Review Article

Indian Journal of Anaesthesia and Analgesia
Volume 3 Number 2, May - August 2016
DOI: http://dx.doi.org/10.21088/ijaa.2349.8471.3216.16

P A Cathetor V/s. A P C O

Manjula Sarkar

Abstract

Cardiac output (CO) monitoring is an integral part of management of patients during cardiac surgery, supramajor surgeries with large fluid shifts and critically ill patients in the ICU. It helps in early identification of insufficient tissue oxygenation and appropriate treatment can be instituted early. Traditionally, CO monitoring is done by thermodilution technique using pulmonary artery catheter. However, it is an invasive modality and several studies criticised and linked it to the increased mortality. This has lead into the development of newer minimally invasive methods most noticeably arterial pressure waveform derived cardiac output (APCO) monitoring system. It is an exciting technology based on normal population arterial waveform algorithm without any need of external calibration and can be attached to the pre-existing arterial line. However, thermodilution is still considered as a gold standard method of cardiac output monitoring.

This article intends to highlight the pro and cons of these two techniques as well as other methods of CO monitoring.

Keywords: Cardiac Output Monitor; Thermodilution; Pulmonary Artery Catheter; Flotrac; LiDCO; Echocardiograhy

P A Cathtor

In medicine *pulmonary artery catheterization* (PAC) is the insertion of a catheter into apulmonary artery. Its purpose is diagnostic; used to detect heart failure or sepsis, monitor therapy, and evaluate the effects of drugs. The pulmonary artery catheter allows direct, simultaneous measurement of pressures in the right atrium, right ventricle, pulmonary artery, and the filling pressure ("wedge" pressure) of the left atriumIn the clinical setting, the perfusion of vital organs usually is assessed by measuring the cardiac output (CO), and usually by thermodilution using a pulmonary artery catheter (PAC).Most clinical assessments have compared less invasive or noninvasive techniques with thermodilutionto achieve clinical relevance and acceptability. Pulmonary artery thermodilution has remained the clinical gold standard for CO. Less Invasive CO monitoring though less precise than PAC but continuous and automatic, improve haemod-ynamic monitoring in the OR & ICU.

Less invasive cardiac output measurement techniques apart from P A C is arterial wave form analysis require arterial catheter.

Thermodilution most Commonly used Technique

Advantages

- Rapid & easy to use,
- No arterial line required,
- Repeat measurements possible,
- Most Widely Used Measure of Cardiac Output,
- Low Cardiac Output correlated with mortality in multiple studies,
- Readily available in ICU.

Disadvantages

- Intracardiac shunts,
- Tricuspid or pulmonic valve regurgitation,
- Inadequate delivery of thermal indicator,
- Warming of iced injectate,
- Thermistor malfunction from fibrin or a clot Pulmonary artery blood temperature fluctuations,
- Post-cardiopulmonary bypass status,
- Rapid intravenous fluid administration,
- Respiratory cycle influences,
- Indicator is time consuming,

Author's Affiliation: Professor, Anaesthesia, Seth G. S. Medical College & KEM Hospital, Parel, Mumbai – 400 012.

Corresponding Author: **Manjula Sarkar,** Professor, Dept. of Anaesthesia, Seth G. S. Medical College & KEM Hospital, Parel, Mumbai – 400 012.

E-mail: drmanjusarkar@gmail.com

- expensive& cumbersome to prepare.

Why Monitor Cardiac Out Put ?

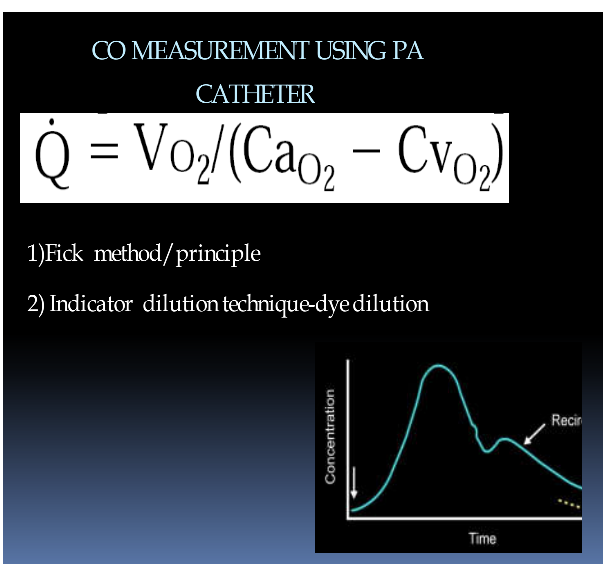
Global assessment of circulation,Critically ill low cardiac output- increase mortality & morbidity- inadequate blood flow to the organs, Clinical assessment of cardiac output-inaccurate "It is well known that the blood volume and cardiac output are usually diminished in traumatic shock before the arterial blood pressure declines significantly" Blalock A, (1943) Surgery 14: 487-508 BP does not change until late due to these compensatory response, CVP & PAOP represent the end diastolic pressures of RV & LV respectively, Do not translate in to systolic function or cardiac output,Cardiac output and other haemodynamic parameters DD of shock,establishing the right treatment plan and monitoring and refining it in real time.

