Bedside Hemodynamic Monitoring Providing Equity of Critical and Maternity Care for the Critically Ill Pregnant or Recently Pregnant Woman

Kenneth James Warring-Davies, PhD

Abstract

The aim of this study was to compare the performance of nurses and medical staff in using two methods of hemodynamic monitoring in cardiac surgery patients. We designed a double-blind study in which nurses and physicians measured cardiac output and other hemodynamic variables using pulmonary artery catheter thermodilution (PACTD; the ‘gold standard’) and a comparator (continuous cardiac dynamic monitoring [CCDM]-HeartSmart®). Hemodynamic values measured using PACTD and HeartSmart® were comparable between nurses and physicians. In addition, PACTD measurements were in good agreement with those derived from CCDM-HeartSmart®. Specialized Cardiac Intensive Care Unit (CICU) nurses are as competent as any member of the medical staff in measuring hemodynamic measurements using PACTD.

Keywords — Doppler, oxygen supply, hemodynamic monitoring, SIRS, thermodilution, cardiac index.

Cite this article as: Warring-Davies KJ. Bedside hemodynamic Monitoring providing equity of critical and maternity care for the critically ill pregnant or recently pregnant woman. JCvD 2014; in press.

I. INTRODUCTION

This is a prospective double-blind study where we made a comparison of skills and knowledge of cardiac intensive care unit nurses to that of experienced intensivist and cardiothoracic anesthetist, using two methods of bedside hemodynamic monitoring.

Assessment of cardiac output/index and optimization of stroke volume or oxygen delivery improve outcome in critically ill patients after major surgery and during early sepsis (Boyd et al 1993; Berridge 1992; Connors et al 1996; Wilson et al 1999). Maintenance of appropriate fluid intake and cardiac output/index) monitoring is therefore a crucial routine duty of many nurses caring for all types of patients. This has particular relevance in the cardiac intensive care unit (CICU), where there remains a need for a relatively simple, reliable bedside method of estimating cardiac index (Tibby and Murdoch 2003) based on physiological variables that are routinely measured during surgery and continuously recorded by nursing staff after surgery. Any new method therefore has to be user-friendly, simple to understand, and easily administered by nurses and doctors.

The CICU nurses and doctors were blindly monitored over a 3-month period, the same questions on management of invasive arterial lines were asked to each nurse/doctor in a conversational way, but not necessarily in the same order. The study was designed in this way so as those nurses/doctors taking part in this study would not see or be able to discuss which questions were put to them in a structured way, if they had realized they were taking part in a blind study of their knowledge and expertise in performing hemodynamic monitoring, rather than that of assessing a novel hemodynamic monitor, it may have altered the nurses/doctors answers and results. Each nurse/doctor was able to discuss with the investigating author any questions they wished, on cardiovascular physiology and or hemodynamics, as well as on the comparative technology (HeartSmart) in relation to the pulmonary artery catheter thermodilution method (PACTD). Each nurse/doctor was closely observed when performing and recording the values of PACTD to that of HeartSmart, the PACTD method was performed first, the HeartSmart system was already connected in line with the PACTD lines giving identical hemodynamic values as the PACTD monitor see figures 1-3.

The first test containing ten questions was on invasive arterial lines:

1. Investigate each nurse/doctor’s knowledge of the essential requirements of invasive arterial line monitoring (see also tables 1-4):
   i. How to Set-Up Hemodynamic Circuit: CICU nurses are responsible for the priming, zeroing, leveling, and maintenance of hemodynamic pressure monitoring circuits and for the
assessment and monitoring of hemodynamic pressures and waveforms. CICU nurses may flush hemodynamic monitoring circuits as required to maintain patency, see figure 1

ii. The Importance of Maintain Accuracy: Why is there a requirement for hemodynamic transducers to be zeroed at each initial setup, with the air-fluid interface (stopcock above transducer) leveled to the mid-axillary line. Why keep accurate record every time a set of measurements are taken?

iii. The purpose of Monitoring of Blood Pressure: The necessity of prior to recording every set of hemodynamic values, evaluate pressure waveforms, verify transducer levels, and ensure that sufficient flush volume and pressure is present. Continuous arterial pressure monitoring is indicated for patients requiring BP monitoring as required, receiving continuous IV infusion of medications that affect cardiac output/blood pressure, requiring frequent blood gas monitoring or who are hemodynamically/neurologically unstable.

iv. The importance of Observation of Monitor Waveforms: Why?

v. The Purpose of Setting & Maintaining Arterial Line Alarms: Appropriate alarms must be set during continuous arterial pressure monitoring. Why and how alarm settings are selected and why? When would an alarm be disabled? Why should documentation include the reason(s) for disabling the alarm and what troubleshooting strategies were employed?

vi. Why Maintain A Closed System: Why must ALL stopcocks must have dead-end (non-vented) luer-lock caps or luer -ock connected infusions, including stopcocks located on transducers. Why are Hemodynamic circuits changed with each new line and when?

vii. How to Obtain Blood Samples & Why: Why must ALL infusion be stopped (introducer, distal and proximal infusions from multiple lines) during blood withdrawal. Why should stopcocks be turned to 45 degrees between syringe changes?

viii. How Often Should Dressings be Changed at the cannulae site?

ix. Why Monitor Arterial Line Site, what are you looking for?

x. How and when do you Remove Arterial Line?

