Tracking Intravascular Volume Using Frequency Analysis of Plethysmographic Waveforms

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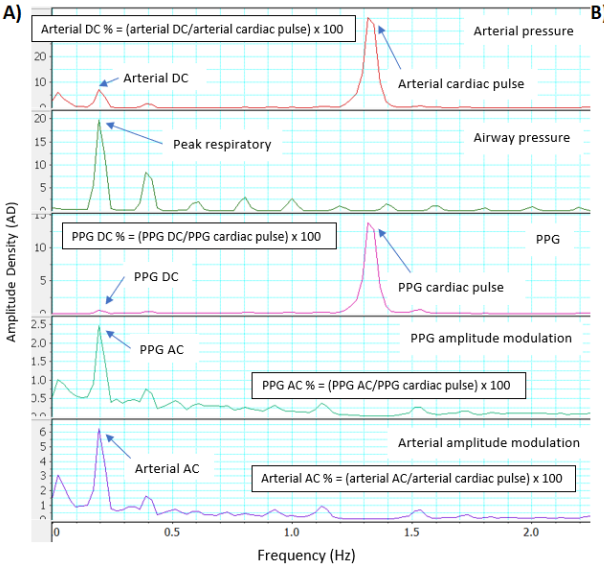
Background: Pediatric spinal fusion surgery offers a unique metric for the study of hemodynamic and resuscitation status monitoring in children given the procedure's substantial blood loss (1). Previous studies have reported the utility of frequency domain analysis of plethysmographic (PPG) and arterial waveforms in children undergoing spinal fusion surgery (2). Frequency domain analysis was chosen as it is less prone to artifact than time domain analysis, and due to findings, that time domain analysis of dynamic measures, such as stroke volume in children is less reliable than in adults given their higher vascular compliance (3). The present study was undertaken to compare the frequency domain analysis of PPG and arterial waveforms before and after resuscitation against mean arterial pressure (MAP) and heart rate (HR) in children undergoing spinal fusion.

Methods: With IRB approval, 32 children undergoing spinal fusion were studied. EKG, blood pressure, invasive arterial pressure, finger pulse oximeter (finger PPG) and airway pressure were recorded at 100 Hz with a data acquisition system (Collect 5/S, GE) and analyzed using frequency analysis (spectrum, 4K, Hamming, Amplitude density) with LabChart 7 (ADInstruments). Amplitude density (AD) at the respiratory frequency yielded PPG DC and PPG AC values. Normalizing this against an internal control of the AD at cardiac frequency yielded PPG DC% and PPG AC% values to allow comparison between patients. The same was done for arterial pressure waveforms (Figure 1A). Data were analyzed before resuscitation and after resuscitation (fluid, blood, or albumin) with some patients yielding multiple data points. A total of 79 data points was obtained. Normality was checked using Shapiro-Wilk ($p<0.05$). We either used paired t-test or Wilcoxon signed-rank test for parametric or non-parametric, respectively. Statistical analyses were conducted using SPSS version 26.

Results: PPG DC %, PPG AC %, arterial DC % and arterial AC % showed significant reduction after resuscitation compared to HR and MAP. PPG DC % and PPG AC % percent changes were greater than arterial DC % and arterial AC %. PPG DC %, PPG AC %, arterial DC %, and arterial AC % reached statistical significance. (Figure 1B)

Discussion: Adequate resuscitation is an elusive goal with a fine line between end organ hypoperfusion and pulmonary edema. Significant change in frequency domain analysis for both PPG and arterial waveforms were seen compared to HR and MAP after resuscitation with a lesser change in the arterial waveform than PPG, which may reflect the high arterial compliance in children. As PPG is a noninvasive monitor, frequency domain analysis of PPG offers an alternative tool to arterial waveform monitoring and hemodynamic parameters in tracking intravascular volume changes to guide fluid therapy and resuscitation.

A)



B)

Parameters	Before Resuscitation	After Resuscitation	% Change
HR	81	81	-0.0
MAP	69	68	-1.4
PPG DC % *	27.1	14.5	-46.5
PPG AC % *	34.5	19.8	-42.6
Arterial DC % *	36.3	24.5	-32.5
Arterial AC % *	32.9	23.2	-29.5

Figure 1: A) Frequency analysis of arterial and PPG waveforms. **B)** Percent change in HR, MAP, PPG DC%, PPG AC%, Arterial DC% and Arterial AC% before and after resuscitation. *statistical significance ($p < 0.05$)

References:

1) Spine 2014;39:1479–87.
2) Anesth Analg. 2016;123(2):346–356.
3) Anesth Analg 2013;117:1380–92.