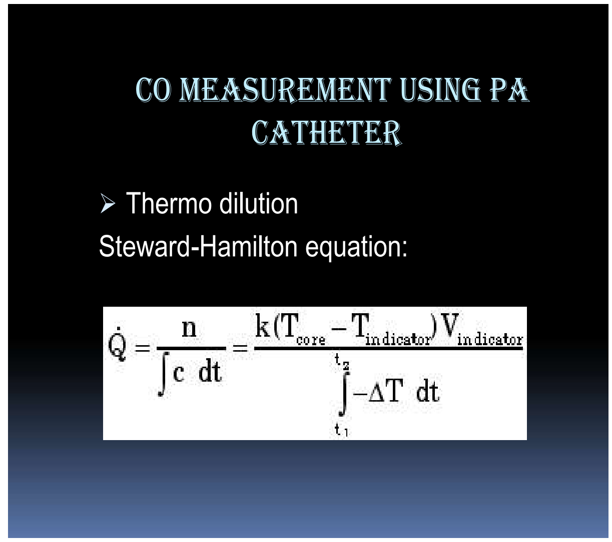
Determinants of Cardiac Out Put

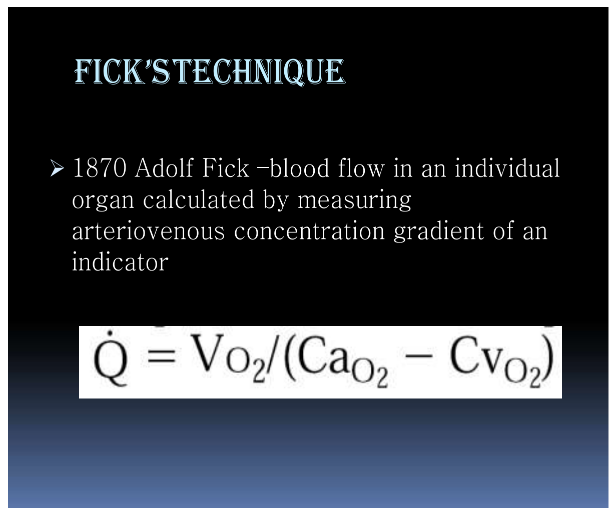
- *Intrinsic Factors:* Heart Rate,Myocardial contractility.
- *Extrinsic Factors :* Preload, Afterload.

Characterstics of Ideal Cardiac out put Monitor

- Precise,
- No bias,
- Non-invasive,
- Readily available in the ICU,
- Leads to treatment changes/improvement in outcome.







Advantages

- Accurate & precise compared to electromagnetic flow probe

Disadvantages

- Not easy to perform in OR.
- Cumbersome.
- Time consuming.
- Repeat measurements not practical.

Dye dilution 1890 George Stewart - Concept of Indicator Dilution

- William Hamilton-measurement of cardiac output using indicator dilution technique
- Ideal indicatorStable.
- Nontoxic.

- Easily measured.
- Uniformly distributed within fluid compartment.
- Not lost from circulation during the first trasit.
- Rapidly dissipated to avoid recirculation.

Dye Dilution

The cardiac output (blood flow) is amount of indicator injected, divided by average concentration in arterial blood.

- Cardiac Output(ml/min)= mg of dye injected x 6 {Avgconc of dye Duration of in each ml of blood for [X] curve induration of curve } second.

