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CENTRAL VENOUS PRESSURE AND PULMONARY CAPILLARY WEDGE PRESSURE MONITORING

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Central venous pressure monitoring

The central venous pressure (CVP) measures the filling pressure of the right ventricular (RV); it gives an estimate of the intravascular volume status and is an interplay of the (1) circulating blood volume (2) venous tone and (3) right ventricular function.

Indications for central venous catheter placement	
i)	Major operative procedures involving large fluid shifts and / or blood loss
ii)	Intravascular volume assessment when urine output is not reliable or unavailable (e.g.: renal failure)
iii)	Major trauma
iv)	Surgical procedures with a high risk of air embolism, such as sitting position craniotomies. In addition to monitoring, the central venous pressure (CVP) catheter may also be used to aspirate intra-cardiac air.
v)	Frequent venous blood sampling
vi)	Venous access for vasoactive or irritating drugs
vii)	Chronic drug administration
viii)	Inadequate peripheral IV access
ix)	Rapid infusion of IV fluids (using large cannulae)
x)	Special Uses (i) insertion of PA catheters (ii) insertion of transvenous pacing wires (iii) haemodialysis/plasmapheresis

Waveforms in CVP

The normal CVP waveform consists of three upwards deflections (a, c, & v waves) and two downward defections (x and y descents). These waves are produced as follows:

1. The 'a' wave is produced by right atrial contraction and occurs just after the P wave on the ECG.
2. The 'c' wave occurs due to isovolumic ventricular contraction forcing the tricuspid valve to bulge upward into the right atrium. (RA)
3. The pressure within the RA then decreases as the tricuspid valve is pulled away from the atrium during right ventricular ejection, forming the X descent.
4. The RA continues to fill during late ventricular systole, forming the V wave.
5. The Y descent occurs when the tricuspid valve opens and blood from the RA empties rapidly into the RV during early diastole.[(1)]

Techniques: The sites and techniques for placing central venous catheters are numerous. Cannulation of internal jugular vein (IJV) was first described by English et al[2] in 1969. Since then, it has steadily increased in popularity to its present position as one of the methods of choice for CVP/RAP monitoring. The reason for this popularity relates to its landmarks; it's short, straight (right IJV), valveless course to the superior vena cava (SVC) and right atrium (RA); and its position at the patient's head, which provides easy access by anesthetists in more intra operative settings. Further, the success rate for its use exceeds 90% in most series of adults[3] and children[4]. For accurate measurement of CVP/RAP and also to aid aspiration of air in venous air embolism, the catheter tip is positioned ideally at the SVC-RA junction,[5] SVC.[6] or high up in the RA, away from the tricuspid valve.[7] Cannulation of the IJV is relatively safe and convenient and various approaches exist for its cannulation. The process of cannulation, regardless of the approach, involves the steps outlined in the following table:

Contraindications	
Absolute	
i.	SVC syndrome
ii.	Infection at the site of insertion *
Relative	
i.	Coagulopathies
ii.	Newly inserted pacemaker wires
iii.	Presence of carotid disease *
iv.	Recent cannulation of the internal jugular vein*
v.	Contra lateral diaphragmatic dysfunction
vi.	Thyromegaly or prior neck surgery:

*= in these cases, the internal jugular vein on the contra lateral side should be considered. It should be remembered that the thoracic duct lies in close proximity to the left IJV[11] and that laceration of the left brachio-cephalic vein or superior vena cava by the catheter is more likely with the left-sided IJV approach to the central circulation. This risk is due to the more acute angle taken by the catheter to enter the superior vena cava form the left side. Venous pressure measured from external jugular vein (EJV) can be used as indicative of right atrial pressure provided there is no kinking of the EJV and there is free flow of blood.[12] Multilumen central venous catheters have been developed to simplify patient care and to avoid complications associates with multiple single lumen central lines.[13]

