriction and vasodilation.
- A change in vascular resistance will affect the pressure in the aorta, thus affecting the afterload.
- If the systemic vessels are vasoconstricted the lumen will be narrower than normal and therefore the pressure in the aorta that the ventricle must overcome will be greater. The patient is said to have a high afterload.

- If the systemic vessels are vasodilated, the lumen will be wider than normal and therefore the pressure in the aorta that the ventricle must overcome will be lower. The patient is said to have a low afterload.

Heart Rate

- Heart Rate is the number of beats per minute. Increasing or decreasing heart rate may increase or decrease cardiac output respectively. However, changes in heart rate alone may inversely affect Stroke Volume because of the reduction in the diastolic filling time.

The Frank-Starling Mechanism

- The Frank-Starling law states that, within limits, the greater the heart muscle is stretched during filling, the greater will be the force of contraction and the greater the quantity of blood pumped into the receiving vessels.
- The Frank-Starling curve illustrates the relationship between the preload and the Stroke Volume (see Figure 2.2). If the patient is on the steep but lower part of the curve, a rapid and reasonable fluid challenge, e.g., 200 mL, will give rise to a ≥10% increase in the Stroke Volume. If there is a ≥ 10% increase in Stroke Volume it would suggest that the patient is fluid responsive but may not yet be optimised and therefore may benefit from a further fluid challenge.
- An inadequately fluid filled patient is likely to respond positively to a rapid fluid challenge resulting in a ≥10% increase in Stroke Volume (in a healthy heart and to some extent in diseased hearts) and therefore move up the Frank-Starling curve. When this rise is less than 10%, this would suggest that a further fluid challenge may not be beneficial (but it is important to consider the clinical situation and any underlying comorbidities). The patient may be on the upper portion of their Frank-Starling curve. It is important to ensure flow is optimal and that afterload is not affecting it.

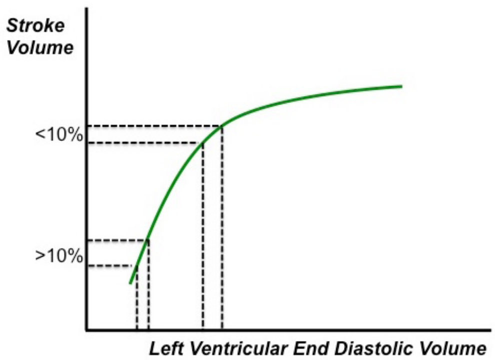


Figure 2.2. A Frank-Starling curve.

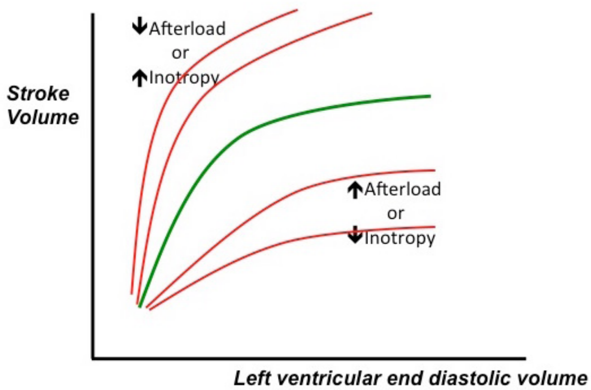


Figure 2.3. A family of Frank-Starling curves with different afterload and inotropic states.

- There is not one Frank-***Starling*** curve, rather a family of curves and a patient will move between curves when their haemodynamics are changing. See figure 2.3. The Stroke Volume may decrease if fluid is given in a failing heart situation, not because of a move onto a ‘descending limb’, but rather to changes in cardiac or vascular compliance which shifts the Frank-Starling curve to the right for example and may therfore be ‘flatter’ in appearance.

Compensation Mechanisms

- If oxygen demand changes, or cardiac output falls, the body will use various mechanisms to try and compensate. If the cardiac output is inadequate and oxygen delivery is not sufficient, cellular dysfunction and even cell death can occur. This is called shock.

Compensation mechanisms are as follows:

- A decrease in blood pressure will be detected by baroreceptors in the body.
- These baroreceptors will stimulate the sympathetic nervous system and cause the release of hormones (e.g. adrenaline and noradrenaline).
- This will cause vasoconstriction of the arterioles and veins in the skin, kidneys, and abdominal viscera, which will help maintain venous return.
- There may also be an increase in the heart rate and in the force of the contraction (contractility) during the systolic phase.
- Due to a reduction of blood flow to the kidneys, the renin-angiotensin-aldosterone pathway will be activated. This will cause the secretion of hormones which vasoconstrict the vessels and cause the kidneys to reabsorb water thus increasing blood volume.
- Water is also conserved by the kidneys following hormone secretion, when a drop in blood pressure stimulates the posterior pituitary gland.

2.3 Pressure

Organ blood flow is determined by the pressure generated within the arterial system as the heart pumps blood into the blood vessels. These vessels form a resistance network. They constrict and dilate to regulate arterial blood pressure, alter blood flow within specific organs and distribute blood volume as needed.

Blood is ejected from the left ventricle into the aorta where the peak pressure is the systolic pressure and the lowest is the diastolic pressure (the period just before the ventricle ejects the blood). The difference between the two is the pulse pressure. Any factor that affects systolic or diastolic pressure will therefore affect pulse pressure.

As the pressure pulse moves away from the heart, the systolic pressure rises, and the diastolic pressure falls and may be due to:

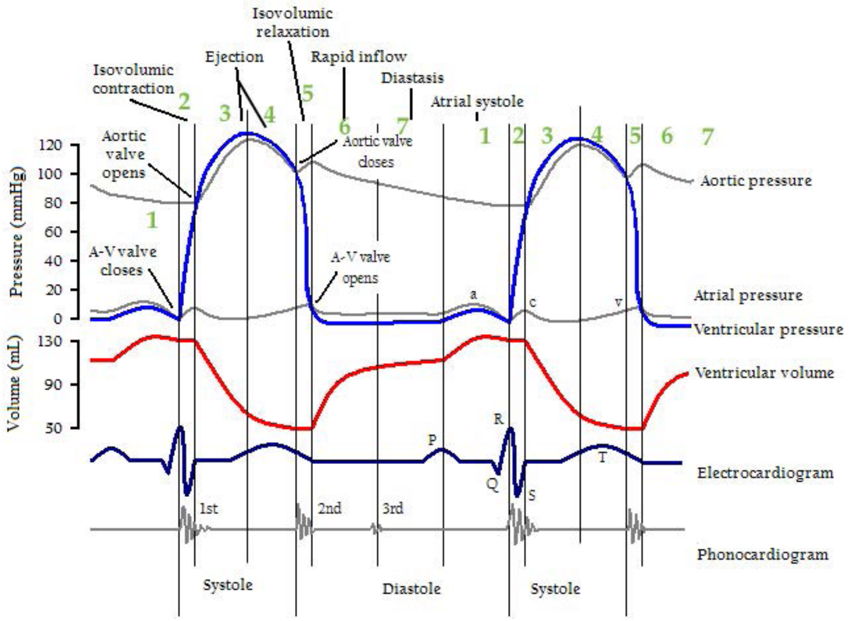
- Decreased compliance of distal arteries.
- Reflective waves.
- Resistance of arteries.
    - Resistance is related to vessel radius, vessel length and its smoothness, and also blood viscosity. The larger the radius, the lower the resistance and the longer the vessel area, the higher the resistance. Vasoconstrictors can reduce the radius of a vessel thereby increasing BP, while vasodilators can increase the radius causing the BP to fall.
    - Increased circulating blood volume allows more blood to return to the heart ready to be pumped to the organs and cells, which therefore influences CO, and the pressure required to achieve this.
    - Viscosity is the thickness of the fluid and refers to the red cell concentration. If viscosity increases, resistance will increase.