Pulse Contour Analysis Technique

The pulse contour technique of measuring cardiac output relies on the principle that the arterial pressure waveform is related to the stroke volume.This was described by Frank and colleagues in 1930and has been studied with varied success ever since. A recent publication describing a novel time-averaged approach to this technique reviews the traditional Windkessel model of the circulation, which is the underlying principle of arterial waveform analysis (Figure 1). Although it is possible to obtain an arterial waveform with noninvasive monitors, pulse contour cardiac output devices currently available require an invasive arterial waveform.There are three techniques. In addition, two of the three require an external calibration with a known cardiac output. One relies on lithium indicator dilution (PulseCO, LiDCO Limited, Cambridge, United Kingdom), where the radial artery lithium concentration is measured after a venous injection of lithium. The other is calibrated with a transpulmonarythermodilution technique (PiCCO, Pulsion Medical Systems, Munich, Germany), applies to the circulation (left), ABP should decay like a pure exponential during each diastolic interval with a time constant (T) equal to the product of the TPR and the nearly constantAC. Thus, an exponential is fitted to the diastolic interval of each ABP pulse to determine T(right) and the time-averaged ABP (MAP) is divided by T to estimate proportional CO. Newerarterial waveform analysis techniques may use significant modifications of this equation or differentequations altogether. Abbreviations: ABP, arterial blood pressure; AC, arterial systemcompliance; MAP, mean arterial pressure; TPR, total peripheral resistance. (Reproduced andtext modified from Mukkamala R, Reisner H, Hojman M, et al. Continuous cardiac outputmonitoring by peripheral blood pressure waveform analysis. IEEE Trans Biomed Eng 2006:53:459–67; with permission.Copyright 2006 IEEE.)

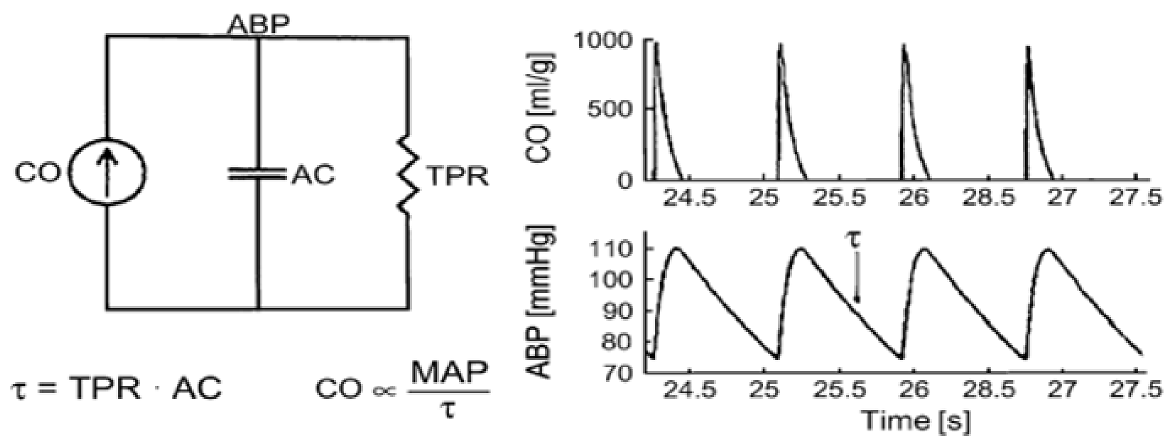
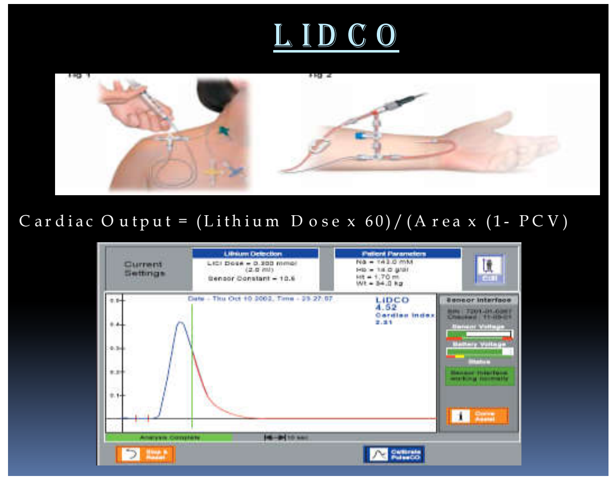


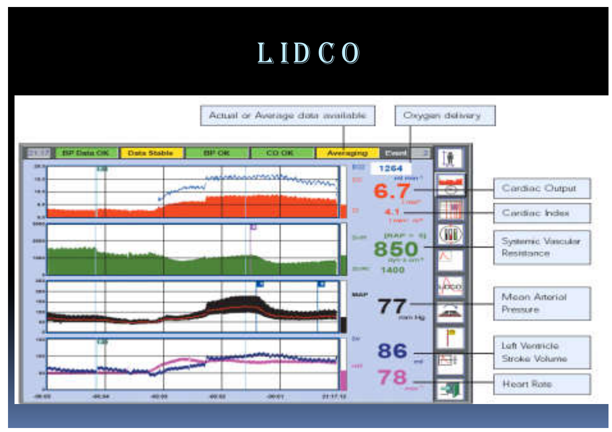
Fig. 1A: Mathematical model for deriving cardiac output from an arterial pressure waveform.According to the ‘‘Windkessel’’ model, which assumes Ohm’s law (described for electrical circuits)

