Journal of Clinical Anesthesia (2016) **32**, 75–81

ELSEVIER

Journal of Clinical Anesthesia

Respiratory variation of systolic and diastolic time intervals within radial arterial waveform: a comparison with dynamic preload index

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Received 20 August 2013; revised 29 January 2015; accepted 21 December 2015

Keywords:
Systolic and diastolic time interval;
Respiratory variation;
Dynamic index

Abstract
Background: A blood pressure (BP) waveform contains various pieces of information related to respiratory variation. Systolic time interval (STI) reflects myocardial performance, and diastolic time interval (DTI) represents diastolic filling. This study examined whether respiratory variations of STI and DTI within radial arterial waveform are comparable to dynamic indices.
Methods: During liver transplantation, digitally recorded BP waveform and stroke volume variation (SVV) were retrospectively analyzed. Beat-to-beat STI and DTI were extracted within each BP waveform, which were separated by dicrotic notch. Systolic time variation (STV) was calculated by the average of 3 consecutive respiratory cycles: $[(STI_{max} - STI_{min})/STI_{mean}]$. Similar formula was used for diastolic time variation (DTV) and pulse pressure variation (PPV). Receiver operating characteristic analysis with area under the curve (AUC) was used to assess thresholds predictive of SVV ≥ 12% and PPV ≥ 12%.
Results: STV and DTV showed significant correlations with SVV (r= 0.78 and r= 0.67, respectively) and PPV (r= 0.69 and r= 0.69, respectively). Receiver operating characteristic curves demonstrated that STV ≥ 11% identified to predict SVV ≥ 12% with 85.7% sensitivity and 89.3% specificity (AUC = 0.935; P< .001). DTV ≥ 11% identified to predict SVV ≥ 12% with 71.4% sensitivity and 85.7% specificity (AUC = 0.829; P< .001). STV ≥ 12% and DTV ≥ 11% identified to predict PPV ≥ 12% with an AUC of 0.881 and 0.885, respectively.
Conclusion: Respiratory variations of STI and DTI derived from radial arterial contour have a potential to predict hemodynamic response as a surrogate for SVV or PPV.

1. Introduction

Fluid management during surgery is critical in maintaining optimal tissue perfusion. Dynamic preload indices based on respiratory variation such as stroke volume variation (SVV) or pulse pressure variation (PPV) have emerged as

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http://dx.doi.org/10.1016/j.jclinane.2015.12.022

useful parameters to estimate the volume responsiveness of a patient to improve patient outcome [1,2]. However, despite the popularity of such parameters, reliability of their measurements has been continuously studied to validate their accuracy [3-5]. Moreover, to measure these indices, a specialized, costly device is necessary for each patient.

Measurement of left ventricular ejection time is a valuable, noninvasive estimation of myocardial performance [6]. However, Doppler echocardiography or phonocardiography is needed for an exact measurement of the value of the measurement. In a single blood pressure (BP) waveform, systolic time interval (STI) exists which represent ventricular ejection time, whereas diastolic time interval (DTI) exists which represent the diastolic filling time. These 2 interval times can simply be divided by a dicrotic notch in a BP waveform. Therefore, the authors suggest a new parameter using STI and DTI measured from the radial arterial pressure contour as a potential measure of fluid responsiveness in substitution for SVV or PPV. The aim of this study was to test whether the cyclic respiratory variations of systolic and diastolic time intervals within the radial arterial waveforms are comparable to SVV or PPV.