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STEPS FOR RIGHT INTERNAL JUGULAR (IJV) CANNULATION		
1	Institute ECG monitoring	Critical for monitoring dysrhythmias
2	Remove pillow, rotate head to left; if conscious , ask patient to raise head off bed and note position of tensed sternocleidomastoid muscle; other wise use the bony landmarks of medial end of clavicle and mastoid process.	Optimizes visualization of landmarks
3	Place patient in Trendelenberg position	Distends IJ and reduces risk of air embolism; may worsen symptoms due to congestive or right ventricular failure
4	Perform careful sterile preparation and drape	Mandatory for central venous cannulation; full glove and gown should be used
5	Recheck landmarks, local infiltration necessary if . patient is conscious .skin wheal, and deeper infiltration with 1% Xylocaine.	IJ often is superficial and may be found during infiltration; withdraw on syringe before injection local anesthetic.
6	Remove local anesthetic from syringe, replace infiltration needle with 19-or 21 gauge 1 ½-in "finder" needle.	Not necessary if vein has been found previously; presence of local anesthetic will make aspirated blood appear bright red
7	Once vein has been located a. Leave finder needle in place or b. Remove finder, remember direction	 Serves as reminder of vein location Finder needle may interfere with subsequent cannulation
8	Insert 18- gauge 1 ¾–in catheter over needle unit into IJ, following same line	Constant aspiration as unit is advanced is required to see flashback
9	When flashback is seen, advance unit =1 mm, then advance catheter over needle into vein.	Once IV placement is established, end of catheter is capped with finger or syringe to avoid air embolism
10	If blood is not aspirated freely: a. Remove needle b. Replace syringes and aspirate c. Withdraw catheter until free flow of blood occurs d. Advance catheter slowly into vein, or insert a wire through catheter	Catheter is probably through back wall Patient may be hypovolemic, and IV fluid bolus will increase success Increased head-down position may be needed
11	Confirm IV placement by a. Check for lack of pulsatile flow. b. Measure pressure in the 18-gauge catheter and simultaneous arterial pressure, comparing absolute valuses and pressure waveforms c. Compare IJ and arterial blood samples, visually or by oximetry	If arterial cannulation is diagnosed, remove catheter and hold pressure for at least 5 minutes to avoid hematoma formation
12.	Pass flexible wire through catheter, remove guide wire	ECG should be monitored because arrhythmias can result
13.	Place central venous pressure catheter over wire or dilator – introducer assembly (pulmonary artery catheter)	Skin nick needed if larger introducer will be placed
14	Place sterile dressing	

It is mandatory to do a 'needle & guide-wire count' at the end of the CVP catheter insertion procedure to avoid embarrassing complications[10]

Steps for right internal jugular venous (RIJV) catheterization

Photo-1: Head turned to left, Trendelenberg position, two heads of sternocleidomastoid identified

Photo-2 : IJV located at the apex of the triangle

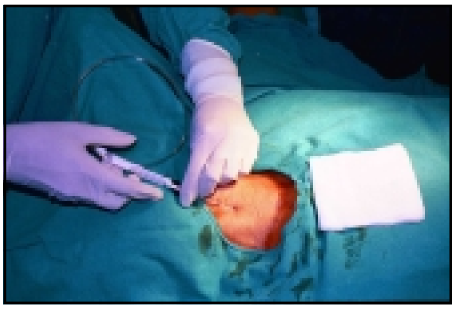

Photo-3 : Guide wire passed through the needle

Photo-4 : Guide wire in place

Photo-5 : Triple lumen central venous pressure catheter inserted over the guide wire, guide wire reserved and CVP catheter in place

Complications of central venous catheterization
Complications of central venous cannulation i) Arterial puncture with hematoma ii) Arteriovenous fistula iii) Hemothorax iv) Chylothorax v) Pneumothorax vi) Nerve injury Brachial plexus Stellate ganglion (Horner's syndrome) vii) Air emboli viii) Catheter or wire shearing
Complications of catheter presence i) Thrombosis, thromboembolism ii) Infection, sepsis, endocarditis iii) Arrhythmias iv) Hydrothorax

PULMONARY ARTERY AND PULMONARY CAPILLARY WEDGE PRESSURE MONITORING

The introduction of pulmonary artery catheter (PAC) in clinical medicine has been one of the most popular and important advances in monitoring. With this catheter, pulmonary artery (PA) pressure, pulmonary capillary wedge pressure (PCWP) as well as central venous pressure (CVP) can be measured easily. The PCWP under most circumstances provides an accurate estimate of the diastolic filling (preload) of the left heart. Cardiac output determination using thermo-dilution technique is an equally important use of this catheter.

Why PCWP?

The filling pressure of the right and left ventricle depends on the blood volume, venous tone, ventricular compliance, contractility and after load. The left ventricle (LV) is less compliant with greater after load than the right ventricle (RV) and the left sided filling pressure is normally higher than the right. Under normal circumstances, the right side of the heart and lungs are merely passive conduits for blood and it is possible to discern a relationship between the central venous pressure (CVP) and the left atrial pressure (LAP). In health, it is possible to make reasonable assumptions about the relationship between the CVP and the LAP and manipulate the circulation according to the measurements of the CVP. However, in a critically ill patient and a patient with cardiovascular disease, no such assumptions can be made and conclusions about left heart based on measurements of CVP may be invalid. Since there are no valves between the pulmonary capillaries and the left atrium, PCWP is a reflection of the LAP. During diastole, when mitral valve is open, the PCWP reflects LVEDP. LVEDP is an index of left ventricular end-diastolic volume[14].

