The Cardiac Output Monitoring EvaluaTion -UK (COMET-UK) study 2A04

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The aim of the Cardiac Output Monitoring EvaluaTion-UK (COMET-UK) study was to update reports of cardiac output (CO) monitoring use and to examine whether there is any association between the frequency of CO monitoring use in adult, general intensive care units and patient outcomes. Questionnaires were sent to all intensive care units in England, Wales and Northern Ireland (n=221) asking whether the unit had used CO monitoring in the last two years and, if so, to give details of average frequency of use and which CO monitors were available. The majority of units (n=100, 45.2%) used CO monitoring most days or a few times a week and 33 (14.9%) monitored CO every day (response rate 100%). The most commonly available methods were oesophageal Doppler (n=127, 57.5%), LiDCO (n=96, 43.4%) and PiCCO (n=92, 41.6%). There was no significant difference in risk-adjusted acute hospital mortality (p=0.25) or length of stay (p=0.48) across categories of frequency of use. However for ventilated *vs* non-ventilated patients and different quartiles of illness severity, there was an association between higher frequency of use and worse outcome among non-ventilated and lowest risk admissions quartiles. The COMET-UK study found that CO monitoring is in common use; however, there was no evidence that more frequent use of CO monitoring was associated with improved outcomes.

Keywords: *intensive care; cardiac output monitoring; outcome*

Introduction

Most UK intensive care units (ICUs) employ some form of cardiac output (CO) monitoring to guide therapy. At least three surveys of CO monitoring in the UK have been published in the last decade.[1-3] The most recent survey,[3] published in 2010 by Labib *et al*, reported that 96% of the responding units routinely used CO monitoring, which had increased from the previous two surveys, and that there had been a decline in pulmonary artery catheter (PAC) use. More than half (57%, n=97) of units had adopted less invasive methods of CO monitoring and another quarter were planning to do so. Sixty-one percent of the lead clinicians felt that CO monitoring may alter patient outcome. However the investigators did not report the frequency of CO monitoring use within each ICU nor the outcome of patients.

The aims of the Cardiac Output Monitoring EvaluaTion-UK (COMET-UK) Study were to build upon these surveys to see whether CO monitoring use has stabilised and if the trends reported by Labib could be confirmed, and to establish whether there is any association between the frequency of CO monitoring use in adult, general ICUs and patient outcomes.

Methods

A questionnaire was designed to ascertain whether any form of CO monitoring was used and if so, to report the details of average frequency of use and types of CO monitors available. The questionnaire was reviewed for clarity and ease of use by eight senior intensive care physicians who were not directly involved with the study. The questionnaire covered the two years between 1 April 2010 to 31 March 2012.

Initially, the final version (**Table 1**) was sent to the lead clinicians of all adult ICUs in England, Wales and Northern Ireland participating in the Case Mix Programme (CMP) (n=207), the national comparative audit of patient outcome, coordinated by the Intensive Care National Audit and Research Centre (ICNARC).[4] Trained data collectors collect raw data to precise rules and definitions, which then undergo extensive local and central validation prior to pooling. The CMP database thus contains pooled casemix and outcome data collected on consecutive admissions to units participating in the CMP and has been independently assessed to be of high quality. Support for the collection and use of patient-identifiable data without consent has been obtained under Section 251 of the NHS Act 2006 (approval number PIAG 2–10(f)/2005). Data were extracted from the CMP database for all admissions to participating adult, general ICUs between 1 April 2010 to 31 March 2012.

Adult, general ICUs not participating in the CMP were identified by reviewing the latest KH03a data available from the Department of Health website,[5] the Directory of Critical Care Networks[6] and by contacting network managers or telephoning hospitals directly to check whether they had an adult intensive care facility.

Questionnaires were distributed electronically via email in April 2012 and non-responding units and those without a valid email address (primarily those not in the CMP) were contacted by telephone.