2. Methods

2.1. Patient characteristics and anesthesia

After approval from our institution ethics committee, 56 data of 19 patients who underwent living donor liver transplantation from June 2008 to August 2008 were retrospectively evaluated by electronic medical record analysis. The data for the first group (SVV $\geq 12\%$) were selected during the anhepatic phase where inferior vena cava is partially clamped, and those for the second group (SVV $< 12\%$) was selected during the preanhepatic phase where the patient is hemodynamically stable. At our institution, beat-to-beat multiwaveforms of hemodynamic variables such as electrocardiogram (ECG), arterial BP, central venous pressure (CVP), and SVV are routinely recorded during liver transplantation surgery with a computerized data acquisition system using WINDAQ (DI-720U; DATAQ Instruments, Inc, Akron, OH) in all recipients. Exclusion criteria included patients with incomplete recording with artifacts, indefinite dicrotic notch, underdamping or overdamping of arterial waveform, preoperative and intraoperative arrhythmia, valvular heart disease, left or right ventricular dysfunction, pulmonary hypertension, and hepatopulmonary syndrome.

Routine anesthesia monitoring was placed, and an invasive BP measurement was performed through radial artery with a 20-gauge angiocatheter. Anesthesia was induced with thiopental 5 mg/kg, fentanyl 1 to 2 μg/kg, and vecuronium 0.1 mg/kg. Mechanical ventilation was started after endotracheal intubation with a tidal volume of 8 to 10 mL/kg and respiratory rate of 10 to 12 per minute to maintain normocapnia. Anesthesia was maintained with sevoflurane with inspired oxygen fraction of 0.5 along with continuous infusion of vecuronium and fentanyl. After the induction of anesthesia, a 7.5F pulmonary artery catheter (Swan Ganz CCOmbo V; Edwards Lifesciences, Irvine, CA) was inserted via a 9.0F introducer (AVA HF; Edwards Lifesciences) through the right internal jugular vein which was connected to Vigilance device (Vigilance; Edwards Lifesciences) to monitor hemodynamic variables such as cardiac output (CO), mixed venous oxygen saturation, and systemic vascular resistance.

2.2. Hemodynamic measurements and data analysis

SVV was measured by Vigileo device (Vigileo/FloTrac; Edwards Lifesciences) which analyzes arterial pressure waveform over 20-second intervals with 1-minute recalibration interval and was digitized and simultaneously recorded in the computerized multiwave data record system.

Continuous CO with CVP measured by the pulmonary artery catheterization was also digitized at 500 Hz and simultaneously recorded and stored in a computer. Systolic, diastolic, and dicrotic notch pressures were automatically detected by CODAS (DataQ Instruments, Inc) and DADiSP (DSP Development Corp, Cambridge, MA) software. Pulse pressure (PP) was calculated by subtracting diastolic BP from the systolic BP. The time from the onset of systolic upstroke of the arterial waveform to the dicrotic notch was designated as STI; and the time from the dicrotic notch to the beginning of the upstroke, as DTI (Fig. 1). Respiratory systolic time variation (STV) was calculated by the average of 3 consecutive respiratory cycles with the following: $[(STI_{max} - STI_{min})/STI_{mean}]$. Diastolic time variation (DTV) was calculated by $[(DTI_{max} - DTI_{min})/DTI_{mean}]$, and PPV was calculated by $[(PP_{max} - PP_{min})/PP_{mean}]$ (Fig. 2). Because both STI and DTI are sensitive to heart rate changes, they were corrected by RR interval of the ECG ($STV/\sqrt{RR} = STV$, $DTV/\sqrt{RR} = DTV$). SVV and PPV threshold of $\geq 12\%$ was used to discriminate fluid responsiveness [7-9]. Respiratory variation of STV/DTV ratio was also analyzed.

2.3. Statistics

Continuous variables were expressed as mean ± SD. Comparisons between groups were evaluated using paired or unpaired *t* test, Mann-Whitney *U* test, and Mann-Whitney rank sum test as appropriate. A scatter diagram with regression line was used to assess linear associations between STV and SVV along with PPV and between DTV and SVV along with PPV. Pearson correlation coefficient (*r*) was used for the comparison. Receiver operating characteristic (ROC) curves and the area under the curve (AUC) were used to determine the optimal cutoff values of STV, DTV, STV/DTV, and CVP with highest sensitivity and specificity. To calculate the sample size, an ROC curve with AUC ≥ 0.8