where a central venous injection of cold or room temperature injectate is sensed by a thermistor-tipped catheter placed in the radial artery. Both the lithium indicator dilution and transpulmonary thermodilution techniques (ie, the calibration techniques for the noninvasive pulse contour) have been shown to correlate well with standard thermodilution. Neither of these pulse contour techniques is truly noninvasive; however, they do not require a pulmonary artery catheter. The third and most recently introduced technique (Flotrac,) does not require external calibration, but it has not been compared adequately with other techniques to warrant conclusions regarding reliability or clinical utility. Although all techniques of pulse contour analysis use the arterial waveform, just how the waveform is analyzed differs significantly. In the case of PulseCO, a proprietary algorithm uses beat duration, ejection duration, mean arterial pressure, and themodulus and phase of the first waveform harmonic in order compute beat-to-beat stroke volume. Both this latter publication and a more recent independent evaluation of this system in 22 postoperative patients showed the pulse contour analysis to compare well with lithium indicator dilution.Certain patient populations cannot be analyzed adequately with this technique, including those on lithium therapy and patients with significant cardiac dysrhythmias, severe aortic incompetence, or a poor arterial waveform. Calibrations with lithium indicator dilution are recommended every 8 hours; if done more frequently, serum lithium levels may interfere with the calibration. A major advantage of the PulseCO system is that the calibration with lithium can be done with a peripheral venous catheter; it therefore only requires the peripheral venous catheter and radial arterial catheter. The PiCCO system uses a more traditional Windkessel model for waveform analysis The proprietary algorithm was revised recently to take into account the shape of the systolic portion of the arterial waveform. Earlier studies with this system showed a fair correlation with thermodilution[in patients after cardiac surgery, the new algorithm correlated well with thermodilution during changes in preload]. Both long radial artery catheters and brachial artery catheters appear to be acceptable alternatives to femoral artery catheters for the transpulmonarythermodilution calibrations. In addition to providing stroke volume and CO, this system can be used to calculate extravascular lung volume. The most recent entry into the field of pulse contour cardiac output analysis is the Flotrac sensor. The product information available from the manufacturer states the proprietary algorithm takes into account the pulse pressure, known determinants of arterial system compliance (such as age, sex, and body surface area), and other undefined aspects of the arterial waveform to calculate stroke volume without the need for external calibration.

Transpulmonary Lithium Indicator Dilution &Arterial Waveform Analysis LiDCO

Central/peripheral venous acess is required. Absence of renal dysfunction or dialysis is ensured. An isotonic (150 mM) solution of lithium chloride - 0.15 -0.30 mmol for an average adult -patient weight (> 40kg) is injected. Ion selective electrode is attached to peripheral arterial catheter which measures Lithium Dilution Curve to derive CO. Thistechnique calibrates software which performs continuous arterial wave analysis by a pulse power method.





Advantages of LIDCO

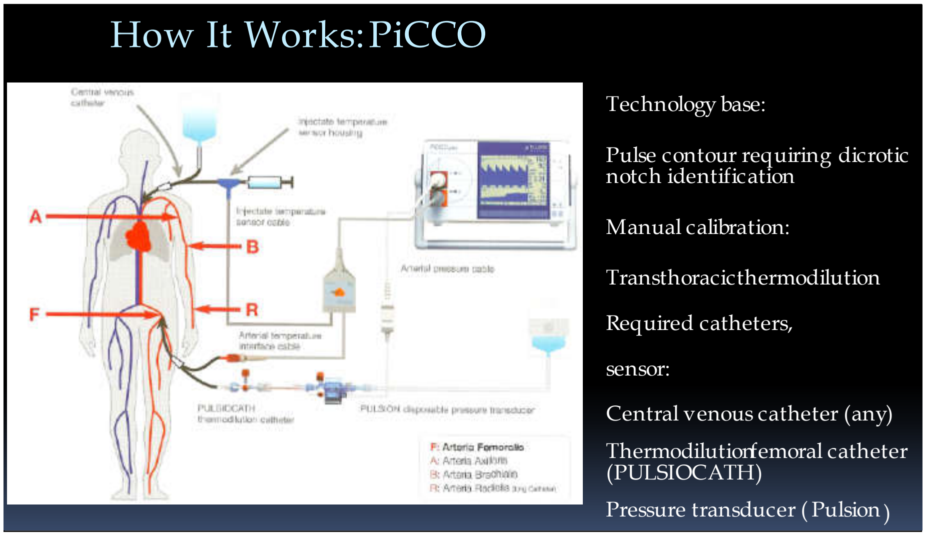
- Compared well with electromagnetic flow probes &thermodilution technique.
- Continuous real-time cardiovascular monitoring.
- Minimally invasive.
- Safe,Simple to use in conscious as well as unconscious patients.
- Newer complete noninvasive LIDCO monitor which derives CO from finger probe (similar to pulse oxymeter) has recently been launched but the accuracy and validation is still not conclusive.