Hospital name:	
Unit name:	
1.	Has your unit ever used cardiac output monitoring in the last two years?
Yes	If Yes, please continue with Question 2
No	If No, please go straight to Question 4
2.	How frequently on average does your unit use cardiac output monitoring?
	Every day
	Most days
	A few (ie ≤3) times a week
	Once a week
	A few (ie ≤3) times a month
	Once a month
	Less frequently than once per month.
3.	Please indicate which method(s) your unit uses from the list below. If more than one, please rank them in order of preference (1 being most frequently used).
	• Pulmonary artery catheter
	• Oesophageal doppler
	• PiCCO (ie pulse contour and thermodilution)
	• Pulse contour cardiac output monitoring (eg Vigileo)
	• Lithium chloride indicator dilution method (eg LiDCO)
	• Inert gas rebreathing methods (eg NICO)
	• Ultrasonic cardiac output monitor (eg SCOM)
	• Bioimpedance cardiac output monitoring
	• HeartSmart
	• TOE or transthoracic echo
	• SvO_2 and/or lactate levels
	• Other methods not listed above:
4.	If you have never used cardiac output monitoring over the last two years, please give the reason:

Table 1 Questionnaire regarding the use of cardiac output monitoring.

Statistical analysis

To check the reliability of the replies from units in the CMP, it was possible to correlate (Spearman's rho) the reported frequency of CO monitoring use in the present study to the percentage of patients receiving advanced cardiovascular support, which is returned as part of the CMP dataset (CO monitoring is included in the CMP dataset definition of advanced cardiovascular support).

Multi-level logistic regression models were used to investigate the relationship between frequency of CO monitoring use and patient factors. The categories of frequency of CO monitoring use were: less than once a month; once a month; few times a month; once a week; few times a week; most days; and every day. Patient factors modelled included acute hospital mortality, length of ICU admission, the presence or absence of sepsis, patient's surgical status, use of mechanical ventilation and severity of illness using the ICNARC 2011 model. Outcome models were adjusted for patient risk (namely age, ICNARC Physiology Score, source of admission, urgency of surgery, CPR within 24 hours prior to admission and primary reason for admission), time trend, hospital status, number of intensive care beds and a random effect of ICU.

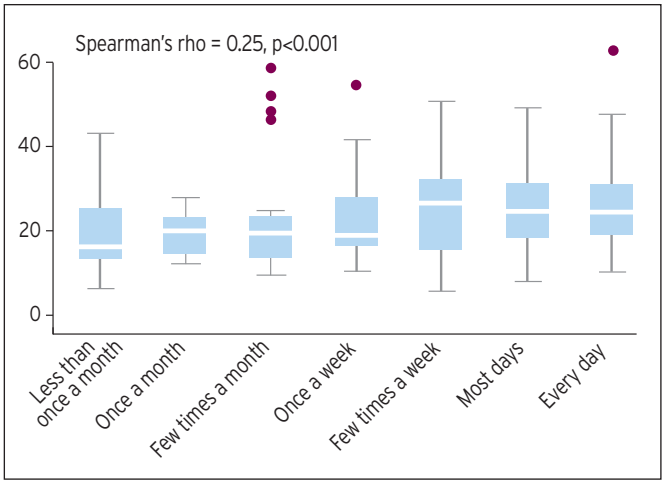

Figure 1 Reported frequency of CO monitoring use varying with percentage of patients receiving advanced cardiovascular support in ICUs participating in the CMP.

Results

Of the 207 CMP units contacted, 178 responses were received via email and 29 via telephone (response rate 100%). Of the 14 non-CMP units contacted, two responses were received via email and 12 via telephone. This represented a 100% response rate from ICUs in England, Wales and Northern Ireland. From the responses, it was clear that the questionnaire did not satisfactorily distinguish between whether or not 'SvO_2 and/or lactate' was a routine parameter measurement or a form of CO monitoring. For this reason presentation of 'SvO_2 and/or lactate' results are limited or presented separately.