2.4 Cardiac Cycle

The seven phases of the cardiac cycle are:

- Atrial systole – atrial contraction to give ‘atrial kick’.
- Isovolumetric contraction (all four valves will be closed) – ventricles begin to contract.

- Rapid ejection of ventricles.
- Isovolumetric relaxation (all four valves will be closed) ventricles start to relax.
- Rapid filling of atria and ventricles.
- Reduced filling of atria and ventricles.
- Reduced ejection of ventricles.



With reference to Daniel Chang MD (revised original work of DestinyQx)

Figure 2.4. Seven stages of the cardiac cycle.

2.5 Adult Normal Values

Please note that any suggested normal values may vary with different haemodynamic resources and are only for resting healthy individuals. When using a TrueVue monitor, it may be more appropriate to seek increased numbers rather than just aiming for normal ones during specific clinical situations, e.g., vasodilation from drugs or sepsis etc., since patients in ICU or surgery are not in a 'normal' situation. This however is always a clinical judgment.

See Chapter 5 for any values given but refer to own reliable resources for further information.

2.6 Questions

1. What happens to blood flow during ventricular systole?

2. What happens to blood flow during ventricular diastole?

3. What is Cardiac Output?

4. What is Stroke Volume?

5. What four factors will affect Stroke Volume?

6. What is preload?

7. What is afterload?

8. What is contractility?

9. Describe a vasoconstricted circulation and how that might affect blood flow.

10. Describe a vasodilated circulation and how that might affect blood flow.

3. Oesophageal Doppler Probes

3.1 General Information

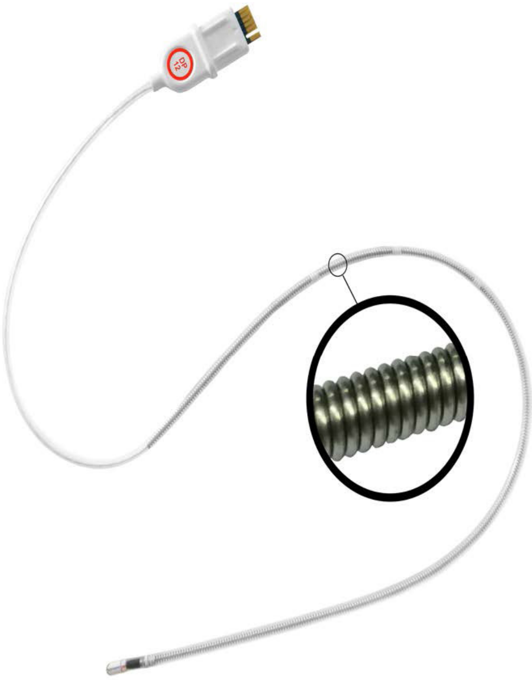


Figure 3.1.1. Image of a DP Probe

Figure 3.1.2. Image of an I2 Probe

- DPn probes (e.g., DP12, DP240) have a stiffer spring and are suitable for sedated or anaesthetised patients; I2n probes (e.g., I2C) are less stiff and are suitable for sedated, anaesthetised, or awake patients.
- The probes are available in different time variants e.g., 240 hours for DP240 or 72 hours for I2C. Please note that not all variants of probes are available in all markets. Speak to your Deltex Medical representative for further information.
- These probes are intended for use on adults (16 years and above) and are single patient use.
- A dedicated paediatric probe is available separately. Paediatrics is not discussed further in this workbook, but more information can be obtained by contacting your Deltex Medical representative.
- The probe is latex free.
- The probe connector on the Doppler probe is for connection to the Dopplink of the TrueVue monitor.
- The probe can be withdrawn and stored for later re-use on the same patient if necessary, providing that the re-use occurs within the defined probe life. If removal is transitory, refer to the hospital policy for cleaning of equipment.
- A circle on the lower left of the waveform screen indicates the length of time until probe expiry. See the Operating Handbook for further details.
- Disposal should be in accordance with hospital policies.

3.2 Contraindications/Considerations

- Adult Doppler probes (DPn and I2n) should not be placed in patients under 16 years of age.
- Do not use where nasal injuries are apparent or may have occurred.
- Do not use where nasal polyps exist.

- Do not use where there are circumstances of facial trauma.
- Do not use where there is a risk of brain injury.
- Do not use in patients undergoing intra-aortic balloon pumping.
- Do not use with carcinoma of the pharynx, larynx, or oesophagus.
- Do not use with aneurysms of the thoracic aorta.
- Do not use with tissue necrosis of the oesophagus or nasal passage.
- Do not use in close proximity to laser surgery.
- Do not use in patients with pharyngo-oesophago-gastric pathology and/or severe bleeding diatheses

For detailed precautions and warnings on probe usage, refer to the individual probe packaging for instructions for use.

3.3 Probe Insertion

- Apply water-based gel to tip of probe.
- Insert probe orally or nasally immediately after intubation and before incision, and ideally before diathermy (also known as electrocautery or bovie), body tilt, or pneumoperitoneum etc. in the operating theatre, or as soon as possible after admission in ICU. This allows a settling in process and helps create a good mucus bond in the oesophagus. Many users find this helps in finding the signal more easily.

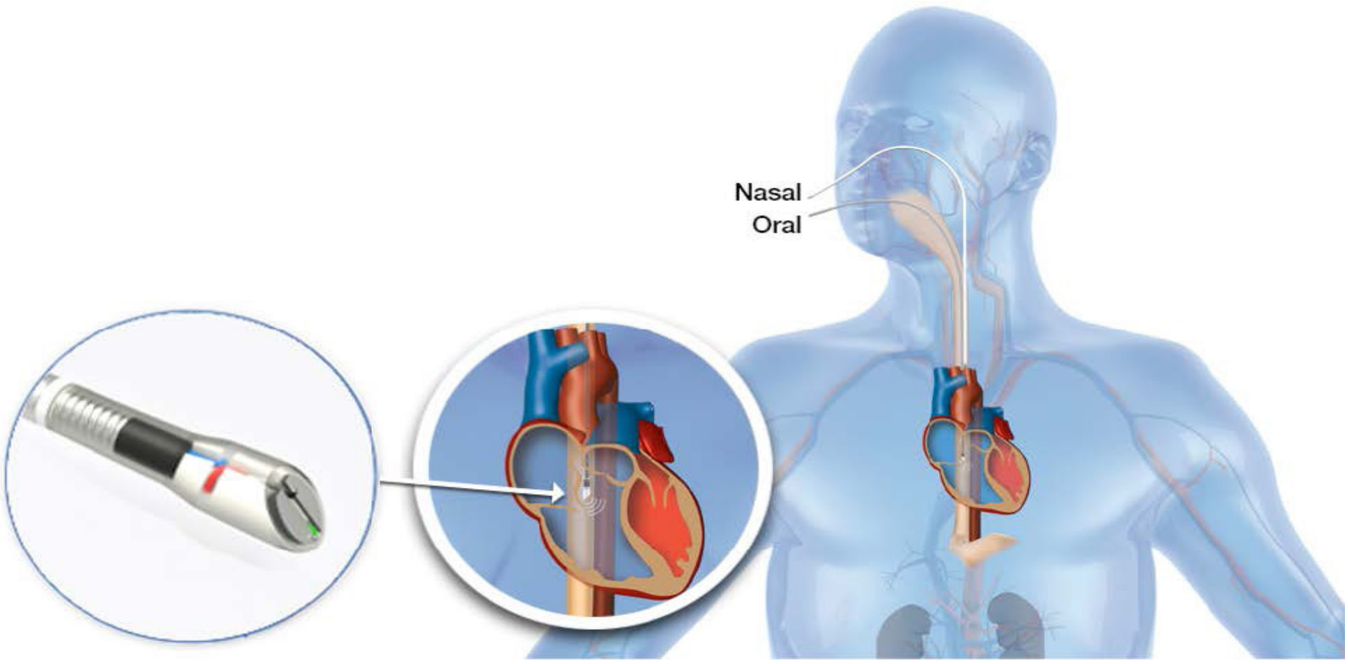


Figure 3.3.1 Nasal and oral probe insertion

3.4 Probe Focus

To obtain signal:

