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Comparison of cardiac outputs during major surgery using the Deltex CardioQ oesophageal Doppler monitor and the Novametrix-Respironics NICO: A prospective observational study

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KEYWORDS
Intraoperative fluids;
Non-invasive cardiac output;
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Abstract *Introduction:* Recent studies have emphasised the importance of optimisation of intraoperative fluid administration in patients undergoing major abdominal surgery. A variety of non-invasive devices capable of measuring cardiac output are available for this purpose. Most studies have used the Deltex CardioQ Oesophageal Doppler monitor (DCQ ODM, Deltex, Chichester, Sussex, UK). A relatively new, totally non-invasive cardiac monitor is now available, the Novametrix-Respironics NICO machine (Novametrix-Respironics, USA).
Aims: This pilot study compared cardiac output values obtained during major abdominal surgery from the simultaneous use of these two devices.
Objectives: To assess the reproducibility and consistency of the readings obtained to determine whether these monitors can be used interchangeably for optimising perioperative fluid administration.
Methods: 182 simultaneous paired cardiac output readings were obtained from 12 consecutive patients undergoing prolonged major abdominal surgery. These were analysed using correlation coefficients, scattergrams and Bland Altman plots.
Results: Although the r value obtained for correlation was 0.3639 ($p < 0.0001$), the Bland Altman plot showed significant differences of between −4.1 and +5.1 lpm between the readings means with a bias of 0.5 lpm for the NICO over the DCQ ODM. In addition, a sequential plot of simultaneous cardiac outputs showed great disparity between the two devices in some patients.
Conclusion: Caution should be exercised before using these monitors to optimise intraoperative fluid administration as potentially very large volumes of fluid may be administered to achieve surrogate endpoints. These devices need to be

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compared side by side with a gold standard method of determining cardiac output before they can be used interchangeably for optimising intraoperative fluid administration in abdominal surgery.

Introduction

A number of recent papers have emphasised the role of optimisation of intraoperative fluid administration using the Deltex CardioQ oesophageal Doppler monitor (DCQ ODM, Deltex, Chichester, UK) during major abdominal and orthopaedic surgery to improve patient outcome.[1–5] The improvement has mainly been confined to a reduction in hospital stay.[2,3,5] The DCQ ODM probe emits a 4 MHz continuous wave ultrasound signal at a fixed angle of 45 degrees and measures descending aortic blood flow velocity from which blood flow can be derived, using a 300 Hz high pass filter. Placement of the probe is optimal when a maximal wave pattern was captured and displayed on the monitor. The position of the probe is continuously monitored and adjusted for optimal quality of the Doppler signal during surgery. In addition flow time corrected (FTc) was also recorded. This is a derived parameter obtained from measuring the duration of aortic blood flow for each beat and correcting it for heart rate. A duration of greater than 350 ms appears to shows that fluid status is optimal.

More recently other non-invasive techniques of measuring cardiac output have been developed. The NICO (Novametrics, USA) machine utilises the differential Fick equation for carbon dioxide using a partial rebreathing technique to determine cardiac output and is inherently simpler to use and even less invasive than the DCQ ODM (and other ODMs using oesophageal probes). It requires no user expertise and is not subject to position or movement artefact and would seem to be an ideal monitor to use for intraoperative optimisation of stroke volume and cardiac output.

The aim of this pilot study was to compare cardiac output readings obtained from both the DCQ ODM and NICO devices in patients undergoing prolonged major abdominal surgery where fluid requirements have traditionally been difficult to assess. The objective was to see whether preliminary data suggested that the NICO could be used in place of the DCQ ODM for fluid optimisation protocols using stroke volume. Although small differences in absolute stroke volume and cardiac output values obtained by both devices may be tolerated, it was deemed essential for both to be able to consistently track *changes* in stroke volume if they are to be used interchangeably to optimise circulatory status involving administration of large volumes of fluids.

