# Cardiopulmonary Monitoring in Thai ICUs (ICU-RESOURCE I Study)

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***Objective:*** *Cardiopulmonary monitoring (CPM) is rapidly progressing but data regarding CPM in Thai ICUs was unavailable. The objective of this study was to describe the situation, and gaps of CPM in Thai ICUs.*
***Material and Method:*** *Data were retrieved from the ICU-RESOURCE I study database survey. CPM was divided into two aspects of device and measurement methods. These were categorized by device availability grading (AG), device availability per bed (DPB) and numeric frequency grading scale (FGS). Device availability was compared between academic and non-academic ICUs. Gap analysis of DPB and FGS was performed. Statistical significant difference was defined as p-value<0.05.*
***Results:*** *One hundred and fifty-five ICUs across Thailand participated in this study. Academic ICUs had significantly more devices available in new equipment with p<0.05 (Vigilio, PiCCO, NICOM, esophageal pressure monitoring, transcutaneous* $PO_2$*, electrical impedance tomography of lung) as well as measurement methods (stroke volume variation [SVV], pulse pressure variation [PPC], central venous oxygen saturation [*$ScvO_2$*], lung mechanics). Most of new and higher technological devices had low density and few were available in all of Thai ICUs. However, in gap analysis, although these new devices and measurement techniques were available in ICUs, they were not frequently utilized.*
***Conclusion:*** *New technology devices of CPM had more availability in ACAD than in non-ACAD ICUs. Formal continuous training in new measurement methods should be established for reducing the availability and utilization gap (Thai Clinical Trial Registry: TCTR-201200005).*

***Keywords:*** *Cardio-pulmonary monitoring, Thai ICUs, Utilization gap, Frequency level, Device availability*

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Cardiopulmonary monitoring is one of the most important pillars of critical care medicine. Measured data from various types of monitoring devices have the goals for rapid detection, early intervention and taking the appropriate actions for the patient. The ability to correlate measured data and physiologic knowledge yields better outcomes; which is a critical part of patient care. Furthermore, recent development of highly technical monitoring devices as well as the revolution of more accurate measurement methods has been proposed[1-6]. However, there were no data regarding these monitoring reformations in Thailand. The objective of the present study was to identify the monitoring situations and gaps of cardiopulmonary monitoring in Thai ICUs.

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## Material and Method

A cross sectional data survey was performed by the ICU-RESOURCE I study record form which was developed by a research sub-committee of the Thai Society of Critical Care Medicine (TSCCM). The present study protocol was registered in Thai Clinical Trial Registry with reference number TCTR-201200005.

The survey focused on the following four major aspects: ICU structures, human resources and burden, outcomes and equipment. For the equipment or monitoring in this survey, the types of monitoring were combined but could be divided into two major parts which were cardiopulmonary monitoring (CPM) and non-cardiopulmonary monitoring (non-CPM). These reported results concentrate on CPM. The study protocol was approved by the Ethics Committee, Faculty of Medicine, Chiang Mai University.

The monitoring system record was separated into two parts including devices available and methods of measurement. Of these, two subdivisions were categorized as cardio-hemodynamic monitoring and pulmonary-gas-exchange monitoring devices. Detailing of these devices was demonstrated in Table 2.

***Definition terms and statistical analysis***

Hospital types were divided by academic activity and number of beds. Therefore, the hospital types were categorized into four major groups including general (less than 500 beds), regional (more than 500 beds), academic (teaching hospital) and private hospitals. The first three hospital types belong to the Thai government.

Academic hospital (ACAD) was defined as the hospitals which have training programs for the undergraduate level and postgraduate level (resident and fellowship). Most of hospitals in this group are university-based hospitals.

Availability grading (AG) was the level of devices available at the cross sectional time. Availability was calculated by dividing the percentage of number of ICUs in which devices could be found by all of the participating ICUs. AG was categorized into six groups in the present study (0%, none; <10% rarely; 10-19.9% few; 20-49.9% moderate; 50-79.9% common; >80% abundance).

