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NON-INVASIVE VERSUS INVASIVE BLOOD PRESSURE MONITORING IN PATIENTS DURING LAPAROSCOPIC BARIATRIC SURGERY: A PROSPECTIVE METHOD-COMPARISON STUDY.

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ABSTRACT

Intra-operative blood pressure monitoring in morbidly obese patients using standard non-invasive blood pressure (NIBP) oscillometric technique with upper arm cuffing is often inaccurate. Invasive arterial blood pressure (IABP) monitoring is the gold standard but is not without complications. The purpose of this study was done to assess the degree of agreement between the forearm and upper arm NIBP with the IABP during laparoscopic bariatric surgery.
The study was conducted in our university hospital. A total of 36 morbidly obese patients undergoing laparoscopic bariatric surgery were studied. The radial artery was cannulated for IABP monitoring on one upper limb while NIBP monitoring was done on the contralateral upper arm and forearm. The NIBP and its corresponding IABP readings were recorded at selected time points at 10 minutes post-induction; 5, 15, and 30 minutes post-insufflation and 15 minutes post- exsufflation.
Results: The mean arterial pressure (MAP) has narrower limits of agreement compared to the systolic blood pressure (SBP) and diastolic blood pressure (DBP) for each method of measurement used. Forearm NIBP showed better agreement with IABP compared to upper arm NIBP. Repeated measures ANOVA showed a similar pattern of changes in SBP, DBP, and MAP measured by NIBP and IABP during the surgery.
Conclusion: Similar patterns of blood pressure changes were observed with IABP, upper arm, and forearm NIBP measurements at all-time points. The forearm NIBP showed better agreement to IABP as compared to upper arm NIBP and may be adequate to monitor patterns of blood pressure changes during laparoscopic bariatric surgery.

Keywords: Intraoperative BP monitoring; Weight loss surgery; Obesity; Hypertension, Forearm and upper arm BP monitoring; IABP; NIBP.

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INTRODUCTION

Obesity is increasingly recognized as a global epidemic disease where more bariatric surgeries have been performed to treat morbid obesity. The laparoscopic approach has gained its popularity over the years as it is minimally invasive and associated with minimal blood loss (1). Therefore, the use of

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invasive arterial blood pressure (IABP) monitoring intra-operatively may be considered unnecessary.

However, laparoscopic surgery involves the induction of pneumoperitoneum by carbon dioxide (CO2) insufflation. This results in an increased intra-abdominal pressure, which is known to affect preload, afterload, cardiac output, and blood pressure (2). Significant blood pressure changes may occur and require timely detection and intervention to avoid adverse outcomes, especially in morbidly obese patients, as obesity is often associated with co-morbidities such as cardiovascular disease and hypertension (3).

Accurate blood pressure measurement in morbidly obese patients often poses a clinical challenge to anaesthetists. IABP is the gold standard for blood pressure monitoring but is an invasive technique, and it is associated with possible complications such as hematoma formation, thrombosis, pseudo- aneurysm formation and is often technically challenging to perform in morbidly obese patients (4,5).

Non-invasive blood pressure monitoring using the oscillometric technique (NIBP) is standard practice in the operation theater with the cuff applied over the upper arm and usually provides reliable blood pressure measurements if correctly applied. However, in morbidly obese patients owing to the conical shaped arm with larger circumference, it is often difficult to get the appropriate cuff size. This results in imperfect fitting and inaccurate measurement (6-9). In contrast to the upper arm, the forearm has relatively unaltered morphology in morbidly obese patients. Therefore, the study of forearm NIBP monitoring has the clinical relevance of providing an alternative site for non-invasive blood pressure monitoring in this group of patients. Our study aims to assess the suitability of forearm NIBP as an alternative approach to the upper arm NIBP and IABP monitoring.

MATERIALS AND METHODS

Study approval from the Institutional Ethics Committee at Universiti Kebangsaan Malaysia Medical Centre was obtained (FF-2015-024). A total of 37 morbidly obese patients who were planned for elective laparoscopic bariatric surgery were enrolled in the study after written informed consent was obtained. Patients aged between 18-65 years, American Society of Anaesthesiologists physical status (ASA) I or II, body mass index (BMI) ≥ 40 or ≥ 35 kg/m2 with co-morbidities and a positive modified Allen test for both upper limbs were included in the study. Patients with significant peripheral vascular disease resulting in a ≥ 10mmHg blood pressure difference between systolic blood pressure (SBP) of both arms, with pre-existing cardiac arrhythmias and presence of vascular fistulas over the upper limb were excluded.