Materials and methods

This was an observational study and ethical committee approval was not sought as the DCQ ODM was used routinely in these patients and the NICO device is totally non-invasive and was not used for assessing fluid administration. The study enrolled 12 consecutive patients where the duration and extent of surgery meant that fluid balance could well prove to be problematical. All these patients routinely have invasive monitoring inserted including an intra-arterial line, central venous pressure monitoring and insertion of the DCQ ODM. In addition, cardiac output was also assessed using the NICO monitor. Fluid input and output were recorded as well as other major parameters such as central venous pressure, blood gases and arterial pressure and oxygenation. In addition, depth of anaesthesia was monitored using BIS (Aspect Medical Systems, USA) and cerebral oxygen saturation (rSO_2) using the Invos cerebral oximeter (Somanetics corporation, USA).

In all cases anaesthesia consisted of intravenous induction with propofol and remifentanil preceded by 5 μg per kg of glycopyrrolate. Maintenance of anaesthesia was with a target controlled infusion with propofol to maintain a BIS level of between 35 and 50. Analgesia was provided by a continuous infusion of remifentanil and muscle relaxation obtained by the use of cisatracurium.

Following induction of anaesthesia and endotracheal intubation, the DCQ ODM probe was inserted into the mid oesophagus orally or nasally. The NICO non-invasive cardiac output circuit was attached to the patient's breathing circuit immediately after endotracheal intubation. Using this monitor, the first cardiac output estimation usually followed within 5 min and at 3 min intervals thereafter.

Simultaneous measurements by both methods of cardiac output and FTc from the DCQ ODM were recorded at between 10 and 30 min intervals throughout the procedures. For consistency in timing, the DCQ ODM reading of cardiac output and FTc was taken immediately following the 3 min updated reading on the NICO. In some patients more than 20 simultaneous measurements were obtained.

Surgical data included estimated blood loss, volume of packs red cells transfused, and the volumes of the crystalloid and colloids administered during surgery. Heart rate, cardiac output, stroke volume were recorded by both methods.

Statistical analysis

Statistical analysis was carried out using Medcalc software (Medcalc, Belgium). The cardiac outputs obtained were compared using Student's paired *t*-test, Pearson correlation coefficients and simple linear regression analysis and a scattergram was obtained to compare the measurements of cardiac outputs. Because a close correlation does not necessarily imply accuracy, a Bland and Altman representation for comparison of the two methods was carried out using the difference between the means plotted against the mean values from the two machines. The mean bias was determined and the upper limits and lower limits of agreement were obtained between the two methods (±1.96 SD).

Results

The DCQ ODM probe was inserted easily in all the patients but frequent repositioning was necessary to obtain optimal signals particularly in the presence of a nasogastric tube. Patient data are shown in Table 1. Table 2 shows starting haemoglobin concentration and minimum haemoglobin concentration, blood loss and replacement and crystalloid and colloid requirements during operation. In addition, an estimation of the third space loss was made based on the fact that all patients were considered to be fluid optimised at the end of the procedure (see later).

Table 1 Demographic data in the 12 patients and some clinical characteristics of the patience including operative duration and the type of operation

Age (year)	60.5 ± 7.3
Gender (M/F)	8/4
Weight (kg)	79 ± 10.5
ASA class (I/II)	5/7
Operation	
Radical prostatectomy	5
Whipple's procedure	3
Hepatic resection	3
Nephrectomy	1
Duration of surgery (h)	7.7 ± 2.9

Table 2 Intraoperative fluid requirements and blood loss (±1 SD IQR = Interquartile range 25—75)

Starting Hb (g per dl)	13.2 ± 1.8
Lowest Hb (g per dl)	8.5 ± 1.3
Average blood loss ml	1296 ± 870
Packed red blood cells replaced (ml)	725 ± 862 (IQR 0—1500, median 450)
Crystalloid administered (Hartmann's) (ml)	1575 ± 633
Colloid administered	
Gelofusin	1545 ± 472
Voluven	1132 ± 486
Estimated third space loss (ml per kg per h)	3.5 ± 1.3

Fig. 1 shows the scattergram and correlation coefficients of the 182 simultaneous paired cardiac output readings obtained. The *r* value obtained was 0.3639 ($p < 0.0001$). However, the Bland Altman plot showed significant differences of between −4.1 and +5.1 lpm between the reading means with a bias of 0.5 lpm for the NICO over the DCQ ODM (Fig. 2). Thus, the limits of agreement of cardiac output between the two monitors are large.