- Insert probe to depth marker 2 for oral use, 3 for nasal use.
- Increase volume by pressing the volume button on the right hand side of the screen and increase or decrease volume using the + or - .
- Rotate probe slowly without letting go.
- If descending aortic signal is not seen, remove the probe by approximately 1 cm. Rotate again. Avoid rotating and changing depth at same time.

Correct signal:

- Tallest brightest waveform above the line with loudest, sharpest ‘whip crack’ sound.
- Incisors near to markers 1 or 2, or nostrils near to markers 2 or 3. Note this position to find signal easily again.
- Re-check at different depths to ensure the optimal signal has not been missed.
- To refocus, return to known depth, increase volume and rotate slowly.
- Waveform is Orange/white along edges with a dark centre.
- Green follower line sits neatly against the waveform with the three white arrows on the points of the triangle.

NOTE: Please use our free learning section on our website - Deltex Academy can be found at https://www.deltexmedical.com/academy/

Academy link	
Probe focus video	
Probe insertion video	

3.5 Questions

1. What is the procedure for focusing a probe?

2. Why is it suggested that the probe is inserted as soon after intubation as possible?

3. Which depth markers are used for:
   a. Oral insertion?

   b. Nasal insertion?

4. What should a descending aortic waveform sound like?

5. What is the optimal colour of a descending aortic waveform?

4. The TrueVue Monitoring System

4.1 General Information

The TrueVue monitor combines Doppler measurement of blood flow velocity in the descending aorta with an option for Pulse Pressure Contour Analysis (PCA). This provides users with the proven highly sensitive Flow Monitoring from the Doppler probe to monitor and guide intervention for the simplest calibration of an arterial waveform for Pressure Monitoring for extended or continuous monitoring.

NOTE: PCA refers to any technology that uses the arterial waveform to calculate cardiac output and includes e.g. pulse contour, pulse pressure or pulse power etc.

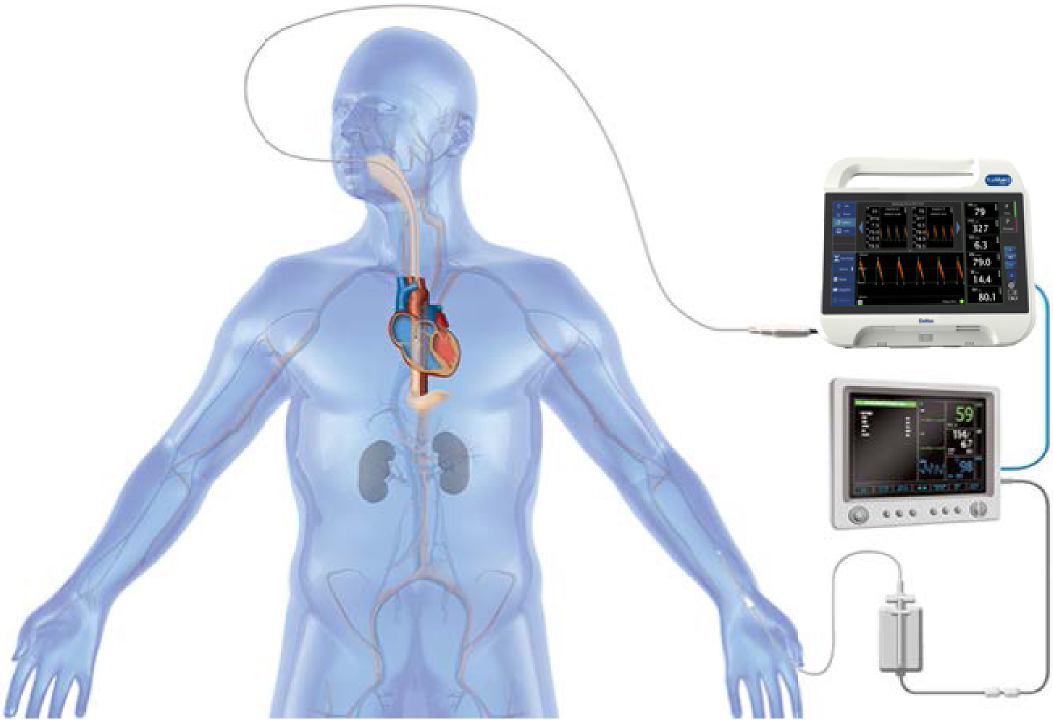


Figure 4.1. The TrueVue monitoring system combined with arterial pressure monitoring

4.2 Getting Started

NOTE: If using the option of an arterial waveform, ensure the arterial line is zeroed, levelled, and test for damping, prior to connecting the TrueVue monitor to your main patient monitor.

- Switch on the TrueVue monitor using the power button on the front of the monitor beneath the Deltex badge. The screen will appear within 10 seconds.
- Connect the probe to the Dopplink and connect the arterial cable from your main ITU monitor output socket to the rear of the TrueVue monitor.
- Select Start on the TrueVue monitor.
- Press Auto Patient ID or press in the white boxed area to enter a specific patient ID.
- Enter patient date of birth, weight, and height (for the nomogram to calculate volumetric results) by pressing in the white boxed area and entering the relevant numerical data.
- Press OK and check patient details, then press confirm if correct.

The adult nomogram limits are as follows:
Age 16 to 99 years.
Weight 30 to 150 kg (66 to 330 lb).
Height 149 to 212 cm (59 to 83 in).

NOTE: If the patient's data is outside the nomogram limits, volumetric measurements (e.g., SV, CO etc.) will not be available. However, linear measurements (e.g., FTc, SD, PV etc. will still be available). Since SD correlates well with SV, this can be used as a substitute for SV.

- Focus probe (see 3.4).
- Adjust the Gain if necessary by selecting Options then increase or decrease as required.
- Select Auto Range if required.
- Check cycle time: Select Options then Cycles and increase or decrease as required.
- Press Snapshot to record snapshots. The snapshots will be displayed in the Gallery area at the top of the screen. Use the large blue arrows to scroll through the snapshots. Press the ellipsis (...) to Set as Baseline or delete as required.

4.3 Cardiac Output Calibration

Uncalibrated PCA algorithms have been shown to be prone to drift due to changes in arterial compliance (a consequence of vasoactive drugs and other interventions). These changes have been reported to be clinically significant. Recalibration is therefore just as important as an initial calibration. The inability to recalibrate easily before or after interventions has resulted in limitations in the accuracy and precision of other PCA devices.

The TrueVue Pressure waveform signal is slaved from the patient's main monitor by connecting the appropriate cable. Contact your Deltex Medical representative for further details.