Patients were assessed a day before the surgery where acid prophylaxis was prescribed, and patients were fasted six hours before the surgery. The patient's forearm circumference was measured at the midpoint between the olecranon and styloid apophysis. Arm circumference was measured at the midpoint between the tip of shoulder and olecranon, using a standard measuring tape. Cuff size for NIBP monitoring was selected based on the patient's arm circumference according to the manufacturer's recommendation.

In the operation room, standard anesthesia monitoring such as pulse oximetry, capnography, and electrocardiograph (ECG) were established. General anesthesia with rapid sequence induction was performed as per standard protocol. Anesthesia was maintained using desflurane in an oxygen and air mixture (ratio of 1:1), with a minimum alveolar concentration (MAC) maintained at 1-1.2. Radial artery cannulation was done after induction of anaesthesia using a 20 G cannula (BBraun®) on one arm with a maximum of three attempts. Patients were dropped out from the study if more than three attempts at radial artery cannulation were required. The cannulated radial artery was connected to an IABP measuring system (iPex™). The arterial pressure transducer was positioned, calibrated, and zeroed to the patient's right atrium.

NIBP monitoring was performed using the NIBP cuff (DURA-CUF®) attached to a Datex- Ohmeda S/5 NIBP module on the contralateral upper limb over the upper arm and forearm. Both the forearm and upper arm NIBP measurements, which included SBP, diastolic blood pressure (DBP), and mean arterial pressure (MAP) were taken consecutively at 10 minutes post-induction, 5minutes, 15 minutes and 30 minutes post-insufflations (after the establishment of pneumoperitoneum) and 15 minutes post-exsufflation. Corresponding IABP measurements were documented at the same time each of the NIBP readings was taken. The intra-abdominal pressure was maintained at 11-16 mmHg during the surgery. The following figures are illustrative.

JMSR
Journal of Medical and Surgical Research

Research Article

ISSN: 2351-8200

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IABP monitoring

NIBP (Arm) monitoring

NIBP (Forearm) monitoring

JMSR
Journal of Medical and Surgical Research
Research Article
ISSN: 2351-8200
JMSR 2020; Vol. VII, n 1: 778- 791

STATISTICAL ANALYSIS

The analysis of data was done using SPSS Version 24 statistical software. Demographic data, which included patients' age, gender, BMI, upper arm circumference, forearm circumference, and co-morbidities were analyzed and recorded as mean, standard deviation, numbers, and percentage. Bland-Altman plots were then created to enable visual observation of the degree of agreement between the different methods of measurements. One sample t-test was done to test the agreement between IABP and NIBP measurements over the forearm and upper arm, respectively, at each time point. Repeated measures ANOVA was used to analyze the pattern of change in the average mean SBP, DBP, and MAP readings of different methods of measurements during laparoscopic surgery. Further analysis was done to demonstrate the presence of statistically significant differences in the average mean of these blood pressure readings using one way ANOVA test. A *p-value* of < 0.05 was regarded as statistically significant.

RESULTS

A total of 37 patients were enrolled in this study. One patient was dropped out due to the unavailability of an appropriate cuff size to fit the upper arm. The demographic characteristics of these patients are summarized in **Table I**.

Table I. Demographic characteristics.