The answers to the above questions then gave an insight to each of the nurse/doctor knowledge and understanding of the subsets of objective tasks: (1) controlling hemodynamics, (2) monitoring trends, (3) interpretation of hemodynamic data, (4) the requirement of intervention and (5) selection of data etc.

Repeatedly, some of the highly experienced CICU nurses in our institution have expressed concerns about their own ability to perform the pulmonary artery wedge pressure, when advancing the pulmonary artery catheter and inflating the balloon at the bifurcation of the pulmonary artery using PACTD method (figure 1). We addressed those concerns, by investigating whether the performance of CICU nurses was as consistent and reliable as that of experienced doctors performing the pulmonary artery wedge pressure when advancing the pulmonary artery catheter and inflating the balloon at the bifurcation of the pulmonary artery and setting the cursor at the mean point of the pulmonary artery wedge pressure waveform, using PACTD method. As part of the same study, we also assessed the nurses’ abilities to learn, use and assess new technologies.

Other nurses were also wary of harming the patient when advancing the catheter or inflating the balloon at the tip of the catheter. Again, these concerns proved unfounded, as no bizarre measurements of the pulmonary artery wedge pressure or adverse events were observed or recorded, either during this part of the study or over the 4-year period of the main study. However, when doctors were asked concerning the relevance of the mean pulmonary artery wedge pressure to that of other hemodynamic variables, for example, the mean central venous pressure or the mean pulmonary artery pressure, there was no clear explanation between those doctors, some said there was no relationship, others said it was a useful measurement to have etc.

To our knowledge, there are no other studies of this nature; however, we surmised that nurses from other institutions may share the concerns expressed by our own nursing staff, when performing PACTD hemodynamic monitoring in CICU patients.

Figure 1 The pulmonary artery catheter in situ (left) and full-size model of the position of the pulmonary artery catheter inside the heart (right)

Figure 2. One of the CICU nurses transporting the HME-dedicated HeartSmart® monitor with the patient en route to the high dependency unit
This prospective, double-blind study was conducted in patients undergoing elective corrective cardiac bypass surgery, necessitating insertion of a pulmonary artery catheter for routine monitoring (Berridge et al 2009; Pandit 2010). We used as a baseline those cardiac index measurements that had been derived during open-heart surgery immediately prior to the patient being transferred to the CICU. These cardiac index estimations were achieved using two different technologies: PACTD, the accepted industry standard, and the empirical physiological formulae embedded in the continuous cardiac dynamic monitoring (CCDM)-HeartSmart® software. CCDM-HeartSmart®, is a new technology that uses empirical physiological algorithms in a computer software program that can perform continuously (Figure 2). CCDM-HeartSmart calculates cardiac index (convertible to cardiac output) using standard physiological variables (central venous pressure, heart rate, mean arterial pressure, height, weight, temperature in °C) that are routinely measured in most intensive care and high-risk surgery patients.

Uniquely, CCDM-HeartSmart® also provides estimates of the mean pulmonary artery and mean pulmonary artery occlusion (capillary wedge) pressures using the data generated from the physiological parameters of core body temperature, mean central venous pressure, heart rate and mean arterial pressure.

Thus, two paired sets of measurements for each hemodynamic variable were obtained, allowing for comparison not only of performance by nurses and doctors, but also of the results obtained by the two technologies. CCDM-HeartSmart® measurements and calculations were included in this study because the pulmonary artery catheter can sometimes migrate away from the 3rd West Zone as the heart beats, resulting in inaccurate left heart pressure values that can confuse the clinical picture, and complicate interpretation of hemodynamic variable measurements. CCDM-HeartSmart® technology does not suffer from this problem (provided that the central venous pressure catheter and arterial lines are properly zeroed); consequently, CCDM-HeartSmart® left heart pressure values can act as a surrogate comparator when comparing all hemodynamic variables in the left side of the heart.

II. METHODS

Institutional ethical approval was obtained and written informed consent was provided by each patient. This study conforms to the Helsinki Declaration.

