Effect of Pneumoperitoneum During Laparoscopic Surgery on Plethysmographic and Peripheral Venous Pressure Waveforms

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Introduction: Laparoscopic surgery consists of insufflation of the peritoneal cavity to create a pneumoperitoneum[1]. This increases intra-abdominal pressure and conduces transmission of abdominal pressure to the thoracic cavity[2,3]. In turn this leads to increases in cardiac filling and airway pressures[4]. A recent study has shown that the peripheral venous pressure (PVP) waveform significantly changes during hypovolemic challenge in healthy volunteers[5]. The PVP waveform may be a minimally invasive and highly sensitive means to detect early blood loss. Methods of extracting arterial and venous volume status from the photoplethysmogram (PPG) waveform have been developed[6], however, the application of these methods during pneumoperitoneum have not been studied. The present study explores the analysis of the PPG and PVP waveforms during laparoscopic surgery to investigate changes in venous and arterial blood pools.

Methods: With IRB approval, 15 patients undergoing elective laparoscopic procedures were studied. All patients were induced with general anesthesia and mechanically ventilated using controlled volume (~8cc/kg). Finger pulse oximeter (finger PPG Nellcor & Masimo), peripheral venous pressure (PVP) transduced from an intravenous catheter, blood pressure, end tidal carbon dioxide, and airway pressure (AWP) were recorded at 100 Hz with a data acquisition system (Collect 5/S, GE) and analyzed using Spectral Fast Fourier Transform analysis (spectrum, 4K, Hamming, Total power, 94% overlap) with LabChart 8.05 (ADInstruments). Analysis included measuring the total power of the AC (amplitude modulation at the respiratory frequency) and DC modulation (baseline modulation induced by ventilation) of the PPG and PVP waveforms. Time domain analysis consisted of measuring the baseline, area, maximum slope, minimum slope, average slope, and width of the finger PPG, PVP, and AWP. Data are presented as percent changes. Student's t-test (Excel Microsoft) were used; $P<0.05$ was statistically significant.

Results: There were significant changes in PPG (amplitude, DC, AC, DC%, and AC%), PVP (mean pressure, DC, AC, DC%), and AWP waveforms during insufflation and following desufflation. These results are summarized in Tables 1-4. Average insufflation pressures ranged from 11 to 20 mmHg (mean 15 mmHg). On average, patients received 2308 ml of crystalloid by end of surgery.

Conclusion: Laparoscopic surgeries are commonly performed for a variety of conditions due to smaller surgical incisions, reduced pain, and shorter length of stay[1,3,7]. However, current understanding of the impact of intra-abdominal pressure (IAP) on hemodynamics is relatively superficial. The results support the notion that pneumoperitoneum decreases stroke volume, decreases preload, and increases venous congestion. A previous study has shown that during hypovolemic challenge the respiratory modulation in the PPG waveform increases while the cardiac modulation decreases[8]. In the present study, both the respiratory power and cardiac power increased upon insufflation. This pattern is suggestive of blood volume congestion rather than hypovolemia during pneumoperitoneum. To our knowledge, the effects of insufflation on blood volume at the periphery have not been shown in the literature. This study contributes to the potential of using the PPG and PVP waveforms, opposed to an arterial and central line, as less invasive methods to monitor volume status in patients; specifically those undergoing laparoscopic procedures. Furthermore, this study provides the basis for developing a clinical monitor for changes in PPG and PVP waveforms during increased and released abdominal pressure (up to 20 mmHg) to guide proper management of abdominal hypertension during early phases of abdominal compartment syndrome. The next point of interest is to compare the PPG and PVP waveforms to bladder pressure catheter readings and understand their relationship.

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Table 1 PPG, PVP, and AWP before and after insufflation

	Direction	Before	After	Percent change	*P* value
PPG amplitude	↓	12.4055	11.0108	-11.24%	0.0009
PPG amplitude variation	↑	0.1782	0.7673	330.53%	0.0431
PPG cardiac power	↓	14.6252	12.2535	-16.22%	0.0072
PPG respiratory power	↑	0.3146	1.2478	296.64%	0.0079
PPG DC%	↑	14.3607	34.1191	137.59%	0.0071
PPG AC%	↑	10.7684	24.8798	131.04%	0.0075
Peripheral venous pressure (mmHg)	↑	15.7205	22.2991	41.85%	0.00001
PVP cardiac power	↑	0.1668	0.3404	104.12%	0.0072
PVP respiratory power	↑	0.6054	1.2258	102.47%	0.0468
PVP DC%	↓	230.1408	207.0807	-10.02%	0.0468
AWP (cm H2O)	↑	10.2198	13.3453	30.58%	0.0001

Table 2 PPG, PVP, and AWP before and after desufflation

	Direction	Before	After	Percent change	*P* value
PPG amplitude	↑	11.4255	12.4396	8.88%	0.0016
PPG amplitude variation	↓	0.4671	0.1404	-69.94%	0.0075
PPG cardiac power	↑	12.1046	14.0520	16.09%	0.0136
PPG respiratory power	↓	0.8565	0.4075	-52.43%	0.0045
PPG DC%	↓	28.0649	18.3272	-34.70%	0.0011
PPG AC%	↓	19.0642	10.1888	-46.56%	0.0008
Peripheral venous pressure (mmHg)	↓	23.8035	16.6796	-29.93%	0.000005
PVP cardiac power	↓	0.8850	0.2731	-69.14%	0.0011
PVP respiratory power	↓	1.8651	0.6322	-66.10%	0.0017
PVP DC%	↑	179.4940	194.9288	8.60%	0.6557
AWP (cm H2O)	↓	15.7578	3.1371	-80.09%	0.000000

Table 3 PPG, PVP, and AWP Peak Analysis before and after insufflation

	Direction	Before	After	Percent change	*P* value
PPG MaxSlope	↓	114.9019	102.3744	-10.90%	0.0037
PPG Slope	↓	78.8163	66.4800	-15.65%	0.0008
PVP Baseline	↑	15.1679	21.4654	41.52%	0.0000
PVP MinSlope	↑	-12.7103	-19.3504	52.24%	0.0268
AWP PeakArea	↑	17.6113	22.0194	25.03%	0.0001
AWP MinSlope	↑	-39.3231	-51.3456	30.57%	0.00015

Table 4 PPG, PVP, and AWP Peak Analysis before and after desufflation

	Direction	Before	After	Percent change	*P* value
PPG Baseline	↑	-4.1483	-4.9779	20.00%	0.0019
PPG PeakArea	↑	3.6214	4.2869	18.38%	0.0043
PPG MaxArea	↑	111.1243	120.3479	8.30%	0.0061
PPG MinSlope	↓	-45.4421	-43.0343	-5.30%	0.0090
PPG Width50	↑	307.6357	347.2357	12.87%	0.0007
PPG Slope	↑	74.5971	82.5343	10.64%	0.005247
PVP Baseline	↓	21.6687	15.7184	-27.46%	0.0000
PVP MinSlope	↓	-24.5475	-17.5671	-28.44%	0.0081
AWP PeakArea	↓	23.6479	17.8421	-24.55%	0.0001
AWP MaxSlope	↓	59.1671	51.7039	-12.61%	0.020455
AWP MinSlope	↓	-55.7829	-41.0850	-26.35%	0.000352
AWP Slope	↓	57.6229	49.4989	-14.10%	0.036320