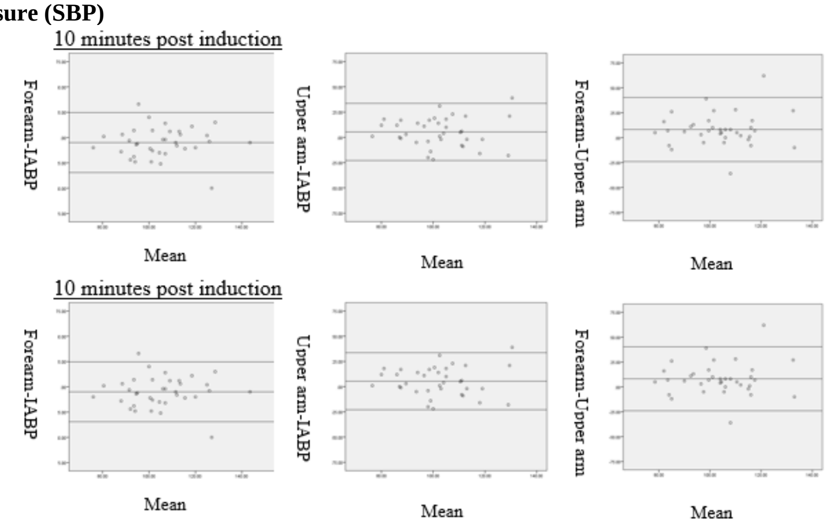
Parameters	
Age(years)	41.75 ± 11.47
Gender	
Male	15 (41.7)
Female	21 (58.3)
BMI (kg/m^2)	
Obesity class 2	10 (27.8)
Obesity class 3	26 (72.2)
Upper arm circumference (cm)	40.64 ± 4.3
Forearm circumference (cm)	27.32 ± 2.87
Co-morbidities	
Hypertension	15(41.7)
Diabetes mellitus	11(30.6)
Ischemic heart disease	2(5.6)

cm=centimetre, BMI= body mass index
Results are expressed as mean± standard deviation. Numbers and percentage where appropriate.

In order to assess agreement between the different methods of blood pressure measurements, the Bland-Altman plot was used. The Bland-Altman plot illustrated limits of the agreement, which indicate where 95% of individual differences (difference between NIBP and IABP readings) are likely to fall were found to be wider for SBP and DBP compared to MAP. The widest limits of agreement were demonstrated when forearm NIBP and upper arm NIBP were compared (**Fig. 1**).

Figure 1. Bland-Altman plots of differences versus mean of SBP, DBP and MAP of each pair. Horizontal lines indicate limits of agreement, where 95% of differences are expected to fall.

Systolic Blood Pressure (SBP)



JMSR
Journal of Medical and Surgical Research

Research Article

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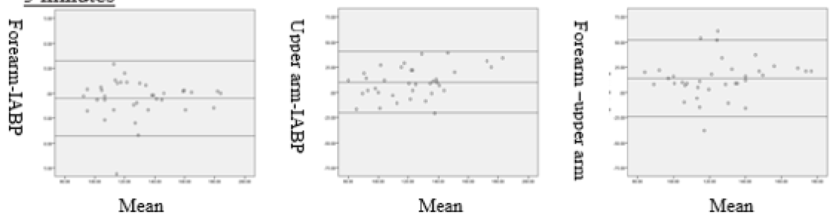
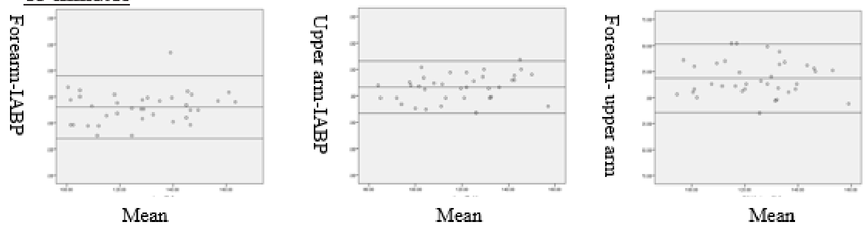
JMSR 2020; Vol. VII, n 1: 778- 791