Participants

Forty-five adult patients undergoing cardiac surgery that necessitated placement of a pulmonary artery catheter took part in the study. Eligible candidates had stable heart rate, central venous pressure, blood pressure and temperature when admitted to the CICU immediately after surgery. The patients had no change in treatment prior to the hemodynamic studies commencing; the first set of studies was conducted as soon as the patient was comfortable and stabilized in the CICU. Twenty experienced CICU nurses (including four ward sisters) from four teams of nurses of mixed grades and experience, all of whom who had been trained to perform PACTD, took part in performing the mean pulmonary artery and mean pulmonary occlusion (wedge) pressures. All participating nurses were taught how to use the HeartSmart® technology during the trial. Twenty doctors of anesthetist and surgeons also participated in this study.
Figure 5  Comparison of pre-bypass CI (l min⁻¹ m⁻²) estimates from PACTD and CCDM-HeartSmart®: difference versus average

Data collection
This was a double blind sub-study: neither the nursing or doctors knew that they were participants in the study of the two technologies being assessed.

The main study design has been reported elsewhere by Berridge et al (2009). Briefly, routine induction of anesthesia and insertion of an arterial line into radial or femoral arteries was followed by placement of a triple lumen central venous catheter and an Edward’s Laboratories™ thermodilution pulmonary artery catheter via the right internal jugular vein. The HeartSmart® computer software was embedded in the LifePulse 400 monitor (2) containing empirical physiological formulae embedded in the CCDM-HeartSmart® software module, the physiological parameters of core body temperature, heart rate, systolic and diastolic blood pressure and mean central venous pressure were fed directly into the LifePulse monitor and were manually entered into the HeartSmart® laptop computer simultaneously (see figures 2 & 3). Patient temperatures were measured from the pulmonary artery catheter, while the electrocardiograph, central venous pressure and arterial pressures were measured using the Philips™ (Guildford, UK) anesthetic monitor. All lines from the Philips™ monitor were branched to the LifePulse 400 monitor loaded and both monitors were calibrated to give the same readings for all physiological parameters in real time, (see 2 & 3).

The anesthetist was blinded to the Life Pulse 400 monitor screen, the author was blinded to the Phillips monitor screen, until both investigators had printed out the results, each investigator then signed off the others results immediately, preserving the integrity of the study.

Nurses on the CICU performed PACTD cardiac output estimation by injecting a bolus of 10 ml saline at room temperature into the right atrial lumen of the pulmonary artery catheter, in accordance with accepted practice. The nurses are trained to make three initial, consecutive measurements, and all three have to lie within 10% of each other; if this does not occur, a further two measurements are taken and the average of the closest three recorded. If, over five estimates of cardiac index, there were not three measurements within 10% of each other, then the measurements were discarded. Systolic and diastolic blood pressures, mean central venous pressure, and mean pulmonary artery and pulmonary artery occlusion (wedge) pressures were recorded at the start of each set of cardiac index estimations.

Cardiac index estimations were made from six sets of measurements from each individual patient; two were taken immediately prior to going on bypass and four after re-warming when coming off bypass. Pre-bypass and post-bypass data were analyzed separately to see if the results were consistent and repeatable. Two sets of post-bypass hemodynamic measurements were recorded from each patient by experienced CICU nurses to evaluate how closely these measurements matched those performed in the operating theatre by the consultant intensivist and cardiothoracic anesthetists prior to the patient being transferred to the CICU. The recording of the second set of comparative measurements was performed when required as part of the patient’s treatment. The author observed and recorded as the nurses performed each set of hemodynamic measurements and, a few minutes later, observed and recorded as the CICU physician or anesthetist performed the second or third set of measurements of the three hemodynamic measurements required to obtain the average or mean values of the same patient. The nurse or doctor signed off the PACTD values against HeartSmart® values at the end of the procedure. The patients were physiologically stable throughout this period, though their fluid treatment regimens had not changed since admission onto the CICU.

Figure 6  Comparison of post-bypass CI (l min⁻¹ m⁻²) estimates from PACTD and CCDM-HeartSmart®: difference versus average

CCDM, continuous cardiac dynamic monitoring; CI, cardiac index; PACTD, pulmonary artery catheter thermodilution. Solid line, mean bias; dashed lines, 95% limits of agreement; filled solid lines, potential outliers
Table 1 Comparison of measurements recorded by nurses and physicians