The relationship between the CVP, PAP, PCWP and LV end-diastolic volume is as follows:

CVP	a	**PADP**	a	**PCWP**	a	**LAP**	a	**LVEDP**	a	**LVEDV**
	-		-		-		-		-	
	Right ventricle		Pulm vasc resistance		Airway pressure		Mitral valve		Left Ventricular compliance	

(PADP = pulmonary artery diastolic pressure, LVEDP = left ventricular end-diastolic pressure, LVEPV = left ventricular end-diastolic volume)

Description of a pulmonary artery (Swan-Ganz) catheter:

The standard 7F thermo-dilution pulmonary artery catheter consists of a single catheter 110 cm in length containing four lumina. It is constructed of flexible, radio-opaque polyvinyl chloride. 10 cm increments are marked in black on the catheter beginning at the distal end. At the distal end of the catheter is a latex balloon of 1.5 cc capacity. When inflated, the balloon extends slightly beyond the tip of the catheter but does not obstruct it. Balloon is useful in three ways (1) it prevents the tip of the catheter from contacting the right ventricular wall during passage and hence reduces the incidence of arrhythmias during insertion (2) it acts to float the catheter into the PA (3) inflation of the balloon allows the measurement of PCWP. Distal catheter lumen terminates at the tip of the catheter. It is used to (i) measure chamber pressures; PAP & PCWP (ii) obtain samples of the mixed venous blood. Proximal catheter lumen terminates 30 cm from the catheter tip placing it in the right atrium (RA) when the distal opening is in the PA. It (i) carries the injectate necessary for cardiac output computation (ii) can be used to measure the CVP (RAP) (iii) can be used to infuse vasoactive drugs. The third lumen carries the electrical leads for thermistor, which is positioned at the catheter surface, 4 cm proximal to the tip.

Indications For PAP & PCWP Monitoring:
A. Cardiac surgery: i) Poor LV function (EF<0.4; LVEDP> 18 mm Hg) ii) Recent MI iii) Complications of MI eg. MR, VSD, ventricular aneurysm. iv) Combined lesions eg. CAD+MR or CAD+AS v) Complicated lesions eg. IHSS vi) IABP
B. Non-cardiac situations: i) Shock of any cause ii) Severe pulmonary disease iii) Bleomycin toxicity iv) Complicated surgical procedure v) Massive trauma vi) Hepatic transplantation

LV= left ventricular; EF= ejection fraction; LVEDP = left ventricular end-diastolic pressure; MI=myocardial infraction; MR=mitral regurgitation; VSD=ventricular septal defect; CAD=coronary artery disease; AS= aortic stenosis ; IHSS= Idiopathic hypertrophic sub-aortic stenosis; IABP = intra-aortic balloon pump

Insertion:

The insertion of PAC is a simple, rapid and effective technique. A number of venous entry sites are employed for PA catheterization. Most anaesthesiologists and critical care physicians choose the right internal jugular vein (RIJV) approach to insert PAC. Prior to insertion, all lumina of the PAC are flushed and distal port is connected to transducer system with a continuous wave from display.

Insertion procedure is as follows :

With the patient supine and in 30^0 Trendelenberg position, the head is turned to the left side. The appropriate area of the neck is surgically prepared and draped. The RIJV is identified with a 22G needle. Then an 18G thin walled 5 cm teflon catheter is placed into the vein and threaded down the vessel for a short distance. The guide wire's flexible end is passed through the 18 G catheter into the superior vena cava (SVC) and the 18 G catheter removed. The skin hole around the guide wire is enlarged with a no. 11 scalpel blade to allow introduction of the dilator set. The dilator set consists of an internal vessel dilator and an external 10 G catheter sheath. This combination is passed into the IJV over the guide wire by a twisting motion until the catheter sheath is in the SVC. Then the 7 F Swan Ganz catheter, which has been filled with fluid and attached to a transducer, is passed through the sheath into the SVC. Location of the catheter tip in a central vein is confirmed by the pressure changes related to respiration or coughing. With the catheter in RA, the balloon is inflated with 1.5 ml of air and the PAC is advanced. Further advancement of the catheter will produce a dramatic change in the pressure tracing as the tip of the catheter enters the RV Pressure changes from that characteristic of RA to a phasic pressure in the range of 25 /0 mm Hg, typical of RV. The catheter is advanced through the RV until it enters the main PA. This can be recognized by an increase in the diastolic pressure (25/12 mm Hg.) Usually there is no change in the systolic pressure.