<u>Post insufflation (establishment of pneumoperitoneum)</u>

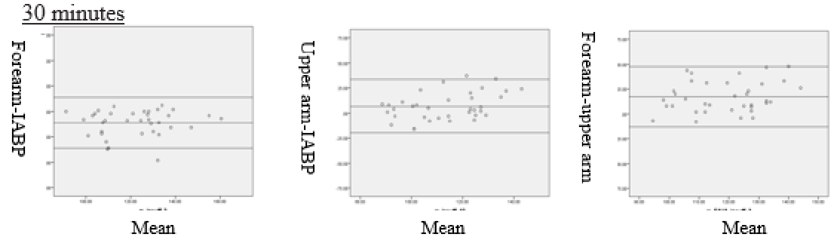
<u>5 minutes</u>



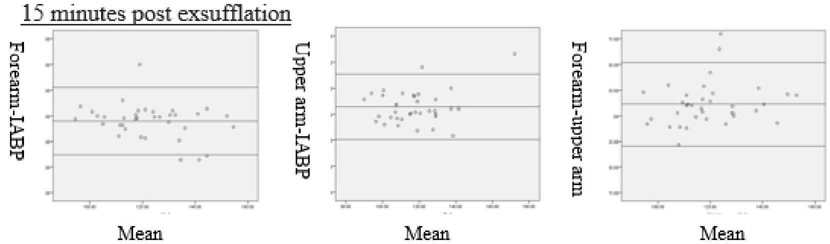
<u>15 minutes</u>



<u>30 minutes</u>

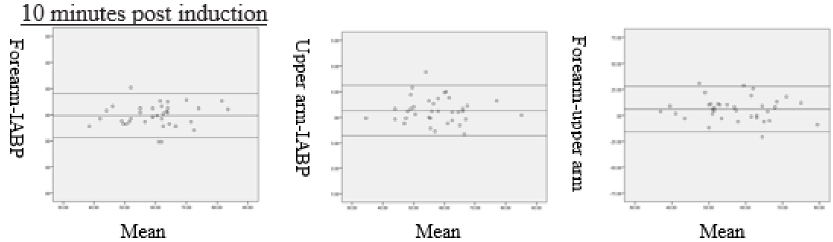


<u>15 minutes post exsufflation</u>



Diastolic Blood Pressure (DBP)