<table>
<thead>
<tr>
<th>Repeatability of test methods</th>
<th>Recorded results</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Nurses</td>
<td>Physicians</td>
</tr>
<tr>
<td>Mean of differences</td>
<td>0.25 l min⁻¹ m⁻²</td>
<td>0.12 l min⁻¹ m⁻²</td>
</tr>
<tr>
<td>Limits of agreement</td>
<td>-1.27 to 1.32 l min⁻¹ m⁻²</td>
<td>-1.32 to 1.56 l min⁻¹ m⁻²</td>
</tr>
<tr>
<td>MPAO or MPWP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean of differences</td>
<td>-1.38 mmHg</td>
<td>1.34 mmHg</td>
</tr>
<tr>
<td>Limits of agreement</td>
<td>-9.1 to 6.35 mmHg</td>
<td>-7.67 to 4.98 mmHg</td>
</tr>
<tr>
<td>MPAP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean of differences</td>
<td>0.85 mmHg</td>
<td>1.03 mmHg</td>
</tr>
<tr>
<td>Limits of agreement</td>
<td>-7.59 to 5.84 mmHg</td>
<td>-8.38 to 6.22 mmHg</td>
</tr>
</tbody>
</table>

Data analysis

The mean values of three PACTD cardiac output estimates were used (provided that each measurement lay within 10% of the others), and were then compared with the HeartSmart® estimates. These comparisons were then analyzed by repeatability of tests within 95% limits of agreement, using the adaptation for repeated pairs of observations (Bland and Altman 2007). The repeatability of this method was assessed by both authors of the current study, who analyzed all clinical trial data reported in this paper (including outlying plots). All calculations were performed using StatsDirect (StatsDirect Ltd., Altrincham, UK). The significance of the bias was tested using a paired t-test on the mean bias for each patient.

III. RESULTS

Of 45 patients included, 34 were male (mean age, 67.8 [range 48–83] years) and 11 were female (mean age, 65.8 [range, 49–75] years). Each patient had six sets of measurements of each hemodynamic variable (pre- and post-bypass), giving a total of 270 paired sets of full, valid sets of measurements for cardiac index, mean pulmonary artery pressure (MPAP), and mean pulmonary artery occlusion pressure (MPAOP). A total of 810 PACTD measurements were recorded for comparison.

We then selected 16 (36%) patients who were physiologically stable upon admission to the CICU. Scattergrams of the recorded hemodynamic values used for statistical analysis are shown in Figures 5–8. In each case, the assumption that the mean difference and the standard deviation of the differences are unrelated to the magnitude of the measurement seems quite plausible for these data. No transformation of the variables was required. For the pre-bypass cardiac index the two methods are highly related to one another, with limits of agreement of -1.26 to 1.08 l min⁻¹ m⁻² and a mean bias of -0.09 l min⁻¹ m⁻² (p=0.3). Hence, for 95% of measurements, CCDM-HeartSmart® would be closer than 1.26 l min⁻¹ m⁻² above or 1.08 l min⁻¹ m⁻² below the PACTD measurement.

The limits of agreement for post-bypass cardiac index (Figure 6) were -1.32 to 1.56 l min⁻¹ m⁻², with a mean bias of 0.12 l min⁻¹ m⁻² (p=0.1). For the pre-bypass mean pulmonary artery occlusion pressure (Figure 7), the 95% limits of agreement were -9.36 to 7.74 mmHg, with a mean bias of -0.91 mmHg (p=0.0002). For post-bypass mean pulmonary artery occlusion pressure (Figure 8), the 95% limits of agreement were -7.67 to 4.98 mmHg, with a mean bias of -1.34 mmHg (p=0.0008).

Scattergrams of the analysis for the nurses’ hemodynamic results are shown in Figures 9–11. Again, in each case, the assumption that the mean difference and the standard deviation of the differences are unrelated to the magnitude of the measurement seems quite plausible, and no transformation of the variables was required. Therefore, for 95% limits of agreement for each hemodynamic measurement, CCDM-HeartSmart® provided cardiac index values of 1.27 l min⁻¹ m⁻² to 1.32 l min⁻¹ m⁻², with a mean of the differences (or bias) of 0.53 l min⁻¹ m⁻². For the mean pulmonary artery occlusion pressure (Figure 7), the 95% limits of agreement were -9.1 to 6.35 mmHg, with a mean bias of -1.38 mm Hg. For the mean pulmonary artery pressure, the 95% limits of agreement were -7.59 to 5.84 mmHg, with a mean bias of -0.85 mmHg (Figures 9–11).

Table 1 shows a comparison of nurses’ and physicians’ measurements of hemodynamic values recorded using PACTD and HeartSmart®. There was a difference of 48% between the measurements for cardiac index; this difference was of little or no significance, as the values of the bias were small overall. The difference between measurements of mean pulmonary artery pressure (17.5%) was also small and perfectly acceptable (Pinsky and Vincent 2005), as was the difference between measurements for mean pulmonary artery occlusion (or wedge) pressure (2.9%). These results show that the hemodynamic studies performed by nurses on patients admitted to the CICU after open-heart surgery are consistent and repeatable.