Numeric frequency grading scale (FGS) was the simple subjective recalling measurement method to evaluate equipment utilization by ICU personal. Because of no standard determination, this grading was initiated by the TSCCM research subcommittee for grading frequency of monitoring usage. FGS was a value to compare utilization among ICU units in the present study (Table 1).

Device availability per bed (DPB) was the device density evaluation in ICU. DPB was calculated by dividing the number of devices by the number of ICU beds (= number of devices/number of bed). These values were divided into four ordinal levels (0, none; <0.3, low density; 0.31-0.69, medium density; $\geq$0.70, high density).

STATA software (version 11.0, STATA Inc., College Station, TX) was used in this study. All continuous variable data were tested for normal distribution and they were reported as mean $\pm$ SD if they had normal distribution or median (25-75 inter-quartile range [IQR]) for non-parametric distribution. Group differences of the two samples were calculated using Pearson's Chi-square for categorical variables.

**Table 1.** Definition of numeric frequency grading scale (FGS) in this study

| Frequency | Grading | Level |
|---|---|---|
| None | 0 | Never |
| More than one month | 1 | Sometimes |
| At least one month | 2 | |
| At least two weeks | 3 | |
| Every week | 4 | Usually |
| A few day (1-3 days) | 5 | |
| Every day but some patient | 6 | Always |
| Every day and every patient | 7 | |

**Results**

One hundred and fifty-five ICUs participated in this survey. The period of study was between March and August, 2012. The data were collected from all regions in Thailand. Nearly 90 percent of participating ICUs were located in government hospitals. Nearly one-fourth (23.3%) were academic ICUs. Two-thirds of ICUs (65.8%) were government and affiliated service hospitals (general and regional level hospital).

Both LiDCO® system (LiDCO®) and Extravascular Lung water devices (ELW) were not found in participating ICUs (Table 2). ACAD had significantly more devices available than non-ACAD with many cardiac output monitoring devices including Vigilioeleo-Flo Tract (Vigilio), PiCCO® system (PiCCO®), Non-invasive cardiac output monitoring (NICOM®) and thermodilution from pulmonary catheter (PAC-thermodilution). No differences were found for some non-invasive cardiac output monitoring devices including Doppler ultrasound cardiac monitoring (USCOM®), Transthoracic echocardiography (TTE), Transeso-phageal echocardiography (TEE) and Pleth variability index devices e.g. Masimo rainbow® (PVI).

There were significantly more new pulmonary and gas exchange devices including esophageal pressure monitoring (Eso-P), Transcutaneous $PO_2$ ($PtcO_2$), Transcutaneous $PO_2$ ($PtcO_2$) and Electrical impedance tomography of lung (EIT) discovered in ACAD than in non-ACAD ICUs. However, the simple monitoring devices of end tidal $CO_2$ ($ETCO_2$) also had more availability in the ACAD ICUs.

In measurement methods, the ACAD had a higher performance on invasive monitoring such as Arterial catheter pressure (ABP), central venous