The catheter is advanced still further until it wedges in a branch o the PA. It will usually have the appearance of an atrial pressure pattern with a, c and v wave components transmitted retrogradely from LA (PCWP=8-12 mm Hg) PCW position is verified by the characteristic waveform, a mean pressure lower than the mean PAP and the ability to withdraw arterialised blood. After achieving a wedge position, the balloon is allowed to deflate. This should produce a typical PAP tracing. Reinflation of the balloon should reproduce the wedge tracing with 1.5 ml of air. If less than 1.0 ml of air results in a wedge position, the catheter should be withdrawn to the point where 1-1.5 ml balloon inflation is associated with PCWP.

Steps for pulmonary artery catheterization using Swan-Ganz catheter :

RIJV identified and guide wire inserted as for CVP cannulation (please see the previous section)

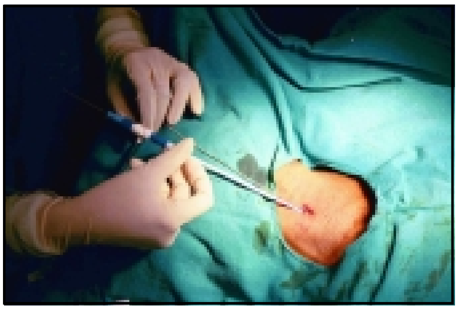

Photo-6: Skin opening enlarged, dilator set passed over the guide wire, dilator & guide wire removed; venous sheath remains in situ

Photo-7: Swan-Ganz catheter filled with fluid and connected to a transducer is passed into the SVC through the venous sheath.

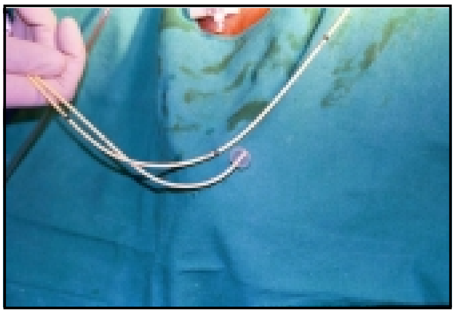

Photo-8: Swan-Ganz catheter with latex balloon at the tip

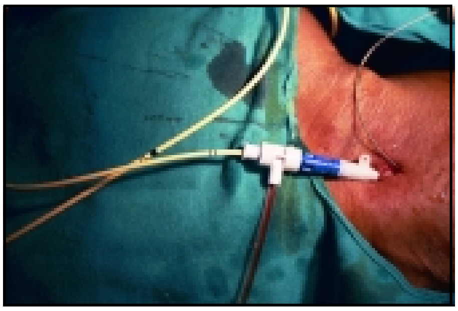

Photo-9: Swan-Ganz catheter is advanced through the vessel sheath.

Types of PA catheters:

1. The thermo dilution catheter is the one described in the text above; using this catheter, thermo dilution cardiac output & other divided haemodynamic parameters may be measured:
2. Pacing: Some PAC's have the capacity to provide intra cardiac pacing.
3. Mixed venous oxygen saturation:
   Special fiber-optic PAC can be used to monitor mixed venous oxygen saturation SVO2 continuously by the principle of absorption and reflectance of light through blood. The normal SVO2 is 75% and a 5 – 10 % increase or decrease is considered significant. A significant decrease in SVO2 may be due to (a) a decrease in the cardiac output (b) increase in metabolic rate (c) decrease in arterial oxygen saturation.
4. Ejection fraction catheter :
   New-catheters with faster thermistor response times can be used to determine the right ventricular ejection fraction in addition to the cardiac output.
5. Continuous cardiac output measurement :
   Continuous cardiac output measuring PACs contain an integrated thermal filament at level of the RV. This filament is activated in a programmed sequence to provide small amounts of heat, which is then detected in the PA by a thermistor. The data by the device yields a rapidly updated, near continuous value for cardiac output.