There were five plots with only one outlier (solid plot) in the pre-bypass cardiac index group (Figure 5); there does not appear to be an explanation for this outlier. There were seven plots outside the plus or minus dashed lines representing 95% repeatability of test methods, and one outlier in the post-bypass group (Figure 6). We conclude that, for the first set of measurements after surgery, the PACTD thermistors had not warmed up sufficiently after the patient had been re-warmed and brought off bypass. There was a total of 13 plots for MPAP that could initially be considered as outliers (Figures 7 and 8): six plots in the pre-bypass group (Figure 7), only two of which are considered true outliers; and seven plots in the post-bypass group (Figure 8), none of which would be considered as proper outliers. One explanation for these outliers would be that HeartSmart® is measuring changes dynamically in “real time”, whereas PACTD is only measuring in “window snapshots”. Of 32 plots in Figure 9, none can be considered true outliers, and 1.6 plots outside of the +/- 2 standard deviation lines would be expected. In Figure 10 there is 1 plot, and in Figure 11 there are 3 plots, none of which are considered to be
true outliers as they are just outside the standard deviation values. Figures 9–11 show that the nurses’ measurements compare favorably with those made by physicians (Figures 5–9). The plots are relatively similar in distribution, and are also similar with regard to the numbers of plots outside the scattergrams and the number of these plots that are outliers requiring further investigation (Table 1).

Table 2 Examples of Maternity Care Required at ICS Levels of Support for Critical Care

<table>
<thead>
<tr>
<th>Level of Care Maternity Example</th>
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<tbody>
<tr>
<td><strong>Level 0:</strong> normal ward care, care of low risk mother</td>
</tr>
<tr>
<td><strong>Level 1:</strong> Additional monitoring or intervention, or step down from higher level of care</td>
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<tr>
<td>» » Risk of hemorrhage</td>
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<tr>
<td>» » Oxytocin infusion</td>
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<tr>
<td>» » Mild pre-eclampsia on oral anti-hypertensives/ fluid restriction etc</td>
</tr>
<tr>
<td>» » Woman with medical condition such as congenital heart disease, diabetic on insulin infusion</td>
</tr>
<tr>
<td><strong>Level 2:</strong> single organ support Basic Respiratory Support (BRS)</td>
</tr>
<tr>
<td>» » 50% or more oxygen via face-mask to maintain oxygen saturation</td>
</tr>
<tr>
<td>» » Continuous Positive Airway Pressure (CPAP), Bi-Level Positive Airway Pressure (BIPAP)</td>
</tr>
<tr>
<td>Basic Cardiovascular Support (BCVS)</td>
</tr>
<tr>
<td>» » Intravenous anti-hypertensives, to control blood pressure in pre-eclampsia</td>
</tr>
<tr>
<td>» » Arterial line used for pressure monitoring or sampling</td>
</tr>
<tr>
<td>» » CVP line used for fluid management and CVP monitoring to guide therapy</td>
</tr>
<tr>
<td>Advanced Cardiovascular Support (ACVS)</td>
</tr>
<tr>
<td>» » Simultaneous use of at least two intravenous, anti-arrhythmic/ anti-hypertensive/ vasoactive drugs, one of which must be a vasoactive drug</td>
</tr>
<tr>
<td>» » Need to measure and treat cardiac output</td>
</tr>
<tr>
<td>Neurological Support</td>
</tr>
<tr>
<td>» » Magnesium infusion to control seizures (not prophylaxis)</td>
</tr>
<tr>
<td>» » Intracranial pressure monitoring</td>
</tr>
<tr>
<td>» » Hepatic support</td>
</tr>
<tr>
<td>» » Management of acute fulminant hepatic failure, e.g. from HELLP syndrome</td>
</tr>
<tr>
<td>or acute fatty liver, such that transplantation is being considered</td>
</tr>
<tr>
<td><strong>Level 3:</strong> advanced respiratory support alone, or support of two or more organ systems above</td>
</tr>
<tr>
<td>Advanced Respiratory Support</td>
</tr>
<tr>
<td>» » Invasive mechanical ventilation</td>
</tr>
<tr>
<td>Support of two or more organ systems</td>
</tr>
<tr>
<td>» » Renal support and BRS</td>
</tr>
<tr>
<td>» » BRS/BCVS and an additional organ supported*</td>
</tr>
<tr>
<td>*a BRS and BCVS occurring simultaneously</td>
</tr>
</tbody>
</table>

IV. DISCUSSION

Bedside measurement of hemodynamic variables is the keystone of general management in patients undergoing corrective heart surgery or in the treatment of other serious medical pathologies. There is a global need for a portable, accurate, rapid, simple, safe and relatively inexpensive method to determine cardiac output/index and other hemodynamic variables, not only in cardiac surgery patients, but also in many different populations where perioperative care necessitates aggressive treatment protocols, early goal-directed therapies, and fluid resuscitation etc.