**Table 2.** Device availability between non-academic and academic hospital

| Monitoring | All n = 155 | Non-ACAD n = 119 | ACAD n = 36 | p-value |
|---|---|---|---|---|
| Cardio-Hemodynamic Devices | | | | |
| Continuous electrocardiography (Continuous ECG)* | 133 (85.81) | 100 (84.03) | 33 (91.67) | 0.25 |
| 12-lead electrocardiography device (12 lead ECG)* | 127 (81.94) | 97 (81.51) | 30 (83.33) | 0.80 |
| Vigilio-Flo Tract (Vigilio) | 20 (12.90) | 7 (5.88) | 13 (36.11) | <0.01 |
| PiCCO® system (PiCCO®) | 6 (3.87) | 1 (0.84) | 5 (13.89) | <0.01 |
| LiDCO® system (LiDCO®) | NA | NA | NA | NA |
| Doppler ultrasound cardiac monitoring (USCOM®) | 17 (10.97) | 11 (9.24) | 6 (16.67) | 0.21 |
| Transthoracic echocardiography (TTE) | 29 (18.71) | 19 (15.97) | 10 (27.78) | 0.11 |
| Transesophageal echo (TEE) | 13 (8.39) | 9 (7.56) | 4 (11.11) | 0.50 |
| Intra-aortic balloon pump (IABP) | 25 (16.13) | 16 (13.45) | 9 (25.00) | 0.10 |
| Non-invasive cardiac output monitoring (NICOM®) | 7 (4.52) | 2 (1.68) | 5 (13.89) | <0.01 |
| Pleth variability index devices e.g. Masimo rainbow® (PVI) | 3 (1.94) | 1 (0.84) | 2 (5.56) | 0.07 |
| Devices could monitor continuous pressure monitoring e.g. ABP, PAP, CVP, ICP (Pressure-monitoring) | 78 (50.32) | 45 (37.82) | 33 (91.67) | <0.01 |
| Devices could calculate cardiac output from thermodilution techniques from PA cath (PAC-thermodilution) | 31 (20.00) | 9 (7.56) | 22 (61.11) | <0.01 |
| Devices could demonstrate auto calculated PPV, SPV, SVV from main monitoring systems (PPV-SPV-SVV device) | 21 (13.55) | 7 (5.88) | 14 (38.89) | <0.01 |
| Pulmonary and Gas-exchange Devices | | | | |
| Esophageal pressure monitor (Eso-P) | 2 (1.30) | 0 (0.00) | 2 (5.56) | 0.01 |
| Extravascular lung water devices (ELW) | NA | NA | NA | NA |
| End tidal $CO_2$ ($ETCO_2$)* | 79 (50.97) | 53 (44.54) | 26 (72.22) | <0.01 |
| $SpO_2$ devices ($SpO_2$)* | 105 (67.74) | 82 (68.91) | 23 (63.89) | 0.57 |
| Transcutaneous $PO_2$ ($PtcO_2$) | 4 (2.58) | 1 (0.84) | 3 (8.33) | 0.01 |
| Intra-unit blood gas analysis machine (ABG-analysis) | 33 (21.29) | 23 (19.33) | 10 (27.78) | 0.28 |
| Ventilator machines could demonstrate respiratory waveform (Resp-wave) | 122 (78.71) | 92 (77.31) | 30 (83.33) | 0.44 |
| Ventilator machines could calculated lung mechanic (Lung-Mech) | 70 (45.16) | 52 (43.70) | 18 (50.00) | 0.51 |
| Electrical impedance tomography of lung (EIT) | 2 (1.29) | 0 (0.00) | 2 (5.56) | 0.01 |
| Measuring methods | | | | |
| Manual blood pressure device (Manual BP)* | 153 (98.71) | 117 (98.32) | 36 (100.00) | 0.43 |
| Automate blood pressure (Automate BP)* | 115 (74.19) | 86 (72.27) | 29 (80.56) | 0.32 |
| Arterial catheter pressure (ABP) | 82 (52.90) | 50 (42.02) | 32 (88.89) | <0.01 |
| Central venous pressure (CVP) | 119 (76.77) | 86 (72.27) | 33 (91.67) | 0.02 |
| Wedge pressure (PAOP) | 42 (27.10) | 20 (16.81) | 22 (61.11) | <0.01 |
| Stroke volume variation (SVV) | 16 (10.39) | 4 (3.36) | 12 (33.33) | <0.01 |
| Plethysemographic variability index (PVI) | 6 (3.87) | 4 (3.36) | 2 (5.56) | 0.55 |
| Pulse pressure variation (PPV) | 25 (16.13) | 10 (8.40) | 15 (41.67) | <0.01 |
| Continuous $ScvO_2$ monitoring ($ScvO_2$) | 21 (13.55) | 9 (7.56) | 12 (33.33) | <0.01 |
| Continuous $SvO_2$ monitoring ($SvO_2$) | 23 (14.84) | 16 (13.45) | 7 (19.44) | 0.37 |
| Basic lung mechanic measurements (Lung-mech) | 26 (16.77) | 13 (10.92) | 13 (36.11) | <0.01 |
| Electrical impedance topography (EIT) | 1 (0.65) | 0 (0.00) | 1 (2.78) | 0.07 |

* Basic cardio-pulmonary monitoring
ACAD = academic ICUs; Non-ACAD = non-academic ICUs

pressure (CVP), wedge pressure (PAOP), stroke volume variation (SVV), pulse pressure variation (PPV) and continuous $ScvO_2$ monitoring ($ScvO_2$). ACAD also had significantly more basic mechanical lung measurements

(Lung-mech) than non-ACAD ICUs.