The arterial waveform is calibrated against the Cardiac Output (CO) from the Doppler signal. This sets the arterial waveform CO to be the same as from the Doppler signal. The calibrated CO can then be used for continuous monitoring when the Doppler signal may be lost e.g. during diathermy.

TrueVue uses a simple, stable and reliable algorithm based on research by Dr James Sun. Sun's research concluded that the algorithm of Liljestrand & Zander is superior to all other versions.

The TrueVue Pressure calibration takes approximately 3 seconds, and involves only the touch of a button (no injectate):

- Focus the Doppler probe and ensure a good quality stable waveform. Select Pressure on the right-hand side of the screen.
- Press Calibrate on the left-hand side of the waveform screen.
- The Cardiac Output parameters now displayed are from the arterial pressure line. Select Flow on the right-hand side of the screen to display Flow based parameters.

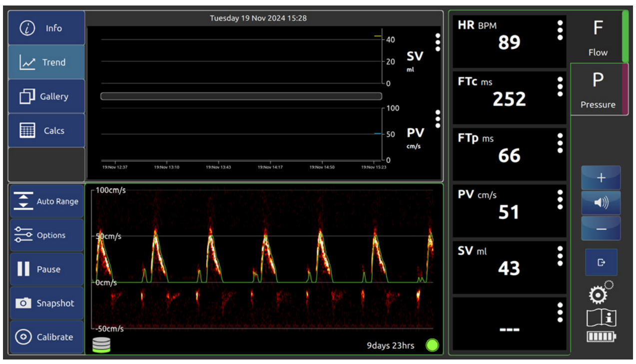


Figure 4.3.1. Flow parameters.

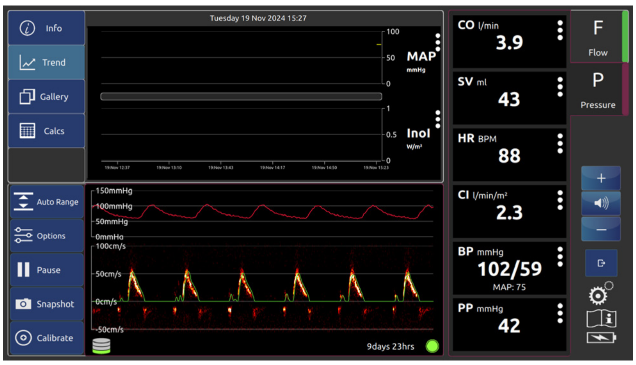


Figure 4.3.2. Pressure parameters.

The Pressure data will remain calibrated for 6 hours for DP6 probes or 12 hours for all other probes, so refer to information above regarding the need to recalibrate. If a calibration is not performed by the end of these periods, calibrated pressure data will expire. However, if there is still probe life remaining, a new calibration can be done.

If displaying SVR, SVRI, DO2 or DO2I calculations and the Stroke Volume (or Stroke Volume Index) changes by 20% (up or down) from the calibrated point, these results boxes will become yellow indicating that a recalibration is required. The boxes will also become yellow if the calibration is older than 4 hours.

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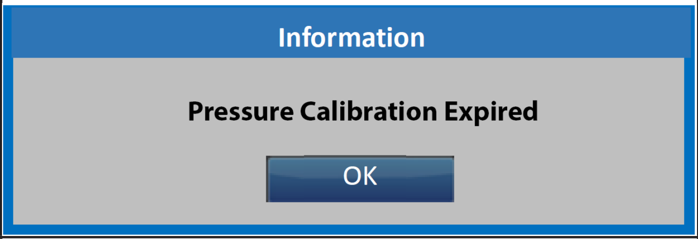
<td>
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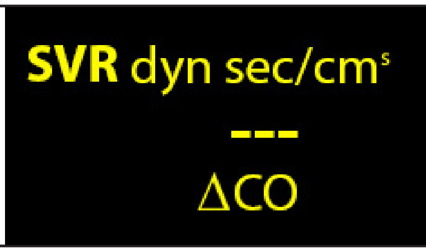
<td>
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<tr>
<td>Figure 4.3.3. Calibration expired alert.</td>
<td>Figure 4.3.4. Recalibration required after 20% SV drift or 4 hours. (dynes/seconds/cm^{-5})</td>
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</table>

Deltex Medical recommends that pressure-based data is used for continuous monitoring and that the Flow based parameters are used for interventions. The user can move between Pressure and Flow by either pressing Pressure or Flow on the right of the screen.

4.4 Flow Parameters

- The parameters displayed are from the Doppler probe signal.
- Interventions should be carried out using the data from these parameters.
- If the arterial line is disconnected, only the flow-based parameters will be displayed.

4.5 Pressure Based Parameters

- PressureWave parameters are only available if an arterial line is connected to the TrueVue and only after a calibration has been carried out.
- These parameters should be used for continuous monitoring if required.

4.6 Calculations

- This menu is available in the top left of the main screen.
- Select Calcs and choose from RR, SVR or DO2.
- RR allows you to input a respiratory rate to obtain Stroke Volume Variation measurements.
- SVR allows you to input CVP and MAP data to obtain Systemic Vascular Resistance and Systemic Vascular Resistance index measurements (continuous if using Pressure Wave)
- DO2 allows you to input SAO2 % and Hbg/dl data to obtain Oxygen Delivery measurements.
- Input data by pressing the white arrows in the blue boxed area until correct data is displayed.
- MAP is automatically added if pressure-based monitoring is in progress.

4.7 Additional Information

Snapshots:

- Press Snapshot to take a snapshot.
- Up to 20 snapshots can be stored per patient. Press Gallery on the top left of the screen to view snapshots.
- Press the ellipsis (...) in the snapshot to Set as Baseline or Delete as required.
- Use the large blue arrows to scroll through the snapshots.

Systemic Vascular Resistance (SVR) Calculation:

- The calculations for SVR and SVRI are:
  - o SVR = (MAP-CVP) x 80/CO.
  - o SVRI = SVR x BSA.
- If SVR / SVRi is to be displayed as a default in the six parameter boxes, press the ellipsis (three dots) in the parameter box and then Select Parameter then select SVR /SVRI. This will now be displayed in this parameter box. Repeat for Pressure based parameters.
- If the arterial line is connected and recognised, SVR can be continuously displayed once CVP has been entered in the SVR section in Calcs.
- The time this data was entered is displayed in the SVR section in Calcs.
- This parameter box will be highlighted in yellow if a calibration is required, i.e. if 6 hours since last recalibration or if the SV has changed by 20%.
- To enter new CVP or MAP data, either press the ellipsis (...) in the SVR / SVRI parameter box or enter Calcs and input CVP & MAP.
- Input data by pressing the white arrows in the blue boxed area until correct data is displayed.
- Alternatively, press Calcs in the top left of the screen and then SVR and enter data as above.

Delivered Oxygen (DO2) Calculation:

- The calculations for DO2 and DO2I are:
  - o DO2 = 1.34 x Hb x SaO2 x CO.
  - o DO2I = DO2f/BSA.
- DO2 can only be calculated as a spot measurement in Calcs by selecting DO2.
- If DO2 is to be displayed as a default in the 6 parameter boxes, select the parameter box where it is to be displayed, press Select Parameter then select DO2, and DO2 will be displayed.
- If DO2 is not selected for display in the 6 boxes, it can be viewed through the DO2 menu in the Calcs on the top left of the screen.
- The time this data was entered is displayed in the DO2 section in Calcs.
- To enter new DO2 data, press Calcs in the top left of the screen and then DO2 and enter SAO2% and Hb g/dL in the white box area by pressing the white arrows in the blue boxes.