One such area is the management and provision of the providing equity of critical and maternity care for the critically ill pregnant or recently pregnant woman. (Royal College of Obstetricians & Gynaecologists 31:07:2011) and (JICS Volume 14, Number 2, April 2013 Obstetric Anesthetists Association.) Maternal critical care is an area which is less discussed than other parts of obstetric, midwifery and critical care practice. The diagnoses precipitating admission to critical care are predictable and include massive hemorrhage (>2,500ml loss), eclampsia, sepsis, thromboembolism, acute organ dysfunction (renal, hepatic, cardiac, respiratory, neurological) and anesthesia-related morbidity such as aspiration, anaphylaxis and muscle relaxant-related problems etc. Notwithstanding those complications the most common cause of death in the critically ill pregnant mother and unborn child is cardiac arrest. In the UK, sepsis is now the leading cause of direct maternal death according to Centre for Maternal and Child Enquiries (CMACE).

Pregnant women are vulnerable to infection and their pregnant state increases their risk of developing serious complications from an infection. Worldwide, infection and the complications of sepsis are among the most common causes of severe maternal morbidity and mortality.

Early goal directed therapy guided by bedside hemodynamic monitoring, has been shown to be beneficial in reducing premature death as a consequence of sepsis –shock, in surgical and medical pathologies (see table 5).

The next question that arises what is maternal care? Maternal critical care, high dependency care and high-risk maternity care are not interchangeable, the term critical care having a more precise definition. The UK Department of Health document ‘Comprehensive Critical Care’ recommends that the terms ‘high dependency’ and ‘intensive care’ be replaced by the term ‘critical care’, also proposes that the care required by an individual be independent of location, coining the phrase ‘critical care without walls’. Within the term, care is subdivided into four levels, dependent on organ support and the level of monitoring required independent of diagnosis.

Table 3 Nurses & Doctors Response to Questions on the Management of Invasive Arterial Lines

<table>
<thead>
<tr>
<th>Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nurses</td>
<td>20</td>
<td>20</td>
<td>19</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>20</td>
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<tr>
<td>Doctors</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>19</td>
<td>19</td>
<td>17</td>
<td>20</td>
<td>16</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Definition of Levels of Care

**Level 0** Patients whose needs can be met through normal ward care.
Level 1 Patients at risk of their condition deteriorating and needing a higher level of observation or those recently relocated from higher levels of care.
Level 2 Patients requiring invasive monitoring/intervention that includes support for a single failing organ system (excluding advanced respiratory support).
Level 3 Patients requiring advanced respiratory support (mechanical ventilation) alone or basic respiratory support along with support of at least one additional organ. The nature of organ support is captured using the Critical Care Minimum Dataset (CCMDS). Any area which satisfies the Department of Health definition for Critical Care setting, will qualify for submission of data.

The role of nurses/doctors in managing routine administration of fluids to all types of surgical and medical patients differs from country to country, as does their training, duties and responsibilities; however, the outcome of this study may well be of international interest.

Cardiovascular Physiology Changes during Pregnancy in Relation to Sepsis-Septic Shock.

There are a number of cardio-dynamic and physiological changes that occurs during pregnancy. As these changes take place there is an increased risk and susceptibility to infection or the consequences of those cyclic alternating changes. In the first trimester of pregnancy, the circulation becomes hyperdynamic (high blood flow) the demand for oxygen becomes greater, with a reduced systemic and peripheral vascular resistance, respectively. Maternal cardiac output may increases steadily as a result of increased venous return, heart rate and stroke volume, reaching a peak of 30-50% above pre-pregnant normal values within approximately 30 weeks gestation. A 40% increase in blood volume occurs, reaching a maximum peak at 32 weeks gestation.

The heart may now become even more severely compromised as the increasing stress of normal pregnancy progresses. Should the pregnant woman develop sepsis –shock due to infection for example, then the heart and blood flow will increase as a result of the sepsis-shock, and if the mean arterial blood pressure which tends to fall as the systolic blood pressure falls below 90mmHg, increasing cardiac output but reducing oxygen supply and demand to the cells, thus the cells are unable to meet the metabolic demands, resulting in release of catecholamines with a further reduction in systemic and peripheral vascular resistance respectively, due to vasodilation and myocardial depression, which then may result myocardial infarction, in this vicious circle of events. Additionally, in normal pregnancy, there is a reduction in serum albumin, which affects colloid osmotic pressure making women more vulnerable to pulmonary edema that can cause congestive cardiac failure to occur.