The basic available CPM devices in ICUs (common and abundance) shown on Table 3 included continuous and 12 lead ECG, SpO2, manual BP, automated BP, pressure monitoring, resp-wave, CVP and ABP. Higher technology or recent equipment including PiCCO®, TEE, PVI, NICOM®, Vigilio®eleo, USCOM®, TTE, IABP, PPV-SPV-SVV device, Eso-P, $PtcO_2$, EIT and ABG-analysis were categorized as rare and very few available grades in this survey. Most of the density of devices were similar to device availability. There were fewer high technology and lower density devices than basic CPM devices in non-ACAD ICUs (Table 4).

For frequency level in Table 5, Continuous ECG, ABG-analysis, $SpO_2$, Resp-wave and Automate BP were always used in ICU patients. Hemodynamic measurement parameters of CVP and SVV were more frequently used than ABP, PAOP, PVI and PPV. Cardiac output was measured by TTE and PVI in ICUs with available devices which were used more frequently than Vigilio®ileo, NICOM®, PiCCO®, USCOM®, TEE, PAC-thermodilution. For pulmonary monitoring, the Lung-mech had more regular use than Eso-P and EIT. Interestingly, although non-invasive pulmonary monitoring, the $ETCO_2$ was, it was used only sometimes in ICUs.

For gap analysis between device frequency usage level and device density level in Table 6, the authors found some discordances between utilization frequency and availability, utilizing the PPV-SPV-SVV device for hemodynamic monitoring which has medium density availability but has limited usage. On the other hand, high technology measurement of CPM had low density and fewer users in Thai ICUs (Table 6).

## Discussion

The progress of new CPM yield greater accuracy and is less invasive and obtains more parameters measured. Some traditional CPM parameters such as CVP and PAOP had recent evidence of less accuracy for clinical predictive parameters[7-9]. In addition, meta-analysis demonstrated the use of pulmonary artery catheter (PAC) neither increased overall mortality or days in hospital nor conferred benefits[10]. These led to a decrease in PAC usage[11]. Of this disadvantage, many pre-load responsiveness for hemodynamic assessment methods were suggested

**Table 3.** Monitoring, device and measurement method categorized by availability grading in Thai ICUs

| Availability grade | Cardio-hemodynamic | Pulmonary-gas exchange | Measurement |
|---|---|---|---|
| None (0%) | LiDCO® | ELW | |
| Rarely (<10%) | PiCCO®, TEE, PVI, NICOM® | Eso-P, $PtcO_2$, EIT | PVI, EIT |
| Few (10-19.9%) | Vigilio®, USCOM®, TTE, IABP, PPV-SPV-SVV device | ABG-analysis | SVV, PPV, $ScvO_2$, $SvO_2$, Lung-mech |
| Moderate (20-49.9%) | PAC-thermodilution | $ETCO_2$, Lung-Mech | PAOP |
| Common (50-79.9%) | Pressure monitoring | Resp-wave | CVP, ABP |
| Abundance (>80%) | Continuous and 12 lead ECG | $SpO_2$ | Manual BP, Automate BP |