Trends:

- This is an automatically generated trend screen and is updated every 30 seconds.
- Press Trend in the top left area of the screen.
- To change which parameters are displayed in trends, select the parameters from the ellipsis (...) on the right-hand side of the trend area

Customising the Settings:

- To display parameters in the 6 boxed area, select each parameter box and set parameters by pressing the ellipsis (...) and Select Parameter.
- Parameters can be moved up and down by selecting Move Up or Move Down to place the parameter in the required box.

4.8 Questions

1. What are the nomogram limits for:
   a. Age

   b. Weight

   c. Height

2. What happens when the patient data entered is outside of these limits?

3. How is a snapshot recorded?

4. How is a snapshot viewed?

5. How do I change which parameters are displayed in Trends?

6. How is the pressure data accurately calibrated?

7. How long does this calibration last for?

8. What data is required to display SVR?

9. How does the user toggle between Flow and Pressure parameters?

10. How do you change the parameters which are displayed in the boxes?

5. TrueVue Data

5.1 Information

Please note that any suggested normal values are only for resting healthy individuals. When using a TrueVue, it may be more appropriate to accept increased numbers rather than just aiming for normal ones during specific clinical situations e.g. vasodilation from drugs or sepsis etc., since patients in ICU or surgery are not in a 'normal' situation. This however is always a clinical judgment.

5.2 Key Parameters and How Changes May Be Defined

<u>**Flow Parameters:**</u>

- **Heart Rate** (HR): beats per minute.
  - HR changes in response to many stimuli e.g. drugs, hypovolaemia, temperature etc.
  - Normal values: approximately 60 – 80 bpm.

- **Stroke Volume** (SV): the amount of blood in mL pumped from the heart during every heartbeat. It is the volume ejected from the left ventricle due to the contraction of the heart muscle. SV can be calculated as a Doppler flow-based parameter (when in flow-monitoring mode). In addition, the TrueVue also calculates SV from the arterial pressure wave (when calibrated and displaying Pressure Wave parameters).
  - SV decreases or increases when there are changes in resistance, preload or contractility e.g. The most common cause of a decreased SV is hypovolaemia, where the preload has decreased but the afterload has increased also to compensate.
  - Normal values: approximately 60 - 100 mL/beat.

- **Stroke Volume Index** (SVI): the amount of blood in mL pumped from the human heart every heartbeat (SV) indexed for body surface area.
  - Normal values: approximately 33 - 47 ml/beat/m^2.

- **Cardiac Output** (CO): the volume of blood being pumped by the heart, in particular by the left ventricle in the time interval of one minute and measured in L/min. Additionally, after the calibration of the SV, the TrueVue can simultaneously calculate the CO from the arterial pressure waveform.
  - CO can be altered to some degree by changes in HR or contractility.
  - Normal values: approximately 4 - 8 L/min.

- **Cardiac Index** (CI): CO indexed for body surface area and is measured in L/min/m2.
  - Normal values: approximately 2.5 – 4 L/min/m^2.

- **Flow Time Corrected** (FTc): a Doppler only parameter. Flow time (FT) is the duration of time of the flow from the left ventricle during systole. FTc is FT normalised to 60 beats/min using Bazett's equation (i.e. it corrects for heart rate).
  - This can be used as an indicator of hypovolaemia. FTc is inversely related to afterload/resistance and the most common cause of an increased afterload/resistance is hypovolaemia. After that, other causes of increased afterload/resistance should be considered. High FTc is usually seen in low afterload/resistance states such as the vasoactive effects of drugs and sepsis.
  - Typical values for normally hydrated resting healthy individuals are 330-360 ms.

- **Peak Velocity** (PV): a Doppler only parameter. PV is the maximal velocity of the blood and is measured in cm/s.
    - o PV is an indicator of contractility and typical values change with age: The peak velocity of 20-year-old may be 90-120 cm/s whereas at age 90 it may only be 30-60 cm/s. Thus, a PV markedly below the typical expected value may be an indicator of increased afterload or decreased cardiac function. A higher-than-normal PV may be indicative of decreased afterload or increased contractility.

- **Stroke Distance** (SD): a Doppler only parameter. SD is the distance the blood ejected by the left ventricle travels down the aorta every beat. It is measured in cm/s.
    - o SD will be converted to SV when the nomogram is used, however it can be used to guide fluid and vasoactive drugs since it correlates well with SV.
    - o No normal values are available. Trends may be used.

- **Minute Distance** (MD): a Doppler only parameter. MD is the distance blood moves in one minute down the aorta.
    - o Generally follows changes in fluid loss or increase or inversely related to changes in afterload.
    - o No normal values are available. Trends may be used.

- **Mean Acceleration** (MA): a Doppler only parameter. MA is the average speed on the up stroke of the waveform and is measured in cm/s.
    - o Can also be used as an indicator of contractility, e.g. a lower MA may be seen in left ventricular dysfunction and the waveform may be 'rounder' in shape.
    - o No normal values are available. Trends may be used.

- **Systemic Vascular Resistance** (SVR): can be calculated as a Doppler flow-based parameter and after calibration of the PPWA algorithm, TrueVue can calculate this parameter as a pressure-based parameter. SVR is the resistance to blood flow due to the peripheral vascular system.
    - o FTc can be used to assess afterload/resistance since it is inversely related to afterload/resistance.
    - o Normal values: approximately 800-1200 dynes/sec/cm^{-5}.

- S**ystemic Vascular Resistance Index** (SVRI): the resistance to blood flow due to the peripheral vascular system indexed for patient body size.
    - o Normal values: approximately 1970–2390 dynes/sec/cm^{-5}/m^{2}.

- **Delivered Oxygen** (DO2): Delivered oxygen can only be calculated as a Doppler flow-based parameter. DO2 is the amount of oxygen in the blood delivered to the tissues. This parameter requires the user to input measurements of haemoglobin concentration and the saturated oxygen concentration. CO as calculated by the monitor is automatically updated as DO2 changes with CO calculated from the flow readings.
    - o Normal values: approximately 950–1150 mL/min.

- **Delivered Oxygen Index** (DO2I): DO2, normalised for body surface area.
    - o Normal values: approximately 400 – 650 ml/min/m^{2}.

- **Stroke Volume Variation** (SVV):
    - o The variations in the maximum and minimum SV due to fluctuations in preload across a breath.
    - o Is sometimes used as a measure of fluid responsiveness. However, the limitations of this parameter are that the patient must meet the following criteria for the result to

be valid (no matter which technology is used):
    - Full mechanical ventilation (no spontaneous breaths).
    - Sinus rhythm (no arrhythmias).
    - Tidal volume (TV) ≥7-8 ml/kg (note that higher TV elicit higher variations or changing TV will fluctuate the threshold).
    - HR:Respiratory rate ratio ≥4 (minimum of 4 heart beats for every breath which is the average amount of time it takes for the blood to travel from the right side of the heart to the left).
    - Changes in lung or chest compliance, PEEP or patient position, and right ventricular dysfunction or abdominal insufflation or the use of vasoactive drugs may also affect readings.
  - Caution is advised and clinicians need to be aware of the particular 'grey zone' values for the technology being used, and the various limitations of this parameter described in the literature.
  - TrueVue calculates the average over 3 respiratory cycles where each has to have a minimum of 4 heartbeats.
  - Normal value (threshold) for Doppler SVV is approximately 14 - 15%.