It therefore becomes obvious, that obstetric nurses and medical staff should be trained to be as skilled as the CICU nurses, in performing bedside hemodynamic monitoring, when the critically ill pregnant or recently pregnant woman condition is so dangerously compromised, potentially a life or death scenario of mother and child. Measuring cardiac output as part of an early goal-directed therapy protocol and perioperative care can lead to real cost savings and better care.
Table 4 Categories of CICU Nurses Knowledge of Hemodynamic Monitoring Performance of Tasks

- Controlling hemodynamics
  - Titrating medications and intravenous fluids to achieve a physiological aim, for example goal directed therapy of the surgically corrected heart.
  - Dynamic nature of goals oxygen supply and demands etc.
  - Predicting the effects of treatments on other systems if necessary.

- Monitoring trends:
  - Available trend functions not routinely used are clinically more useful than single sets of measurements, efficacy of the hearts performance of drug regime etc.
  - Need to visualize and chart interrelationships between interventions and physiological trends, indicating the patients prognosis etc.
  - Defaulting to memory for trend assessment
  - Multiple data displays and output devices

- Data interpretation
  - Applying meaning to the hemodynamic variables and cardiodynamics
  - Visualizing the full clinical picture
  - Understanding interrelationships between hemodynamic variables and symptoms
  - Diagnostic responsibilities if any
  - Time constraints to correct hemodynamic variables

- Independent interventions
  - Decision to intervene is based on interpretation of hemodynamic data when?
  - Anticipating the needs of the health care team during emergent situations
  - Scope of independence practice depends on the institution and level of experience

- Selective data acquisition
  - Selecting the relevant data for each patient depending upon the patients condition.
  - Limited by ability to understand and/or conceptualize hemodynamic variables, what do they really mean?

- Using current technologies
  - Institutions have difficulty keeping up with technological advances, CICU nurses play an important role in testing new technologies on performance, friendly and making nursing easier etc.
  - Trusting the accuracy of computer acquired data

Importantly, this strategy has also been shown to achieve many benefits for the patient in terms of reducing length of stay in special or intensive care units, faster healing with a better prognosis, and reducing both mortality and morbidity in certain groups of intensive care patients (including those with sepsis) 30 days after discharge (Donati et al 2007; Hadian and Pinsky 2006; Pearse et al 2005; Rivers et al 2001; Warring-Davies and Bland 2010). Experienced nurses trained to perform hemodynamic studies have an enormous role in monitoring fluid management, and this role can be fulfilled most effectively when best practice is in place, resulting in clinical excellence and potential economic benefits (Angus et al 2001; Chen et al 2010; Huang et al 2007; Lundberg et al 1998; Society of Critical Care Medicine 1999; Warring-Davies and Bland 2010).

It follows then, that obstetric and gynecology nurses are just one of many groups of nurses, that could be taught to become as equally skilled as our intensive care cardiac nurses in hemodynamic monitoring and fluid resuscitation of the pregnant mother, reducing the risk of the number of premature deaths of mother and child, caused by the complications of the pregnancy, rather than the pregnancy itself! PACTD maybe overly invasive for the information that it provides, so it is important to establish whether less invasive alternatives are equally accurate and precise (Pinsky and Vincent 2005; Tibby and Murdoch 2003). This sub-study used a well-validated method (Bland and Altman 2007) to compare PACTD with HeartSmart®; the 95% limits of agreement analysis assesses how closely two methods of measurement of a variable agree, and the means of the differences are an estimate of the average bias of PACTD relative to that of CCDM-HeartSmart®.

The results showed good correlation between the two groups of variables; data collected before and after cardiopulmonary bypass showed that the 95% limits of agreement and the mean bias were statistically sufficiently close across the full range of cardiac index and mean artery occlusion pressures observed, thus suggesting that CCDM-HeartSmart® is comparable to PACTD at estimating cardiac index and other hemodynamic variables. Those studies performed by the CICU cardiac nurses also confirmed these findings (Table 1). The results of this study are comparable to those obtained from other groups of ICU patients, especially those patients suffering from sepsis-shock, demonstrating that CCDM-HeartSmart® can be used interchangeably with, or in place of, PACTD. CCDM-HeartSmart® thus allows for intervention goal-directed therapy not only for those patients after major surgery but for those patients with medical pathologies, also at the highest risk of mortality and morbidity in hospital or within 30 days of discharge from hospital. CCDM-HeartSmart® may also be useful in helping to monitor achievement of the physiological targets for “goal-directed therapy in early sepsis” as recommended by Rivers et al (2001).