All but one unit reported using CO monitoring. Most units (n=100, 45.2%) reported using CO monitoring on most days or a few times a week. Thirty-three units (14.9%) reported that CO monitoring was used every day. The remaining units (n=88, 39.8%) used CO monitoring once a week or less frequently (**Table 2**).

Intensive care units reported a median (interquartile range) of 3.0 (2 to 4) methods for CO monitoring available (range 1-6). The most commonly available methods were oesophageal Doppler (n=127, 57.5%), LiDCO (n=96, 43.4%) and PiCCO (n=92, 41.6%) (**Table 3**). However in those units with several forms of monitoring available, the preferred choice was PiCCO (57.6%, n=53), LiDCO (49.5%, n=47) and Doppler (38.3%, n=48); these three modalities were ranked as first to fourth choices in 315/487 (64.7%) of all choices expressed (**Table 4**). Although transoesophageal echo (TOE) or transthoracic echo and PAC monitoring was available in 27.6% and 24.9% of ICUs respectively, these monitoring modalities were predominantly reserved as second, third or fourth choices. If non-invasive monitoring is defined as monitoring which does not require vascular access (ie, oesophageal Doppler, TOE or transthoracic

Reported frequency of use of cardiac output monitoring	CMP units n (%)	Non-CMP units n (%)	Total n (%)
Every day	32 (15.5)	1 (7.1)	33 (14.9)
Most days	56 (27.1)	2 (14.3)	58 (26.2)
A few (ie ≤3) times a week	39 (18.8)	3 (21.4)	42 (19.0)
Once a week	28 (13.5)	3 (21.4)	31 (14.0)
A few (ie ≤3) times a month	29 (14.0)	4 (28.6)	33 (14.9)
Once a month	11 (5.3)	1 (7.1)	12 (5.4)
Less than once a month	11 (5.3)	0	11 (4.9)
Never	1 (0.5)	0	1 (0.5)
Total intensive care units	**207**	**14**	**221**

Table 2 Distribution of frequency of CO monitoring use (CMP and non-CMP units).

Monitor	CMP units n (%)	Non-CMP units n (%)	Total n (%)	Labib *et al*[3] %
Oesophageal Doppler	117 (56.5)	10 (71.4)	127 (57.5)	34.6
LiDCO	92 (44.4)	4 (28.6)	95 (43.4)	21.8
PiCCO	84 (40.6)	8 (57.1)	92 (41.6)	20.5
TOE or transthoracic echo	59 (28.5)	2 (14.3)	61 (27.6)	
Pulmonary artery catheter	51 (56.5)	4 (28.6)	55 (24.9)	12.8
Pulse contour cardiac output monitoring	40 (19.3)	2 (14.3)	42 (19.0)	6.4
Bioimpedance cardiac output monitoring	10 (4.8)	0	10 (4.5)	
Inert gas rebreathing methods	2 (1.0)	0	2 (1.0)	
Ultrasonic cardiac output monitor	2 (1.0)	0	2 (1.0)	
HeartSmart	0	0	0	
SvO_2 and/or lactate levels	93 (44.7)	1 (7.1)	94 (42.5)	68
Total intensive care units	**207**	**14**	**221**	**171**

Table 3 Distribution of type of CO monitoring used (CMP and non-CMP units). Note: all reported available monitoring types presented.

echo, bioimpedance, inert gas and ultrasonic techniques), then non-invasive CO monitoring was 39.8% (140/351) of first or second choices (*vs* 60.1%, 211/351 first or second choices for invasive CO monitoring) ('SvO_2 and/or lactate' results excluded).