<u>10 minutes post induction</u>

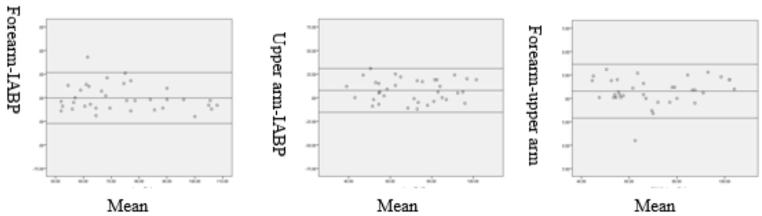


JMSR
Journal of Medical and Surgical Research
ISSN: 2351-8200

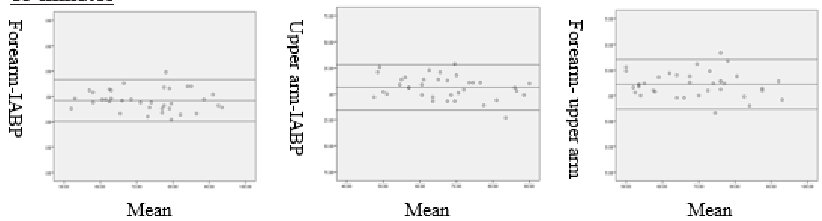
JMSR 2020; Vol. VII, n 1: 778- 791

Post insufflation

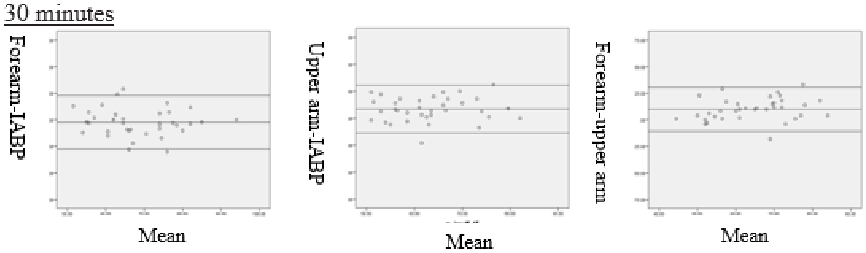
5 minutes



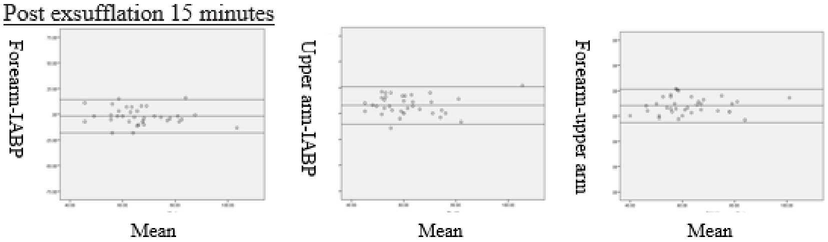
15 minutes



30 minutes

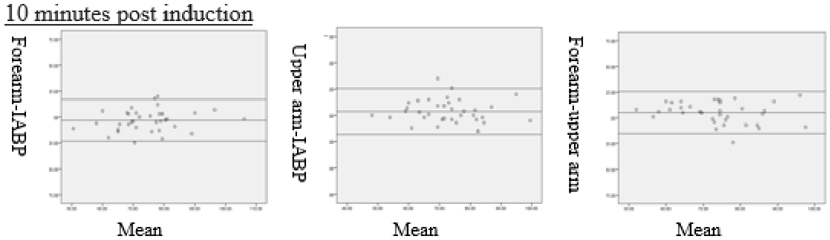


Post exsufflation 15 minutes



Mean Arterial Pressure (MAP)

10 minutes post induction



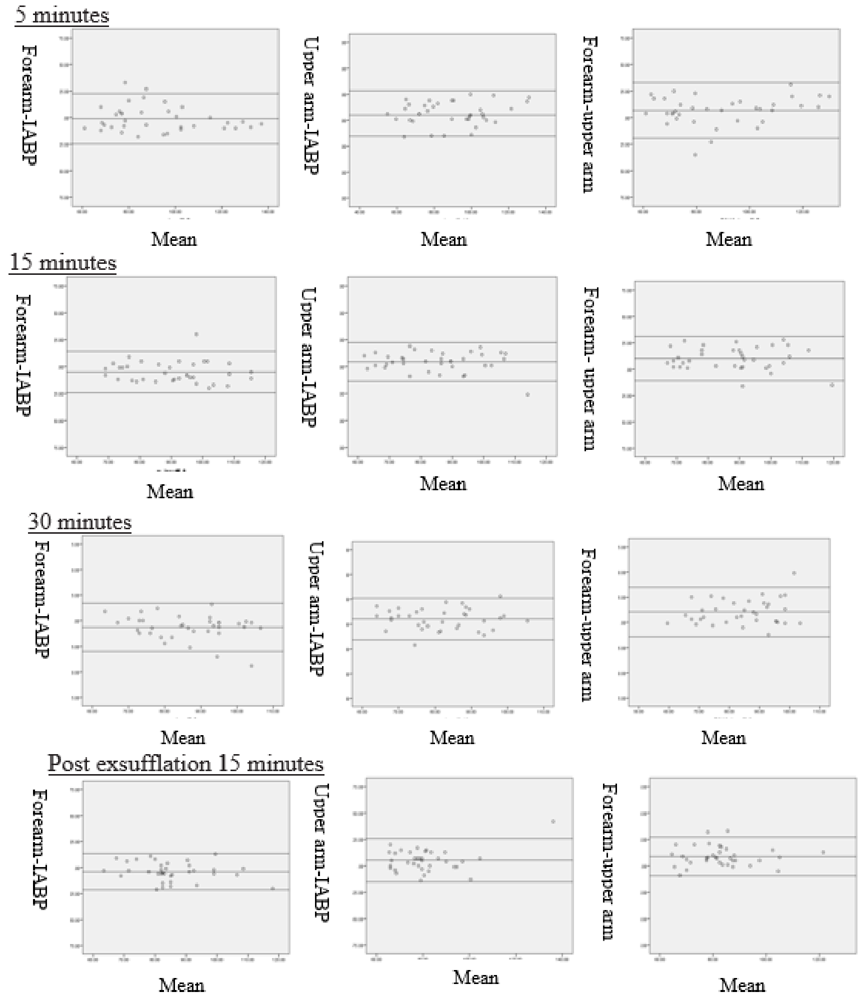
JMSR
Journal of Medical and Surgical Research

Research Article

ISSN: 2351-8200

JMSR 2020; Vol. VII, n 1: 778- 791

Post insufflation



NIBP=non-invasive blood pressure, IABP=invasive blood pressure, SBP=systolic blood pressure, NBP= diastolic blood pressure, MAP=mean arterial pressure

Further analysis using the One Sample t-Test found the agreement between forearm NIBP and IABP measurement for SBP, DBP as well as MAP readings at the post-induction, post-insufflation (after the establishment of pneumoperitoneum) and post-exsufflation phase. However, upper arm NIBP was shown to only have an agreement with IABP MAP readings at the 10 minute post-induction time point. There was no statistically significant agreement established between the forearm and upper arm NIBP readings (**Table IIa-c**).