Normal Intracardiac Pressures (mm Hg)

TYPE	MEAN	RANGE
Right atrial pressure	5	1-10
Right ventricular end-systolic / end diastolic pressure	25/5	15-30 / 0-8
Pulmonary arterial systolic/ diastolic pressure	23/9	15-30 / 5-15
Mean pulmonary arterial pressure	15	10-20
Pulmonary capillary wedge pressure	10	5-15
Left atrial pressure	8	4-12
Left ventricular end-diastolic pressure	8	4-12
Left ventricular systolic pressure	130	90-140

Derived Hemodynamic Parameters

FORMULA	NORMAL VALUE
CI = CO / BSA	2.8 – 4.2 L / min / m^2
SV = CO. 1000 / HR	50-110 mL/beat
SI = SV/BSA	30-65 mL/beat/ m^2
LVSWI = 1.36. (MAP – PCWP).SI / 100	45-60 g.m / m^2
RVSWI = 1.36. (PAP – CVP). SI/ 100	5-10 g.m / m^2
SVR = (MAP-CVP). 80 / CO	900-1400 dyne. sec. cm^{-5}
SVRI = (MAP-CVP). 80 /CI	1500-2400 dyne.sec.cm^{-5}
PVR= (PAP-PCWP). 80 / CO	150-250 dyne.sec. cm^{-5}
PVRI= (PAP-PCWP). 80 / CI	250-400 dyne.sec. cm^{-5}

CI=Cardiac index; CO=cardiac output; BSA=body surface area; SV=stroke volume; HR=heart rate; MAP=men arterial pressure; PCWP=pulmonary capillary wedge pressure; PAP=pulmonary arterial pressure; CVP=central venous pressure; SVR=systemic vascular resistance; PVR=pulmonary vascular resistance; SI=stroke index; LVSWI=left ventricular stroke work index; RVSWI=right ventricular stock work index; SVRI= systemic vascular resistance index; PVRI=pulmonary vascular resistance index.

Oxygen Delivery Parameters

FORMULA	NORMAL VALUES
Arterial O_2 content $Ca\ O_2 = (1.39.\ Hb.\ Sa\ O_2) + (0.0031.PaO_2)$	18-20 mL/dl
Mixed venous O_2 content $Cv\ O_2 = 1.39.\ Hb.\ Sv\ O_2 + 0.0031.\ PvO_2$	13-16 mL / dl
Atreriovenous O_2 content difference $av\ DO_2 = Ca\ O_2 - Cv\ O_2$	4-5.5 mL/ dl
Pulmonary capillary O_2 content $Cc\ O_2 = 1.39.\ Hb.Sc\ O_2 + 0.0031.\ Pc\ O_2$	19-21 mL/dl
Pulmonary shunt fraction $Q_s / Q_t = 100.\ (Cc\ O_2 - Ca\ O_2) / (CcO_2 . Cv\ O_2)$	2-8 percent
O_2 delivery $DO_2 = 10.CO.\ Ca\ O_2$	800-1100 mL/ min
O_2 consumption $V\ O_2 = 10.\ CO.\ (Ca\ O_2 - Cv\ O_2)$	150-300 mL/ min

Hb=Hemoglobin; SvO_2=venous oxygen saturation; PvO_2 =venous oxygen tension; ScO_2=pulmonary capillary oxygen saturation; PcO_2=pulmonary capillary oxygen tension.

Condition Resulting In Discrepancies Between Pcwp And Lvedp

PCWP > LVEDP	
☞	Positive – pressure ventilation
☞	PEEP
☞	Increased intrathoracic pressure
☞	Non-west Lung Zone III PAC placement
☞	Chronic obstructive pulmonary disease
☞	Increased pulmonary vascular resistance
☞	Left atrial myxoma
☞	Mitral valve disease (stenosis, regurgitation)
PCWP < LVEDP	
☞	Noncompliant LV (ischaemia, hypertrophied LV)
☞	Aortic regurgitation (premature closure of the mitral valve)
☞	LVEDP > 25 mm Hg.

Contraindications for Swan-Ganz

A. Absolute
i) Tricuspid or pulmonary valvular stenosis ii). Right atrial or right ventricular masses (tumor or thrombus) iii). Tetralogy of fallot.

B. Relative
i). Severe arrhythmia ii). Coagulopathy iii). Newly inserted pacemaker wires

Complications of Swan-Ganz

A. Complications of cannulation
i) Arterial puncture (carotid, subclavia) ii) Haematoma, haemothorax iii) Pleural effusion iv) Nerve injury (brachial plexus, stellate ganglion) v) Emboli (air, catheter insertion)

B. Complications of catheter insertion
i) Cardiac perforation ii) Cardiac dysrhythmia , heart block iii) Knotting iv) Tricuspid, pulmonary valve injury

C. Complications of catheter presence
i) Thrombosis, thromboembolisin ii) Infection, endocarditis, sepsis iii) Pulmonary artery rupture iv) Pulmonary infarction

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