- **Peak Velocity Variation** (PVV)
  - A direct measurement of variations in aortic blood flow induced by small reversible changes in preload due to ventilator- induced changes in venous return. Unlike variables based on arterial blood pressure measurements, flow measurements are not affected by arterial compliance or changes in arterial tone.
  - Literature suggests wide variations in thresholds; 7 – 20%.

- **Stroke Output Index** (SOI)
  - SVI x 1000/FTc = SOI. This is a ratio that represents the volume of blood ejected by the heart at each systole divided by the systolic time and is presented as ml/s/m^2. If there is a change in SOI of ≥11% during a fluid challenge, the SV will likely have an increase of at least 10% during the next fluid challenge. If there is a change in SOI of <11% during a fluid challenge, then the SV is unlikely to show a response to a subsequent fluid challenge.

<u>**Pressure Parameters**</u>

- **Blood Pressure** (BP): the pressure exerted by the circulating blood upon the walls of the blood vessels and is created from the pumping action of the heart. BP decreases as the circulating blood moves away from the heart through the vascular system. It is measured in mmHg and consists of systolic pressure (SP) and diastolic pressure (DP) displayed as SP/DP. SP is the pressure created when the heart contracts and DP is the resting pressure when the heart relaxes.
  - Normal values are approximately 120/80 mmHg.

- **Mean Arterial Pressure** (MAP)
  - The average arterial pressure during a single cardiac cycle.
  - It is believed that a MAP that is greater than 70 mmHg is enough to sustain the organs of the average person.
  - Normal values are approximately 65 - 110 mmHg.

- **Heart Rate** (HR)
  - See Flow Parameters.

- **Stroke Volume** (SV) **and Index** (SVI)
  - See Flow Parameters.

- **Cardiac Output** (CO) **and Index** (CI)
    - o See Flow Parameters.

- **Systemic Vascular Resistance** (SVR) **and Index** (SVRI)
    - o See Flow Parameters.

- **Stroke Volume Variation** (SVV)
    - o See Flow Parameters.
    - o Literature for SVV from pressure and PPV have large variations in thresholds; 8.5 – 13.5%.

- **Pulse Pressure Variation** (PPV): the variations in pulse pressure due to fluctuations in preload across a respiratory cycle. PPV is available only on the TrueVue as a pressure-based parameter only.
    - o See SVV in Flow Parameters.
    - o Literature for SVV from pressure and PPV have large variations in thresholds; 8.5 – 13.5%.

<u>**Combined Parameters:**</u>

- **Cardiac Power Output** (CPO): requires the simultaneous measurement of flow and pressure and describes the pumping ability of the heart. The formula is as follows: CPO = MAP x CO/451.
    - o CPO has been found to be the strongest independent haemodynamic correlate of in-hospital mortality in patients with cardiogenic shock and chronic heart failure, following the review of the SHOCK trial results in 2000. A cut off value of 0.53 watts had a predictive value for in hospital mortality. Patients with a value below 0.53 watts had a 71% probability of in hospital mortality, whereas those with a value above 0.53 watts had a 58% probability of mortality before discharge. Increasing age and female gender are independently associated with a lower CPO.

- **Cardiac Power Index** (CPI): CPO normalised for body surface area.

- **Dynamic Elastance** (Eadyn)
    - o Can be estimated by the relationship or ratio between PPV and SVV using the formula Eadyn = PPV/SVV.
    - o Eadyn can be calculated when a user has both flow- and pressure-based signals. Normally, SVV can be calculated from either flow or pressure mode of the TrueVue. However, if both SVV and PPV were to be obtained from pressure mode (i.e. SVV based on arterial waveform analysis rather than Doppler flow measurements), there is potential for error due to a mathematical coupling factor.
    - o Has been shown to predict the arterial pressure response to a fluid challenge in hypotensive, preload-dependent patients. Therefore, a clinician can predict whether fluid alone will sufficiently raise MAP, or whether a vasopressor is required.
    - o Eadyn ≥0.73 predicted an arterial pressure response (>10%). The grey zone was 0.72 to 0.88.

5.3 The Decision Tree

The Decision Tree consolidates the evidence base of flow-based treatment strategies. It is clear from the evidence that Doppler guided Stroke Volume Optimisation is beneficial to patients. It is also clear that both excessive fluid volumes and inadequate volumes are extremely detrimental. What is less clear from the evidence base is the benefit of vasoactive and inotropic interventions, although these are widely used in haemodynamic management of patients. The Decision Tree is a rational approach to using Doppler flow-based measurements to guide therapy and can be applicable for perioperative and critically ill patients.

Using the Decision Tree

- Please note that caveats are presented which may lead to an alternative pathway and are in a red box with red pathways. Caveats should be ignored if inappropriate to the patient. Please go to www.dopplerdecisiontree.info for where there are links to evidence and education, or visit www.deltexmedical.com/academy for further information.

Trigger Points/Concerns

- The Decision Tree was developed to be used in conjunction with flow measurements using the Oesophageal Doppler Monitor.

NOTE - These trigger points/concerns:

- **SHOULD NOT BE ASSESSED IN ISOLATION.**
- **ARE NOT THE SAME AS PHYSIOLOGICAL TARGETS.**
- **ARE INDICATIVE AND NOT ABSOLUTE.**
- **ARE NOT PRIORITORISED.**

Primary Clinical Indicators

- HYPOTENSION: e.g. Systolic <100 mmHg, MAP <60-70 mmHg or a clinically significant drop in MAP, e.g. 30-40 mmHg from assumed 'normal' or baseline.
- TACHYCARDIA: e.g. >90 bpm.
- OLIGURIA: < 0.5 mL/kg/h.
- LOW CARDIAC OUTPUT STATE.

Flow Indicators

- REDUCED FTc: <330 ms or considered low for clinical condition e.g. any high resistant state.
- LOW CARDIAC OUTPUT: significantly below 'normal' e.g. CO <4-6 L, CI <2.5 L/min/m^2.
- LOW STROKE VOLUME: significantly below 'normal' e.g. SV <50-70 ml, SVI <30 mL.

Supplementary Clinical Indicators

- HYPERTENSION: e.g. Systolic >180 or >30-40 mmHg above baseline.
- LACTATE: >2 mmol/L.
- BASE EXCESS: -3 or +3 mEq/L.
- PERIPHERAL SHUTDOWN: e.g. looks 'unwell' e.g. pale, sweaty or a clinical picture of poor perfusion.
- SaO2: <93% or having to increase FiO2 by 20% to maintain Oxygen saturations.
- LOW ScVO2 : <65-70%.
- REDUCED CONSCIOUS LEVEL: any deterioration rather than a score.

Exclusions (refer to the Decision Tree website for further information)

- TEMPERATURE, DO2, CVP, SVR and SVV/PPV.