ISSN: 2351-8200
JMSR 2020; Vol. VII, n 1: 778- 791

Table II a The mean systolic blood pressure (SBP) of both forearm and upper arm using NIBP and IABP were compared

	Forearm NIBP versus IABP	Upper arm NIBP versus IABP	Forearm NIBP vs Upper arm NIBP
SBP Post-induction			
10 minutes	0.057	0.031	0.005
SBP Post-insufflation			
5 minutes	0.107	<0.001	<0.001
15 minutes	<0.001	<0.001	<0.001
30 minutes	<0.001	0.005	<0.001
SBP Post-exsufflation			
15 minutes	0.078	0.015	0.003

Abbreviation: NIBP=non-invasive blood pressure, IABP=invasive blood pressure, SBP=systolic blood pressure, NBP= diastolic blood pressure

Table IIb The mean diastolic blood pressure (DBP) of both forearm and upper arm using NIBP and IABP were compared

	Forearm NIBP versus IABP	Upper arm NIBP versus IABP	Forearm NIBP versus Upper arm NIBP
DBP Post-induction			
10 minutes	0.582	0.004	0.002
DBP Post-insufflation			
5 minutes	0.876	<0.001	0.003
15 minutes	0.035	0.002	<0.001
30 minutes	0.284	<0.001	<0.001
DBP Post-exsufflation			
15 minutes	0.183	<0.001	<0.001

NIBP=non-invasive blood pressure, IABP=invasive blood pressure, SBP=systolic blood pressure, NBP= diastolic blood pressure

ISSN: 2351-8200
JMSR 2020; Vol. VII, n 1: 778- 791

Table IIc The mean of mean arterial pressure (MAP) in both forearm and upper arm using NIBP and IABP were compared

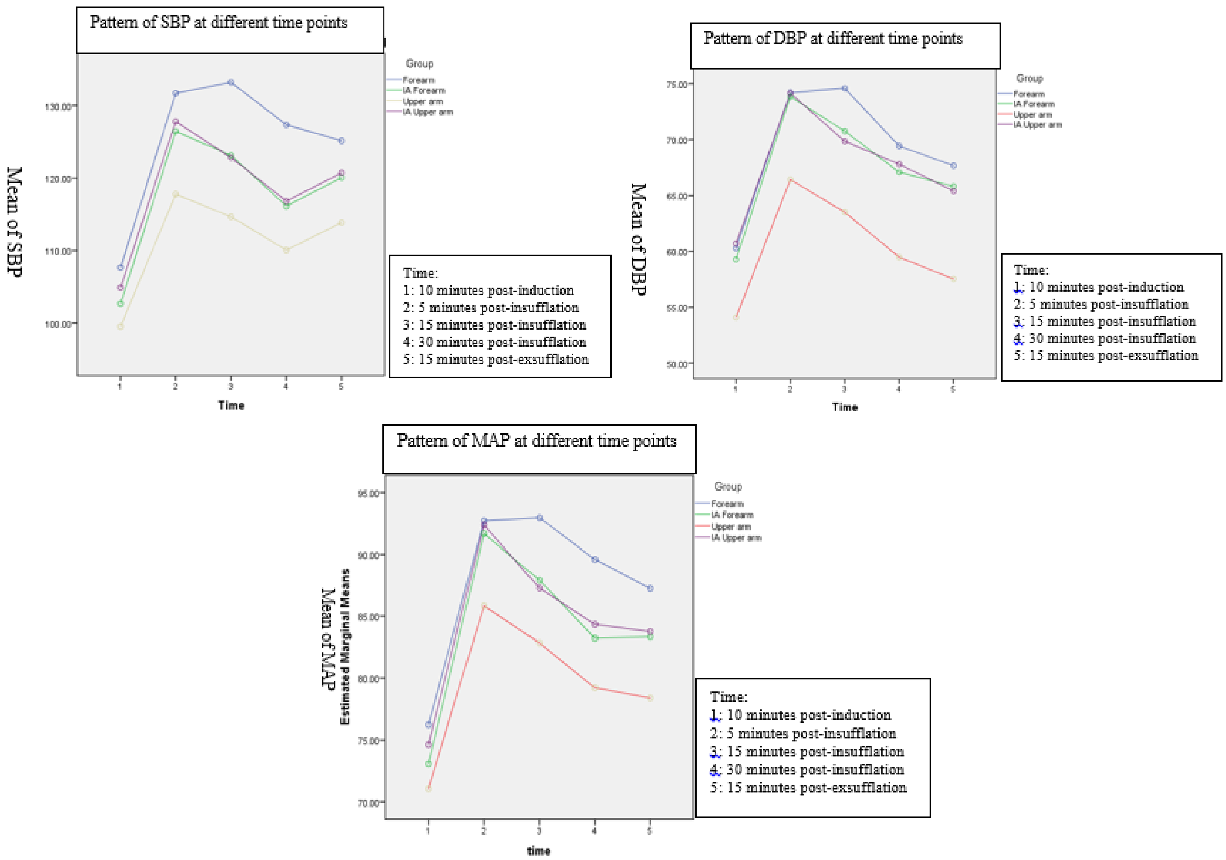
	Forearm NIBP vs IABP	Upper arm NIBP vs IABP	Forearm NIBP vs Upper arm NIBP
MAP Post-induction			
10 minutes	0.077	0.062	0.005
MAP Post-insufflation			
5 minutes	0.613	0.001	0.004
15 minutes	0.004	0.006	<0.001
30 minutes	0.003	0.007	<0.001
MAP Post-exsufflation			
15 minutes	0.012	0.004	<0.001