Data from 252,212 admissions in the CMP database were included in the analysis. There was a trend of an increasing percentage of patients receiving advanced cardiovascular support with reported increasing frequency of use (p<0.001; **Figure 1**). Overall there was no significant difference in ICU standardised mortality ratio (SMR) (p=0.366; **Figure 2**) or length of ICU stay (LOS) (p=0.48, **Figure 3**) across categories of frequency of use. Using first 24 hours of data, there was no significant difference in patients with or without severe sepsis and surgical status (ie elective *vs* emergency *vs* non-surgical) (data not shown). However for ventilated (n=107,088) *vs* non-ventilated (n=143,212) patients and different quartiles of illness severity, there was an association between higher frequency of use and worse outcome among non-ventilated (**Figure 4**) and lowest risk admissions quartiles (**Figure 5**). This association appears to be stronger with more frequent use.

Discussion

The COMET-UK study found that CO monitoring is almost universal in adult, general ICUs in England, Wales and Northern Ireland. The one unit that reported not using CO monitoring was concerned about its clinical effectiveness; the SMR of that unit varied between 0.86 and 1.03 over the study period (personal communication). The three most frequently used modalities are oesophageal Doppler, LiDCO and PiCCO, which are the same as reported by Labib.[3] When considering the choices expressed, these three modalities remained the most popular, receiving almost two thirds of the preferences expressed. Since Labib's study, PACs have fallen from 12.8% to 7.3% as first choice of monitoring. While intensivists may aspire to greater use of non-invasive techniques, 60% of ICUs

Monitor	Preferred monitoring	Second choice	Third choice	Fourth choice
	Number of CMP (non CMP) units			
Oesophageal Doppler	44 (4) 38.8%	46 (6) 40.9%	23 18.1%	4 3.1%
LiDCO	44 (3) 49.5%	31 (1) 33.7%	14 14.7%	3 3.2%
PiCCO	48 (5) 57.6%	29 (1) 32.6%	4 (2) 6.5%	3 3.3%
TOE or transthoracic echo	6 9.8%	26 (1) 44.3%	20 (1) 34.4%	5 8.2%
Pulmonary artery catheter	4 7.3%	12 (1) 23.6%	11 (3) 25.5%	15 27.3%
Pulse contour cardiac output monitoring	24 (1) 59.5%	6 (1) 16.7%	6 14.3%	3 7.1%
Bioimpedance cardiac output monitoring	3 30.0%	3 30.0%	2 20.0%	2 20.0%
Inert gas rebreathing methods	0 0	2	0	
Ultrasonic cardiac output monitor	1 0	1	0	
HeartSmart	0 0	0	0	
SvO_2 and/or lactate levels	42 (1) 45.7%	22 23.4%	19 20.2%	9 9.6%

Table 4 Distribution of CO monitoring preferences CMP (and non-CMP units). Percentages are the total for both types of units. Note: some preferences were expressed as first or second equal.

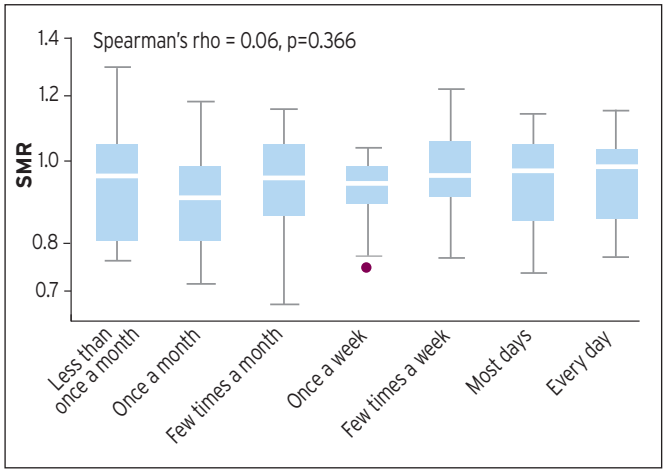

Figure 2 Unit SMR by frequency of unit CO monitoring use (CMP units only).