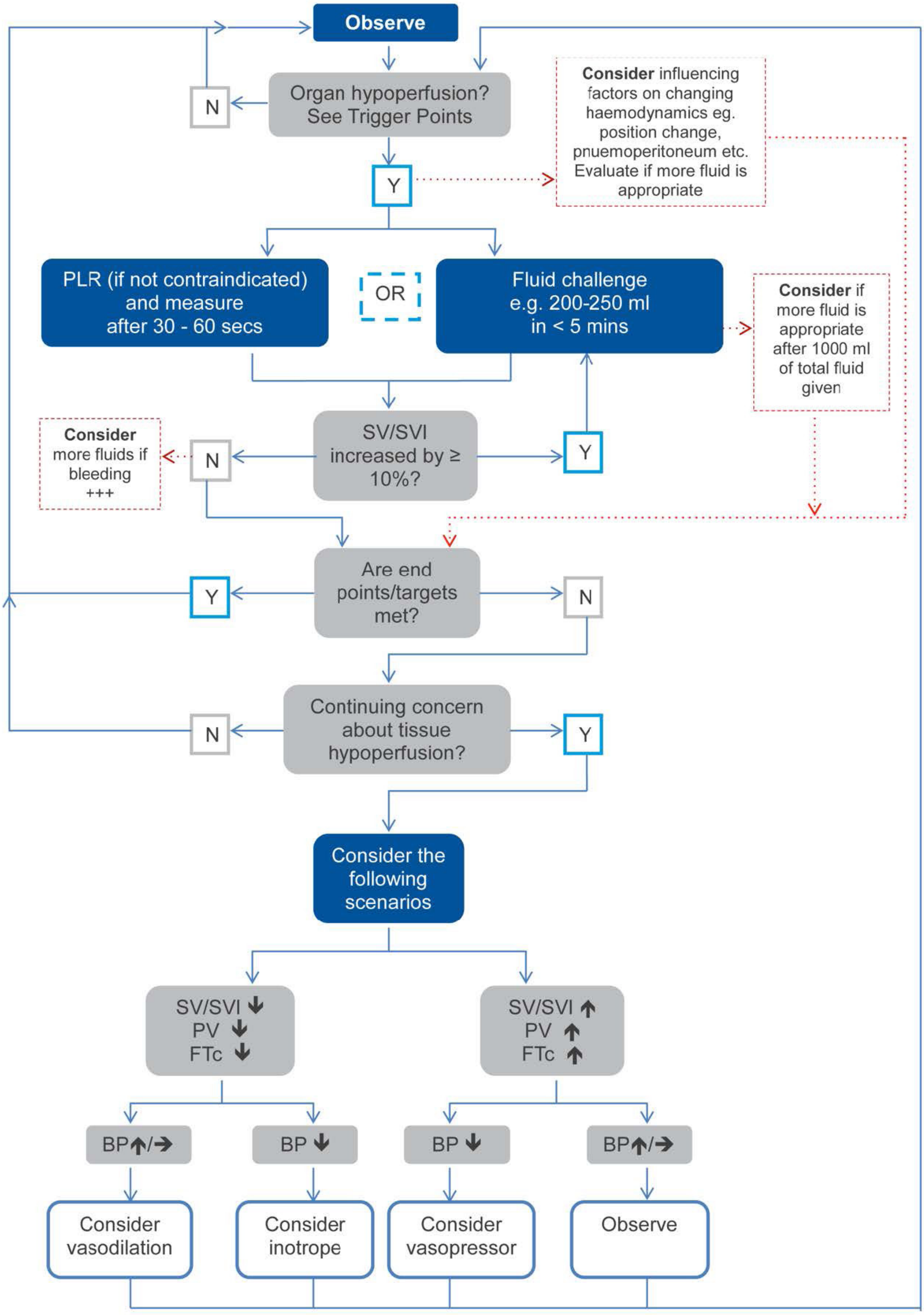


Figure 5.3. The decision tree

5.4 Questions

1. What is the most common cause of an increased afterload/resistance?

2. What effect will this have on the SV?

3. What does FTc stand for?

4. What could cause this to be reduced?

5. What does PV stand for?

6. When could this be raised?

7. What is SVRi?

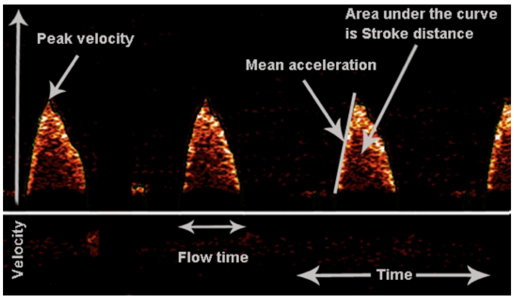
8. When would this be raised?

9. What does SVV stand for?

10. What is SVV, and how would this be useful when managing a patient's fluid status, but what are the limitations of this parameter?

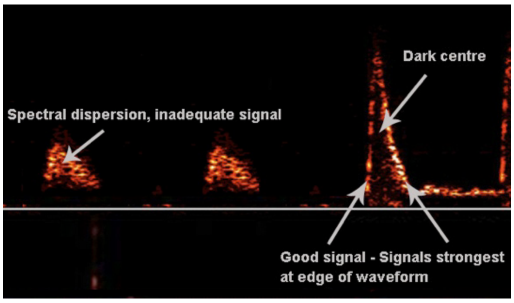
6. Screenshots

6.1 Anatomy of a Waveform

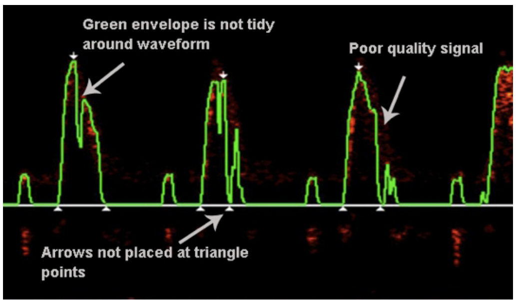


Descending aortic flow at approximately T5/T6 areas. Flow time is the duration of flow during systole. Peak velocity is a measure of the fastest speed of flow. See Section 5 for further information on these parameters.

6.2 Signal Quality

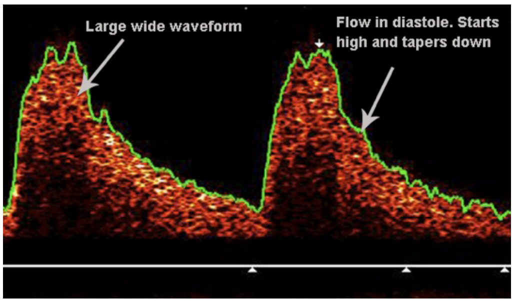


A dark centre is required to indicate the probe is facing the centre of the aorta. If the waveform is filled in and is smaller (known as spectral dispersion), it may indicate inadequate focus. Refocusing improves the sound quality and a dark centre is now seen. Aim for loudest, sharpest ‘whipcrack’ sound together with the tallest and brightest waveform as near to the appropriate depth markers as possible. See Section 2.4 for further information.



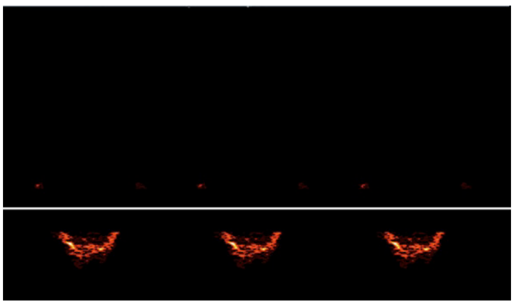
Untidy green line, misplacing of arrows and poor signal quality is likely to be indicating inadequate focus. Do not use the parameters until an optimal signal is obtained.

6.3 Signals from Other Vessels

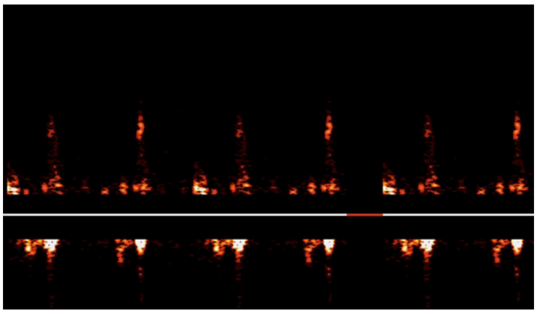


Coeliac axis. Distinctive tapering of diastolic flow with implausible parameters. Probe is likely to be too deep. Withdraw slightly and refocus.