Disadvantages

- NDMR interferes with the lithium sensitive electrode.
- Dysrhythmias result in irregular data output.
- Damping of waveform results in eror.

Transpulmonary Thermo Dilution &Arterial Waveform Analyses (PiCCO)

Cold saline is injected via central venous catheter and temperature of arterial blood in femoral or brachial artery is measured. CO calculated using modified Stewart Hamilton equation.



Advantages

- Compared well with electromagnetic flow probes &thermodilution technique.
- Enables continuous hemodynamic monitoring.
- Measures Transpulmonary cardiac output (C.O.), Intrathoracic blood volume (ITBV), Extravascular lung water (EVLW), Stroke volume variation (SVV) in conscious as well as unconscious patients.

Disadvantages

- More invasive than LiDCO.
- Specific thermistor tipped catheter.
- Damping of waveform or change in aortic compliance results in error.
- Needs Recalibration.
- Dependent on Compliance of Arterial Tree.
- Little Validation in Patients with Shock.

Flotra or Vigilio

It is the technique of arterial pressure waveform analysis without external calibration. Patient demographic data is used to calculate CO. The device connects to any existing peripheral arterial line using the FloTrac pressure transducer and CO is displayed on a continuous basis after entering patient height, weight, and age. The FloTrac sensor measures variation in arterial pulse pressure.The Vigileo monitor uses the FloTrac measurements to continuously compute stroke volume. Age, gender, height, and weight determine patient-specific vascular compliance. The vigileo monitor supports both the flotrac sensor for continuous cardiac output and the presep central venous catheter for continuous central venous oximetry (scvo2).The vigileo monitor continuously displays and updates continuous cardiac output, cardiac index, stroke volume, stroke volume index, systemic vascular resistance, systemic vascular resistance index, and stroke volume variation every 20 seconds when used with the flotracsensor.These parameters help guide the clinician in optimizing stroke volume through precision guided management of preload, afterload, and contractility. The vigileo monitor uses the patient's arterial pressure waveform to continuously measure cardiac output with inputs of height, weight, age and gender, patient-specific vascular compliance is determined. The flotrac sensor measures the variations of the arterial pressure which is proportional to stroke volume. Vascular compliance and changes in vascular resistance are internally compensated for. Cardiac output is displayed on a continuous basis by multiplying the pulse rate and calculated stroke volume as determined from the pressure waveform. The flotrac sensor is easily setup and calibrated at the bedside using the familiar skills used in pressure monitoring."Validation of a continuous cardiac output measurement using arterial pressure waveform", critical care, mar 05 supplement (abstract) Dr Mcgee's study is the largest validation study of its kind. The study was conducted in 4 centers, 2 american and 2 european, in both ORs and ICUs, over a wide range of ages. This study presents a "real life" validation as patient sample bias often caused by homogeneous demographics and the effect of a limited number of participatingclinical sites has been minimized. APCO responds quickly to changes in cardiac output. One of the most significant factors affecting differences in the magnitude and timing of changes in trends between the two continuous technologies, APCO and CCO, is the averaging time. The APCO algorithm detects changes in vascular tone via analysis of waveform characteristics. CO systems based upon an indicator dilution method of calculating CO require regular calibration because they do not compensate continuously for changes in vascular tone. APCO does not require a manual method of recalibration.

Advantages

- Continuous monitoring.
- No Calibration.
- Less invasive.