ACAD = academic ICUs; Non-ACAD = non-academic ICUs

**Table 4.** Monitoring, device and measurement method categorized by median density level in available ICUs

| Density level | Cardio-hemodynamic | Pulmonary-gas exchange |
|---|---|---|
| None (DPB = 0) | LiDCO® | ELW, $PtcO_2$ |
| Low density (DPB <0.3) | 12 lead ECG, Vigilio®, PiCCO®, USCOM®, TTE, TEE, IABP, NICOM®, PVI, PAC-thermodilution | Eso-P, $ETCO_2$, EIT, ABG-analysis |
| Medium density (DPB 0.31-0.69) | PPV-SPV-SVV device | - |
| High density (DPB $\geq$0.70) | Continuous ECG, Pressure monitoring | $SpO_2$, Resp-wave, Lung-mech |

ACAD = academic ICUs; Non-ACAD = non-academic ICUs using new equipment including PPV-SPV-SVV, passive leg raising and end expiratory occlusion test[1]. Of these methods, either continuous cardiac output monitoring or pressure monitoring was essential. Therefore, both minimally invasive and non-invasive cardiac monitoring devices and techniques were developed such as LiDCO®, PiCCO®, USCOM®, TTE, TEE, NICOM®, Vigilio® and PVI. However, some of these require an expensive single use catheter. The present study demonstrated that CVP and PAOP are still more frequently used than PPV and SVV in Thai ICUs. This might be explained by unavailable equipment of most continuous cardiac monitoring devices (low density, Table 4 and 5) and less familiarity with these new measurement methods which were confirmed by PPV-SPV-SVV devices having medium density but sometime used (Table 6). Therefore, continuous education of these new measurement methods should be established.

Most of Thai ICUs had only basic CPM including continuous ECG, $SpO_2$, pressure and respiratory wave form monitoring as well as mechanical lung measurement devices (Table 6). However, ICUs in academic hospitals had significantly more availability of higher technology or innovation devices than non-academic hospitals (Table 1). Interestingly, although $ETCO_2$ was non-invasive, with non-disposable devices and many clinical benefits, its available density was low and sometimes used in the Thai ICUs.

There were many limitations in the present study. First, availability, density and frequency grade had no standard measurement rule. Despite the validation process, the present study proposed a simple method for categorizing and analyzing instrument measurement. Second, the instrument limitation and accuracy was beyond the scope of this study. Low density levels of devices might be confounded by this reason. Third, budgetary limitations in the government hospital area were major factors in the selection of devices which led to selection bias. If the private ICUs participated more in the survey, the density of instrument results might be altered. Finally, the differences of monitoring of the present study were not related to clinical outcomes. Further study should be performed to identify effect of advances of

**Table 5.** Monitoring, device and measurement method categorized by median of frequency level in available ICUs

| Frequency level | Cardio-hemodynamic | Pulmonary-gas exchange | Measurement |
|---|---|---|---|
| Never (FGS = 0) | LiDCO® | ELW, $PtcO_2$ | |
| Sometime (FGS <3) | Vigilio®, NICOM®, PiCCO®, USCOM®, TEE, IABP, PAC-thermodilution, PPV-SPV-SVV device | Eso-P, $ETCO_2$, EIT | Manual BP, ABP, PAOP, PVI, PPV, $ScvO_2$, EIT, |
| Usually (FGS 4-5) | 12 lead ECG, TTE, PVI, Pressure-monitoring | Lung-mech | CVP, $SvO_2$, Lung-mech, SVV |
| Always (FGS 6-7) | Continuous ECG | ABG-analysis, $SpO_2$, Resp-wave | Automate BP, |

ACAD = academic ICUs; Non-ACAD = non-academic ICUs

**Table 6.** Monitoring, device and measurement methods categorized by median density level and frequency level in available ICUs

| Frequency/Density | Sometime (FGS <3) | Usually (FGS 4-5) | Always (FGS 6-7) |
|---|---|---|---|
| Low density (DPB <0.3) | Vigilio®, NICOM®, PiCCO®, USCOM®, TEE, IABP, PAC-thermodilution, Eso-P, $ETCO_2$, EIT | 12 lead ECG, TTE, PVI | ABG-analysis |
| Medium density (DPB 0.31-0.69) | PPV-SPV-SVV device | - | - |
| High density (DPB $\geq$0.70) | - | Pressure-monitoring, Lung-Mech | Continuous ECG, $SpO_2$, Resp-wave |

ACAD = academic ICUs; Non-ACAD = non-academic ICUs monitoring and patient outcomes. However, the study results of availability and frequency gap were important data for future direction of device provision and training.