Figure 9 Differences between nurses’ measurements of PACTD MCI and HSCI: results of paired t test.
HCl, HeartSmart® cardiac index; MCI, measured cardiac index; PACTD, pulmonary artery catheter thermodilution. Mean of differences, 0.025 l min⁻¹ m⁻²; standard deviation, 0.66 l min⁻¹ m⁻²; standard error, 0.12 l min⁻¹ m⁻²; 95% limits of agreement, –1.27 to 1.32 l min⁻¹ m⁻².
One potential limitation of this methodology is the degree of error in measured cardiac output that is often observed when using PACTD in clinical practice. This degree of error depends on the temperature and volume of inject, timing of injection with respiration, speed of injection of inject, hypothermia, and low cardiac output (Hadian and Pinsky 2006; Harvey et al 2005; Nishikawa and Dohi 1993; Stetz et al 1982). We and the nurses/doctors took great care to avoid these major sources of error.

The CCDM-HeartSmart® provides comparable results to that of the pulmonary artery catheter thermodilution method of all the hemodynamic variables, in those patients with or without stable hemodynamics, especially those sepsis septic patients. CCDM-HeartSmart® has a short learning curve, whether a junior nurse or doctor or for experienced skilled nurses/doctors, it takes a few hours to master using the CCDM-HeartSmart® bedside hemodynamic monitor. CCDM-HeartSmart® friendly to use, especially if the external jugular venous pressure is assessed using ultrasound as a surrogate for the mean central or right atrial pressures etc.

**Table 5 Clinical features of severe sepsis-shock**

1. Hypotension
2. Arterial hypoxemia
3. Raised lactate
4. Acute oliguria (urinary output < 0.5 ml/kg/h)
5. Deranged renal function
6. Deranged liver function
7. Altered mental status
8. Coagulation abnormalities
9. Hyperglycemia in absence of diabetes
10. Abnormal electrolytes etc.

Our primary result is that these CICU nurses are as capable as any member of the medical staff when performing cardiac output measurements using PACTD. We also found that PACTD measurements are in good agreement with those derived from CCDM-HeartSmart®. When measuring the mean pulmonary artery occlusion (wedge) pressure using PACTD, some nurses were concerned about their ability to accurately place the pulmonary artery catheter in West Zone 3, while others questioned whether they were accurately placing the cursor to get the correct pressure values.

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**Figure 10 Differences between nurses’ measurements of MPAP and HSPAP: results of paired t test for PACTD versus CCDM-HeartSmart®.**

CCDM, continuous cardiac dynamic monitoring; HSPWP, HeartSmart® mean pulmonary artery occlusion (wedge) pressure; MPWP, mean pulmonary wedge pressure; PACTD, pulmonary artery catheter thermodilution. Mean of differences, –1.38 mmHg; standard deviation, 3.94 mmHg; standard error, 0.70 mmHg; 95% limits of agreement, –9.1 to 6.35 mmHg.

**V. CONCLUSIONS**

Specialized CICU nurses are as competent as any member of the medical staff in performing hemodynamic measurements using PACTD. The study also showed that CICU staff are keen to understand new technologies, such as CCDM-HeartSmart®, and are prepared to give an unbiased opinion of that technology during evidenced based clinical trials.

In the management and provision of the providing equity of critical and maternity care for the critically ill pregnant or recently pregnant woman, those nurses and doctors can be taught to perform bedside hemodynamic monitoring of critically ill pregnant mother, of which many mothers prematurely die due to cardiac pathologies, as a result of the complications of the pregnancy and the anatomical difficulties of the developing child in the womb, restricting the use of...
invasive placement of hemodynamic central catheters and esophageal probes required by those bedside hemodynamic monitors.

CCDM-HeartSmart is proving to overcome many of the existing difficulties, indeed in the area of the management and provision of the equating of critical and maternity care for the critically ill pregnant or recently pregnant woman. The measurement of the external jugular venous pressure by way of ultrasound can be used as a surrogate for the mean central venous pressure in the CCDM-HeartSmart empirical physiological formula to calculate the cardiac index in l/min/m2.

The CCDM-HeartSmart then becomes a entirely non – invasive bedside hemodynamic monitoring system.

VI. ACKNOWLEDGMENTS

With special gratitude to the patients and the patients’ relatives who gave kind permission to allow the pulmonary artery catheter to be photographed in situ, and who gave unlimited rights of ownership to the first author to publish and use this photograph unconditionally. Our thanks go to all the patients, doctors and nurses who took part in this study. We would also like to thank Julie Smith for editorial assistance in the preparation of parts of this manuscript. Professor John Martin Bland reviewing the medical statistics of this study: Department of Health Sciences, Sebohm Rowntree Building, University of York, Heslington, York, YO10 5DD, UK

Financial support for this assistance was provided entirely by the author. Dr. Kenneth Warring-Davies is the inventor of the patented and trademarked continuous cardiac dynamic monitor empirical physiological formulae known as CCDM-HeartSmart®. This work is self-financed and no financial support has been received in connection with CCDM-HeartSmart®. There were no financial gifts or payments made to any institution or party in the performance of this clinical study.

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