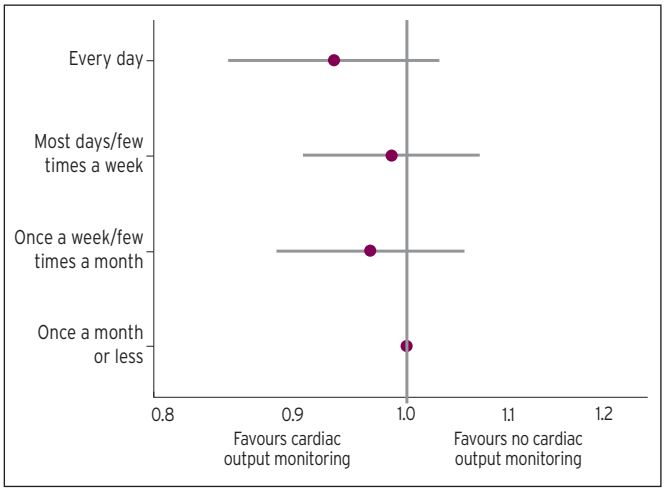

Figure 3 Adjusted relative difference in ICU LOS among survivors by unit frequency of CO monitoring use (CMP units only). CI-confidence interval. Once a month or less is the reference group. Adjusted for age, ICNARC Physiology Score, source of admission, urgency of surgery, CPR within 24 hours prior to admission and primary reason for admission, time trend, hospital status, number of intensive care beds and a random effect of ICU. p=0.47.

still prefer invasive techniques (such as LiDCO and PiCCO) as their first or second choices.

The COMET-UK study suggests that more frequent use of CO monitoring is not associated with lower risk-adjusted acute hospital mortality or shorter LOS. Indeed, sub-group analysis would suggest that for ventilated patients and the less ill, patient outcomes are worse with increasing frequency of use. Advanced CO monitoring provides supplementary data upon which to base further treatment decisions. While clinicians might value such extra information to guide therapy, COMET-UK would suggest that the data derived from CO monitoring is not associated with any clear outcome benefit; 23 (11%) CMP ICUs use CO monitoring less than once per month and yet have the same SMR and LOS as others.

Given that this was an observational study, we cannot assume that observed associations are causal; a randomised controlled trial of advanced *vs* basic CO monitoring would help establish such a link. The PAC-Man trial failed to show any clear benefit of PAC use;[7] since then PAC use has declined in the UK. Other monitoring modalities have replaced the PAC but while such modalities perform well, there is little evidence to suggest that the actual process of CO monitoring improves outcome. It is clear from the comments added to the returned questionnaires that views of the clinical effectiveness of CO monitoring are both polarised and entrenched.

Variation in outcomes between ICUs that remain despite risk adjustment warrants exploration. This study suggests that frequency of CO monitoring use may not be a primary determinant of patient outcome. Intensive care delivery is complex and the effect of other factors such as staffing levels, teamwork and work rosters, standardisation of care via protocols and empowerment of the nursing staff may all influence care or may in part compensate for infrequent use of CO monitoring. The impact of unit-level organisational factors can be significant. For example, Sexton[8] identified six domains that might influence

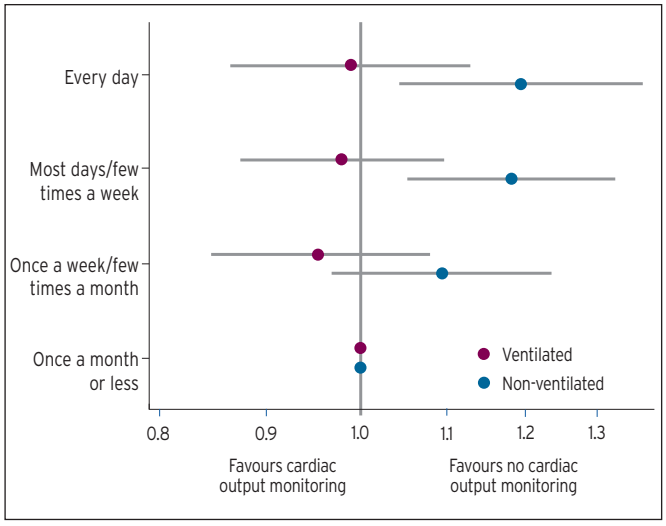

Figure 4 Adjusted odds ratio for acute hospital mortality in ventilated (n=107,088) and non-ventilated (n=143,212) patients by unit frequency of CO monitoring use (CMP units only). CI – confidence interval. Once a month or less is the reference group. Adjusted for age, ICNARC Physiology Score, source of admission, urgency of surgery, CPR within 24 hours prior to admission and primary reason for admission, time trend, hospital status, number of intensive care beds and a random effect of ICU. p<0.001.