Pulmonary artery. Flow is seen below the line. Probe tip is likely to be too high. Advance probe until as near to appropriate depth markers as possible and refocus.

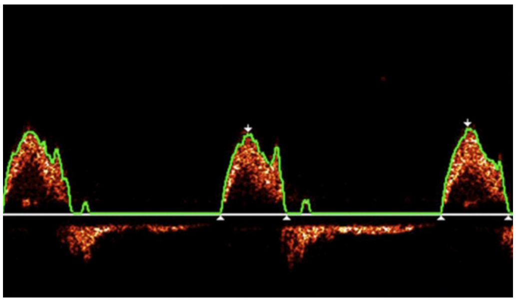


Venous. Probably azygos vein. Flow is seen below the line. Sounds more ‘whooshy’ and slower. Probe is likely to be too deep. Withdraw slightly and refocus.

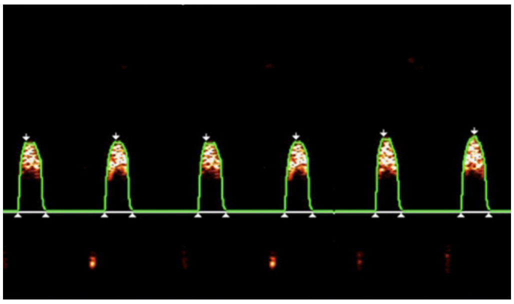


Intracardiac. Flow above and below line due to different flow directions within the heart. Sounds like a ‘galloping horse’. Try rotation and refocus or change depth and refocus if necessary.

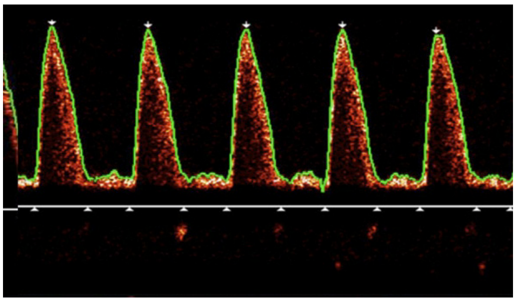
6.4 Clinical Examples



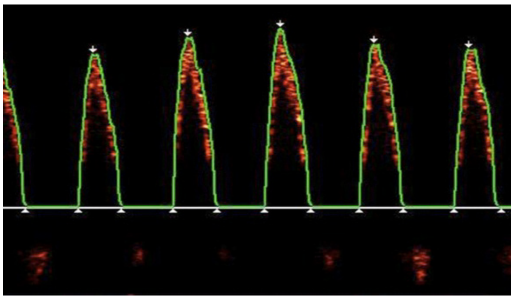
Aortic regurgitation. Forward flow above the line with backward flow below the line.



Increased afterload. Patient with cardiogenic shock. Short and narrow waveform. Reduced flow parameters. User may wish to try small fluid challenge and if no response, may try an inotrope/dilator and possible further fluid challenge later if necessary.



Reduced afterload/low resistant state. Septic patient. High flow parameters. Some horizontal diastolic flow (may be seen in low resistance states). Usually give fluid as per Frank-Starling responses and if BP remains low when no further SV responses are seen, a vasonstrictor may be considered.

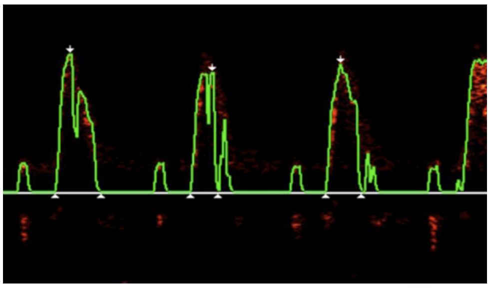


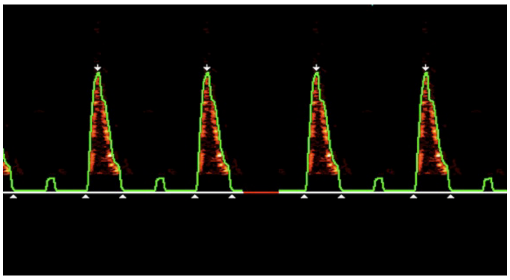
Respiratory swing. Tops of waveforms do not reach the same height and will vary regularly with ventilator breaths. Patient may be hypovolaemic and may respond to fluid challenges. Narrow base, reduced flow parameters.

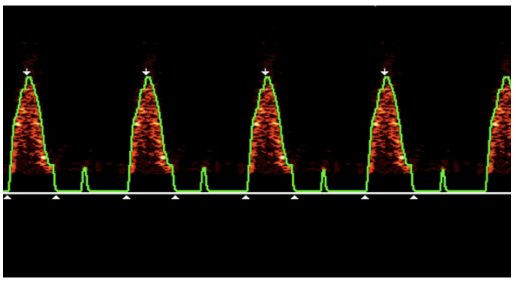
6.5 Waveform Analysis

With each screenshot (all from the same patient), consider the following:

- As far as possible, can it be determined if the waveform is optimally focussed.
- What do the parameters suggest?
- What would be the likely suggestion about what to do next?







7. FAQs

Q. I have connected my probe to the Dopplink but the Start button is still not accessible.

A. Check that the probe is firmly connected to the Dopplink. If necessary, try a different probe. If the problem persists, please contact Customer Services at Deltex Medical on 01243 774837

Q. Why can't I change the patient details?

A. Once you have confirmed the patient details, you cannot change the values. If the values are incorrect, you should use a new probe.

Q. When entering the patients' weight, do I enter dry, ideal or actual body weight?

A. Enter the patients' actual body weight at the time of placing the probe.

Q. Can other tubes be placed in the oesophagus while the probe is in situ?

A. Only if indicated in the nasogastric tube IFU. Oro/nasogastric tubes and temperature probes can be used. There may be a diminished signal when using the Doppler probe alongside a NG tube if the NG tube is in the path of the Doppler transmission. The air in the tube can diminish the intensity of the Doppler signal. Suggestions to avoid this situation include inserting the Doppler probe before the NG tube or placing the Doppler probe to the left of the NG tube.

Q. I can only get FTc, PV but cannot see CO or SV.

A. Perhaps the patient is outside of a nomogram limit and therefore volumetric calculations cannot be displayed. Use SD as a surrogate for SV as it correlates well with SV.

Q. How do I know I have the best waveform?

A. Typically, the tallest and brightest waveform together with the loudest and sharpest sound when placed as near to the appropriate depth markers as possible indicates the best signal.

Q. The top of the waveform is not visible on the screen?

A. Alter the range by selecting Auto Range on the left-hand side of the waveform screen.

Q. There are orange spikes at the beginning of systole. What are they and how do I stop them?

A. Low frequency signals may interfere with the measurements, e.g. excess noise from heart valves. Try adjusting the probe position, or if necessary, activate the filter to help eliminate this problem. Select options on the left-hand side of the waveform screen and select "on" under the filter settings.

Q. What is the Gain Option for?

A. Gain will adjust the return signal strength to ensure best amplification. This can be done manually by selecting Options on the left-hand side of the waveform screen and increasing or decreasing the Gain setting as appropriate.

Deltex Medical can add further FAQs. Please contact your Deltex Medical representative for assistance.

8. Bibliography

A meta-analysis as well as other information can be obtained from Deltex Medical Ltd at www.deltexmedical.com

Further information regarding the Decision Tree and any related evidence and education can be obtained from www.deltexmedical.com

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Please contact customer.services@deltexmedical.com for further information.