Source of Error

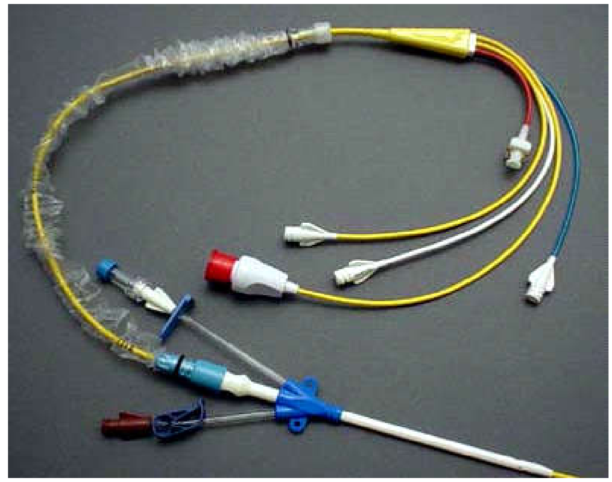
- Dysrhythmia.
- Sensor heightAortic balloon pump.
- Patient arm movement.
- Line bubbles.
- Pressure dampening.

PA Catheter

❖ *General Indications are*

- Management of complicated myocardial infarction.
- Assessment of respiratory distress.
- Assessment of type of shock.
- Assessment of therapy
  - o Afterload reduction
  - o Vasopressors
  - o Beta blockers
  - o Intra-aortic balloon counter-pulsation
- Assessment of fluid requirement in critically ill patients
  - o Hemorrhage
  - o Sepsis
  - o Acute renal failure aka Acute Kidney Injury
  - o Burns
- Management of postoperative open heart surgical patients.
- Assessment of valvular heart disease.
- Assessment of cardiac tamponade/constriction.

Note: No study has definitively demonstrated improved outcome in critically ill patients managed with PA catheters. Therefore, the primary justification has been on the basis of clinic experience.



Procedure

The catheter is introduced through a large vein—often the internal jugular, subclavian, or femoral veins. From this entry site, it is threaded, often with the aid of fluoroscopy, through the right atrium of the heart, the right ventricle, and subsequently into the pulmonary artery.The standard pulmonary artery catheter has two lumens (Swan-Ganz) and is equipped with an inflatable balloon at the tip, which facilitates its placement into the pulmonary artery through the flow of blood. The balloon, when inflated, causes the catheter to "wedge" in a small pulmonary blood vessel. So wedged, the catheter can provide an indirect measurement of the pressure in the left atrium of the heart, showing a mean pressure, in addition to a, x, v, and y waves which have implications for status of the left atria and the mitral valve. Left ventricular end diastolic pressure (LVEDP) is measured using a different procedure, with a catheter that has directly crossed the aortic valve and is well positioned in the left ventricle. LVEDP reflects fluid status of the individual in addition to heart health.

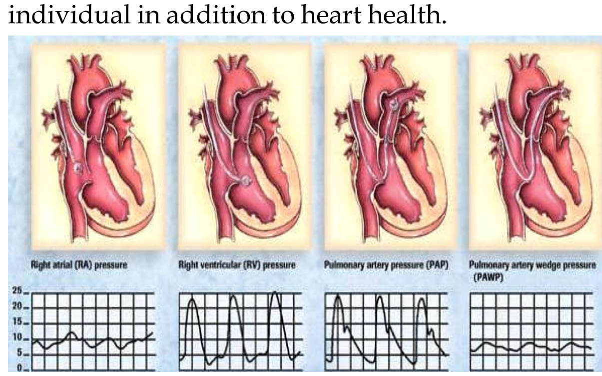


Fig. 2: This is a typical waveform progression as the pulmonary artery catheter floats throigh Cardiac chambers. Monitoring these waveform tells clinicians where in the heart the catheter is as it advances.

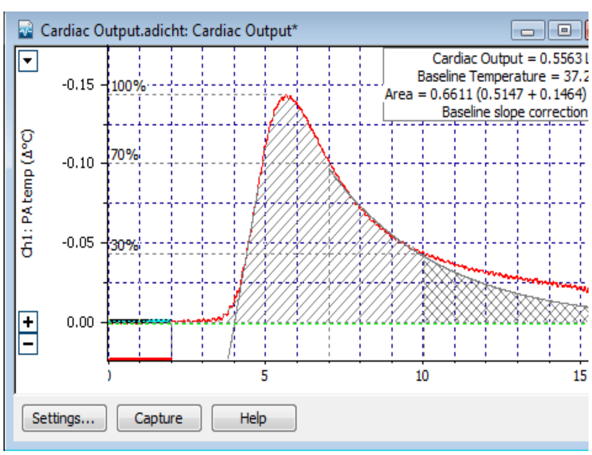
Technical Developments

Thermal Dilution

After Swan developed the initial balloon tip, Ganz used Fronek's idea and added a small thermistor (temperature probe) about 3 cm behind the tip. Either cold 10 ml of saline (0.9% NaCl) under 10° Celsius or room temperature (not as accurate) is injected into an opening in the right atrium. As this cooler fluid passes the tip thermistor, a very brief drop in the blood temperature is recorded. A recent variation in design is the incorporation of a heating coil on the catheter (30 cm from the tip, residing in the atrium area) which eliminates the cold fluid bolus, a major factor in human technique variation.