## Conclusion

There were more available technology devices of CPM in ACAD than in non-ACAD ICUs. Formal continuous training in new measurement methods should be established for reducing the availability and utilization gaps.

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## Potential conflicts of interest

None of the authors had conflicts of interest from the present study. The abstract was presented as posture in 33rd The International Symposium on Intensive Care and Emergency Medicine (ISICEM) in Brussels, 19th-22nd March 2013.

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***การสำรวจเครื่องมือการติดตามระบบไหลเวียนและการหายใจในประเทศไทย (ICU-RESOURCE I study)***

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***วัตถุประสงค์:*** *แม้ว่าจะมีความก้าวหน้าอย่างต่อเนื่องเกี่ยวกับเครื่องมือการติดตามระบบไหลเวียนและการหายใจในปัจจุบัน แต่ข้อมูลในเรื่องดังกล่าวในไอซียูไทยยังคงไม่มีศึกษา วัตถุประสงค์ของการศึกษาดังกล่าวเพื่อศึกษาสถานการณ์และช่องว่างของเครื่องมือดังกล่าวในไอซียูไทย*

***วัสดุและวิธีการ:*** *ศึกษาโดยใช้ฐานข้อมูลจาก ICU RESOURCE I study เครื่องมือการติดตามระบบไหลเวียน และการหายใจแบ่งเป็น 2 ประเด็นการศึกษา คือ ชนิดของเครื่องมือและวิธีการวัด การประเมินเหล่านี้การแบ่งระดับความสามารถในการเสาะหา (availability grading, AG) ความถี่ของเครื่องมือต่อเตียง (device availability per bed, DPB) และ จำนวนความถี่ของการใช้งาน (frequency grading scale, FGS) โดยความสามารถในการเสาะหาของเครื่องมือจะเปรียบเทียบระหว่างไอซียูในสถาบันฝึกอบรมและไอซียูในโรงพยาบาลอื่น ๆ มีการวิเคราะห์ช่องว่าง ระหว่าง DPB และ FGS ความแตกต่างอย่างมีนัยสำคัญเมื่อ $p<0.05$*

***ผลการศึกษา:*** *ไอซียูจำนวน 155 แห่ง ทุกภาคของไทยเข้าร่วมในการศึกษานี้ไอซียูในสถาบันการฝึกอบรมมีโอกาสที่จะพบเครื่องมือชนิดใหม่อย่างมีนัยสำคัญ ($p<0.05$) ได้แก่ Vigilio, PiCCO, NICOM, esophageal pressure monitoring, transcutaneous $PO_2$, electrical impedance tomography of lung รวมถึงการเทคนิกการตรวจวัดแบบใหม่ได้แก่ stroke volume variation [SVV], pulse pressure variation [PPC], central venous oxygen saturation [$ScvO_2$], lung mechanics เครื่องมือที่ใช้เทคโนโลยีใหม่ดังกล่าวพบมีความถี่ต่ำและความสามารถในการเสาะหาต่ำในไอซียูไทย อย่างไรก็ตามการวิเคราะห์ช่องว่างของเครื่องมือดังกล่าวพบว่าถึงแม้ในไอซียูที่มีเครื่องมือดังกล่าว แต่ความถี่ของการใช้เครื่องมือดังกล่าวอยู่ในระดับบางครั้งเท่านั้น*

***สรุป:*** *เครื่องมือใหม่ของการติดตามระบบไหลเวียนและการหายใจสามารถเสาะหาได้ในไอซียูสถาบันฝึกอบรม มากกว่าไอซียูโรงพยาบาลทั่วไป การจัดฝึกอบรมการใช้เครื่องมือสำหรับเครื่องมือใหม่ดังกล่าวมีความสำคัญ เพื่อลดช่องว่างของการมีเครื่องมือกับการใช้งาน*