However, if they do not agree on absolute values, do they track changes in cardiac output in an identical fashion? A DCQ ODM versus NICO series was plotted with the number of reading along the x axis and the cardiac outputs obtained simultaneously from both monitors on the y axis. (Fig. 3). One can see in some patients that both monitors appear to track changes in a fairly consistent fashion. However, equally well one can observe occasions where the monitors do not appear to be tracking changes simultaneously and the simultaneous cardiac outputs are markedly different.

Discussion

Historically, intraoperative fluid administration has been the subject of much controversy. Since the pioneering work of Shires et al., the emphasis has been on *high volume fluid replacement* using balanced salt solutions such as Lactated

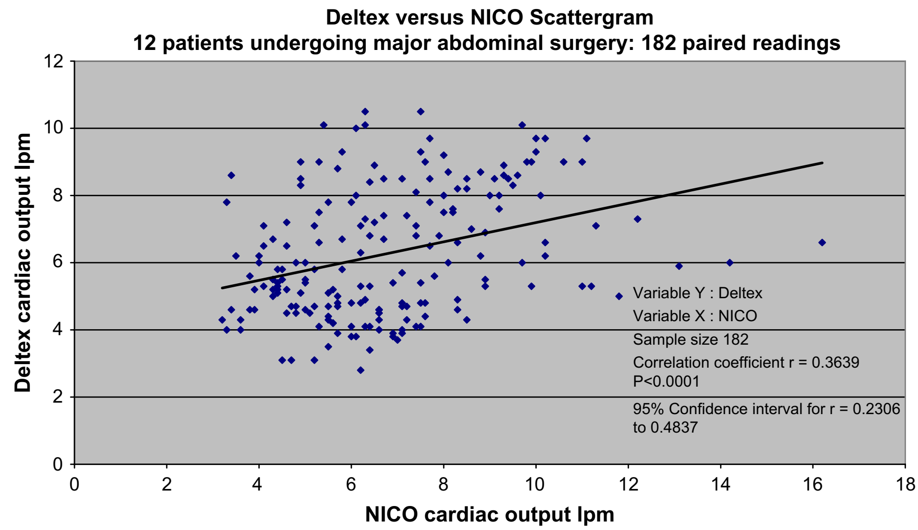

Figure 1 Scattergram of DCQ ODM versus NICO cardiac output (in lpm).

Ringer's or Hartmann's solution.[6,7] These solutions are designed to replace loss of functional extracellular fluid volume (FECV), the so-called *third space*. The problem is in defining in individual patients the extent of this so-called *third space* loss. Thus, the amount of fluid recommended to maintain FECV has ranged from 0 to 15 ml per kg per h. Central venous pressure (CVP) monitoring, although useful in assessing fluid balance, does not necessarily give an accurate indication of FECV, *third space* loss, cardiac output and organ perfusion, especially in the elderly population.[8,9]

Can the DCQ ODM be used to optimise fluid intake during major surgery by optimisation of stroke volume, cardiac output and FTc? Firstly, accuracy of the monitor needed to be assessed. Early versions of the DCQ ODM did appear to be accurate.[10] When tested against the ''gold standard'' thermo-dilution cardiac output (TDCO) technique in 38 ICU patients it showed good correlation.[11] However, other studies using a new generation ODM (Accucom 2, Datascope, USA) found poor agreement between the two techniques, and suggested that the difference in cardiac output values could be inconsistent i.e. a change in