By attaching both the injector site and the ventricular thermistor to a small computer, the thermodilution curve can be plotted. If details about the patient's body mass index (size); core temp, Systolic, diastolic, central venous pressure CVP (measured from the atrium by the third lumen simultaneously) and pulmonary artery pressure are input, a comprehensive flow v/s. pressure map can be calculated. this measurement compares left and right cardiac activity and calculates preload and afterload flow and pressures which theoretically if stabilized or adjusted with drugs to either constrict or dilate the vessels to raise or lower the pressure of blood flow to the lungs, respectively, in order to maximize oxygen for delivery to the body tissues. The true art remains with the consultant in balancing fluid load.

Temperature-versus-time curve



Pharmacotherapy Lumens

Modern catheters have multiple lumens — five or six are common — and have openings along the length to allow administration of inotropes and other drugs directly into the atrium. Drugs to achieve these changes can be delivered into the atrium via the fourth lumen, usually dedicated to medication. Common drugs used are various inotropes, norepinephrine or even atropine. A further set of calculations can be made by measuring the arterial blood and central venous (from the third lumen) and inputting these figures into a spreadsheet or the cardiac output computer, if so equipped, and plotting an oxygen delivery profile.

SvO_2 Measurement

One further development in recent years has been the invention of a catheter with a fiber-optic based probe which is extended and lodged into the ventricle wall providing instant readings of SvO2 or oxygen saturation of the ventricle tissues. This technique has a finite life as the sensor becomes coated with protein and it can irritate the ventricle via the contact area.

Complications

(a) Complications of Central Venous Puncture

Arterial puncture, arterial or venous hematoma, arteriovenous fistula (AVF), pseudoaneurysm formation, thoracic duct injury, pneumothorax/ hemothorax, thrombosis and air embolization.

(b) Complications related to PAC Insertion and Manipulation: Cardiac Arrhythmias

The incidence ofarrhythmia has been reported to range from 12.5% to over 70% during PAC insertion (16–18). The National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network. Pulmonaryartery versus central venous catheter to guide treatment of acute lung injury. N Engl J Med 2006 ;354: 2213–2224. Iberti TJ, Benjamin E, Gruppi L, et al: Ventricular arrhythmias during pulmonary artery catheterization in the intensive careunit. Prospective study. Am J Med 1985;78:451–454 18. Groeneveld ABJ, Thijs LG: Hemodynamic monitoring in septicshock. Springer, Berlin 1991;179–196.

(c) Mechanical Complications

Mechanical damage to cardiac structures (i.e., valves, chordae) can occurduring PAC placement/ manipulation but is uncommon (~0.9%) (25–29). Arnaout S, Diab K, Al-Kutoubi A, et al: Rupture of the chordate of the tricuspid valve after knotting of the pulmonary artery catheter. Chest 2001; 120: 1742–

1744. Polderman KH, Girbes ARJ: Central venous catheter use Part 1: Mechanical complications. Intensive Care Med 2002; 28: 1–17. Hofbauer R, Moser D, Kaye AD, et al: Thrombus formation on the balloon of heparin-bonded pulmonary artery catheters: Anultrastructural scanning electron microscope study. Crit Care Med 2000; 28: 727–735. Lange HW, Galliani CA, Edwards JE: Local complications associated with indwelling Swan-Ganz catheters: Autopsy study of 36 cases. Am J Cardiol 1983; 52: 1108–1111. Elliott CG, Zimmerman GA, Clemmer TP: Complications of pulmonary artery catheterization in the care of critically ill patients. A prospective study. Chest 1979; 76: 647–652.

Thrombosis and Venous Embolism Infections

Complications associated with short- or long-term presence of the PAC inthe cardiovascular system Pulmonary Artery Rupturep Fortunately this complication is rare (incidence of 0.03%–0.20%) [7–8].

PAC Knotting: The incidence of PAC knotting is estimated to be 0.03% of all PAC placements.

Balloon Failure and breaking of the *PAC* with repeated inflation, cracks within the PAC balloon can occur resulting in up to 17% balloon rupture rate in early PAC series.