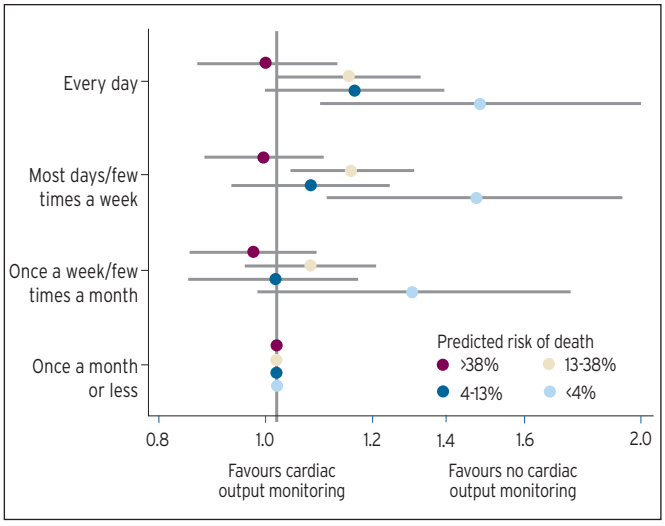

Figure 5 Adjusted odds ratio for acute hospital mortality stratified by predicted risk of death by unit frequency of CO monitoring use (CMP units only). CI – confidence interval. Once a month or less is the reference group. Adjusted for age, ICNARC Physiology Score, source of admission, urgency of surgery, CPR within 24 hours prior to admission and primary reason for admission, time trend, hospital status, number of intensive care beds and a random effect of ICU. p <0.005.

ICU performance (teamwork, job satisfaction, perception of management, safety climate, working conditions and stress recognition). Using the same domains, Huang[9] went on to report that for every 10% decrease in an ICU's percentage of positive scores for perceptions of management, the increased odds of death were 1.24 (95% CI: 1.07-1.44) and for every 10% decrease in an ICU's percentage of positive scores for safety climate, LOS increased 15% (95% CI: 1-30%).

We believe that this is the most comprehensive survey of CO monitoring in adult, general ICUs in England, Wales and Northern Ireland as there was 100% response rate from the CMP units and rigorous steps were taken to identify and obtain replies from the remaining adult general ICUs. The outcome data for units in the CMP forms part of a high quality national database with an international reputation for reliability and quality. One weakness of the study was the lack of clarity regarding 'SvO_2 and/or lactate' as a form of CO monitoring. Many modern automated blood gas analysers measure lactate level routinely and some respondents indicated that they did not consider such routine lactate measurement as advanced CO monitoring. Recall bias undoubtedly affects questionnaire responses. Accepting that advanced cardiovascular support encompasses more than just CO monitoring, it is re-assuring to find that there was a significant trend towards increasing reported frequency of use and greater percentage of patients receiving advanced cardiovascular support as measured in the CMP; this suggests that the responses to the questionnaire were reliable.

In conclusion, COMET-UK found that CO monitoring is almost universally used in adult, general ICUs in England, Wales and Northern Ireland. The three most frequently used modalities are oesophageal Doppler, LiDCO and PiCCO. Monitoring techniques requiring vascular access remain the preferred choices. However, there is no evidence to suggest that more frequent use of CO monitoring is associated with lower risk-adjusted acute hospital mortality or shorter LOS.

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Competing interests

Dr Ridley is an assistant editor of *JICS*.

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