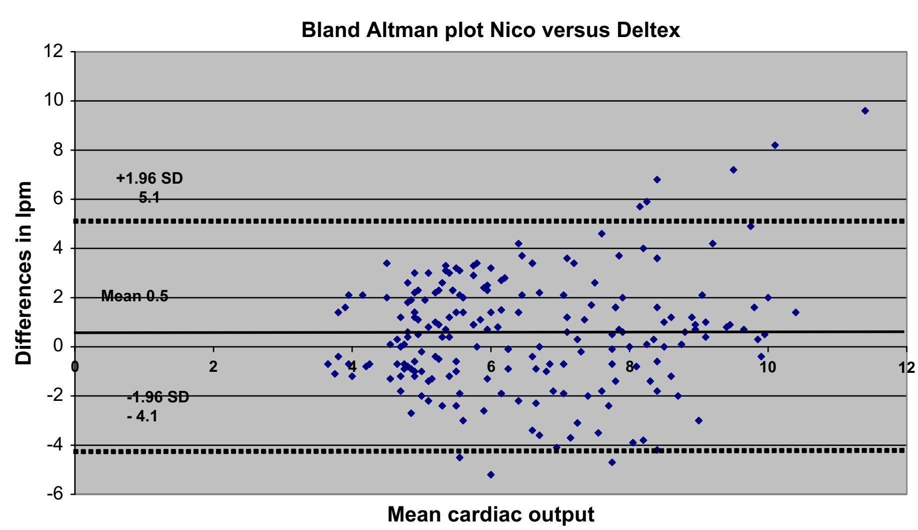

Figure 2 Bland and Altman plot for assessing the limits of agreement between the cardiac outputs measured by the two techniques. The solid line represents the mean difference between the NICO and the DCQ ODM (systematic bias) and the dotted lines define the limits of agreement (95% confidence interval). The bias mean $\pm$ 1.96 standard deviations is 0.5 $\pm$ 4.6 lpm.

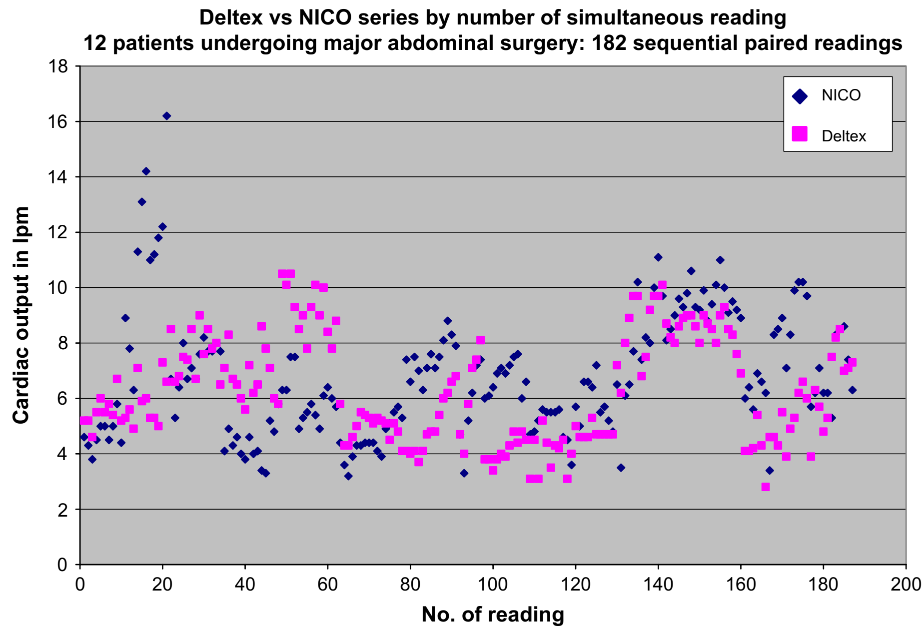

Figure 3 Cardiac output from NICO versus DCQ ODM on the y axis plotted by number of simultaneous readings in all 12 patients on the x axis.

cardiac output detected by TD was not necessarily matched by a proportionate change with the DCQ ODM.[12] However, using an earlier version of the DCQ ODM (ODMII Abbott, USA) in comparison with a continuous cardiac output pulmonary flotation catheter during cardiac surgery the investigators concluded that ''both devices suffered significant intraoperative problems which led us to question their suitability as operating theatre monitors''.[13] The ODM's reliance on deriving stroke volume, and therefore cardiac output, from descending aortic blood flow velocity must also be deemed questionable, particularly in elderly patients with aortic atheromatous disease.