(d) Incorrect Interpretation/use of PAC-Derived data

Evidence of Benefit

Several studies in the 1980s seemed to show a benefit of the increase in physiological information. Many reports showing benefit of the PA catheter are from anaesthetic, and Intensive Care settings. In these settings cardiovascular performance was optimized thinking patients would have supra-normal metabolic requirements.

Evidence of Harm or Lack of Benefit

Contrary to earlier studies there is growing evidence the use of a PA catheter (PAC) does not necessarily lead to improved outcome [2].The following explanations have been advanced. One explanation could be that nurses and physicians were insufficiently knowledgeable to adequately interpret the PA catheter measurements. Also, the benefits might be reduced by the complications from the use of the PAC. Furthermore, using information from the PAC might result in a more aggressive therapy causing the detrimental effect. Or, it could give rise to more harmful therapies (i.e. achieving supra-normal values could be associated with increased mortality).

Utility of Pulmonary Artery Catheterization

This interpretation of Adolph Ficks' formulation for Cardiac Output by time/temperature curves is an expedient but limited and invasive model of right heart performance. It remains an exceptional method of monitoring volume overload leading to pulmonary edema in an ICU setting.

A feature of the pulmonary artery catheter that has been largely ignored in the clinical setting is its ability to monitor total body oxygen extraction by measuring the mixed venous oxygen saturation. Regardless of the value obtained by measurements of the cardiac output, the mixed venous oxygen saturation is an accurate parameter of total body blood flow and therefore cardiac output. The assumption that a low mixed venous oxygen saturation (normal = 60% except for the coronary sinus where it approximates 40% reflecting the high metabolic rate of the myocardium) represents less than adequate oxygen delivery is consistent with physiological and metabolic observations. High oxygen extraction is associated with low cardiac output and decreased mixed venous oxygen saturation. Except during hypothermia and in severe sepsis, low mixed venous oxygen saturations are indication of inadequate hemodynamics. The ability of the pulmonary artery catheter to sample mixed venous blood is of great utility to manage low cardiac output states.

Non-invasive Echocardiography and pulse-wave cardiac output monitoring are concordant with (and much safer) if not better than invasive methods defining right and left heart performance. The advent of MRSA and similar hospital based catheter infections now clearly limits the utility of this type of invasive cardiac ICU intervention.

Conclusions

APCO, a less invasive technique requiring simply an arterial catheter, does not require calibration.

APCO correlated well with ICO and CCO showing comparable bias and precision.

APCO performed well in the real world setting of both medical and surgical critically ill patients.

The development of an accurate less invasive simple method of measuring cardiac output may contribute to the expansion of hemodynamic monitoring to patients currently not monitored.

P A Cathetor is more invasive but gives accurate parameters for diagnosing the problem and perfact treatment.

References

1. Shah, M. R.; Hasselblad, V; Stevenson, LW; Binanay, C; O'Connor, CM; Sopko, G; Califf, RM (2005 Oct 5). "Impact of the Pulmonary Artery Catheter in Critically Ill Patients: Meta-analysis of Randomized Clinical Trials". *JAMA: The Journal of the American Medical Association*. 294 (13): 1664–1670. doi:10.1001/jama.294.13.1664. PMID 16204666.

2. Sandham, James Dean; Hull, Russell Douglas; Brant, Rollin Frederick; Knox, Linda; Pineo, Graham Frederick; Doig, Christopher J.; Laporta, Denny P.; Viner, Sidney; Passerini, Louise; Devitt, Hugh; Kirby, Ann; Jacka, Michael. "A Randomized, Controlled Trial of the Use of Pulmonary-Artery Catheters in High-Risk Surgical Patients". New England Journal of Medicine. 2003 Jan 2; 348(1): 5–14. doi:10.1056/NEJMoa021108. PMID 12510037.

3. Bland, R.D.; Shoemaker, W.C.; Abraham, E.; Cobo, J.C.: Hemodynamic and oxygen transport patterns in surviving and non-surviving postoperative patients. Critical Care Medicine. 1985; 13(2); 85-90.

4. Fronek A.,GanzV.:Measurement of cardiac output and peripheral blood flow by a local thermodilution method, Csl.Fysiol. 1959; 8; 189.

5. Fronek A.,GanzV.:Measurement of flow in single blood vessels including cardiac output by local thermodilution, Circ.Research. 1960; 8: 175.

6. Swan HJ, Ganz W, Forrester J, Marcus H, Diamond G, Chonette D. "Catheterization of the heart in man with use of a flow-directed balloon-tipped catheter". *N. Engl. J. Med*. 1970 August; 283(9): 447–51. doi:10.1056/NEJM197008272830902. PMID 5434111.