Despite these reservations, a number of recent papers have emphasised the role of optimisation of intraoperative fluid administration using the DCQ ODM during major abdominal and orthopaedic surgery in an attempt to improve patient outcome.[1–5] The improvement has mainly been confined to a reduction in hospital stay.[2,3,5] In major abdominal and orthopaedic surgery, the DCQ ODM has been the technique of choice for optimising fluid administration using cardiac output and stroke volume, as the pulmonary artery catheter has been deemed too invasive for the types of surgery being undertaken. Intraoperative optimisation involves repeated colloid fluid boluses to achieve predetermined increases in either stroke volume or flow time corrected, FTc. The latter is a derived parameter obtained from measuring the duration of aortic blood flow for each beat and correcting it for heart rate. A duration of greater than 350 ms appears to shows that fluid status is optimal.

Pilot data produced from the group at Worthing have suggested that the improved outcomes in patients undergoing abdominal surgery when monitored and optimised by use of the DCQ ODM have been due to the requirement for considerable additional volumes of fluid during surgery.[19] The contention is that patients are relatively under filled during major abdominal surgery and correcting this deficit will improve outcome by improving organ perfusion. It is pertinent to note that the Worthing group infused *one litre of Hartmann's solution per hour* to the intervention group in their pilot study. Although they don't include the weight in their demographic data this would equate to approximately 10—15 ml per kg per h loss of FECV requirement. Additional colloid was also administered at a rate of about half this amount, although they do not record whether the blood loss was replaced by blood or by transfusion of colloid. However, when the full study on 145 patients was published, the fluid administration protocol in both groups was changed and the intervention group no longer received 1 l per h of Hartmann's solution in addition to colloid fluid boluses. Indeed, the overall amount of crystalloid to both groups was similar (3 l) and there was only 500 ml difference in the amount of colloid administered (1.5 versus 2 l). This was much less fluid than the intervention group received in the pilot study. It is difficult to account for these differences.

The average extracellular fluid replacement in this pilot study was only 3.5 ml per kg per h, a considerable difference with the pilot Worthing study. The patients studied here were not optimised by stroke volume improvements resulting from colloid transfusion but by adequacy of cardiac output and an FTc or greater than 350 ms, as was used in the optimisation study by Gan et al.[3] This was achieved in 10 of the 12 patients studied. It is difficult to account for the disparity in fluid required to achieve optimisation in these patients in comparison with the preliminary data from the Worthing group[19] although the difference is not as great as compared with the final trial published data.[5] In the author's experience, the use of the DCQ ODM has not resulted in an increased intraoperative fluid requirement. This is supported by recent studies which have suggested that an improvement in outcome can be achieved by fluid *restriction* during major abdominal surgery.[20,21]

More recently other non-invasive techniques of measuring cardiac output have been developed and compared with TDCO. The NICO (Novametrics, USA) machine used here utilises the differential Fick equation for carbon dioxide using a partial rebreathing technique to determine cardiac output but again, results have been inconsistent.[14–17] For background information on both the DCQ ODM and NICO devices the reader is referred to the following review.[18] The NICO has not been used to manage fluid replacement by optimisation of stroke volume and cardiac output during major abdominal surgery, but would appear at the outset to be an ideal monitor to use instead of the DCQ ODM for reasons of simplicity and lack of dependence on user skill or interpretation (vide infra). However, as demonstrated in this pilot trial, when used alongside the DCQ ODM it would appear that the two monitors do not track changes in cardiac output and stroke volume in a consistent manner in all patients. This would suggest a cautious approach when using either monitor to optimise stroke volume by the administration of potentially large volumes of fluids. There is clearly an urgent need to compare the outputs from these two monitors, used simultaneously in major abdominal surgery, with a gold standard indicator dilution method of monitoring cardiac output, such as thermal or lithium dilution.[22–26]

Conclusion

This pilot study suggests that caution should be exercised before using monitors such as the DCQ ODM and NICO to optimise intraoperative fluid administration, especially as potentially very large volumes of fluid may be administered to achieve surrogate endpoints. The absolute lack of agreement between the two monitors in this pilot study suggests that they cannot be used interchangeably in this situation until further comparative studies have been done.

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