Repeated measures ANOVA was done to investigate the pattern of changes of SBP, DBP, and MAP for NIBP and IABP at specific time points: 10 minutes post-induction, 5, 15, and 30 minutes post-insufflation and 15 minutes post-exsufflation. The patterns in SBP, DBP, and MAP changes were not significantly varied between the different methods of measurements at different time points (**Fig. 2**).

JMSR
Journal of Medical and Surgical Research
ISSN: 2351-8200

JMSR 2020; Vol. VII, n 1: 778- 791

Figure 2. Patterns of changes of SBP, DBP and MAP using oscillometric technique (NIBP over the forearm and upper arm) and the IABP readings taken simultaneously at different time points.



NIBP=non-invasive blood pressure, IABP=invasive blood pressure, SBP=systolic blood pressure, NBP= diastolic blood pressure, MAP=mean arterial pressure, IA Forearm: IABP reading when forearm NIBP is recorded, IA Upper arm: IABP reading when upper arm NIBP is recorded

Further analysis was then performed using the one way ANOVA test to detect a statistically significant difference in the mean SBP, DBP, and MAP at different time points. The average SBP was not significantly varied between the different methods of measurements at 10 minutes post-induction (p=0.166) and post-exsufflation phase (p=0.064). However, a significant difference was detected for mean SBP measurements between the forearm and upper arm NIBP (p=0.003) after the establishment of pneumoperitoneum (Table III). While for the average DBP, the significant mean difference was found during post-insufflation (p=0.007) and post-exsufflation phase (p=0.006) (Table IV). There was no statistically significant difference in average MAP readings at all-time points for the different methods of measurement employed (**Table V**).

Table III Comparison of mean SBP.

Time	Forearm NIBP n=36		IABP 1 n=36		Upper arm NIBP n=36		IABP 2 n=36		F stat (df)[a]	P value[a]
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)		
Post-induction [b]										
10 minutes	107.67	16.26	102.69	16.27	99.53	15.17	104.92	15.31	1.72(3;140)	0.166
Post-insufflation										
5 minutes	131.69	26.59	126.42	27.09	117.78	23.36	127.78	29.16		
15 minutes	133.19	18.24	123.14	21.17	114.67	18.53	122.83	21.94		
30 minutes	127.33	16.87	116.14	17.95	110.08	13.82	116.83	18.93		
Average[c]	130.74	17.93	121.90	18.96	114.18	16.18	122.48	20.24	4.88(3;140)	0.003
Post-exsufflation										
15 minutes	125.14	19.25	120.06	15.06	113.86	16.11	120.72	19.93	2.47(3;140)	0.064

[a] One way ANOVA [b] Baseline SBP [c] Average SBP post-insufflations; IABP 1: IABP reading when forearm NIBP is recorded; IABP 2:IABP reading when upper arm NIBP was recorded
NIBP=non-invasive blood pressure, IABP=invasive blood pressure, SBP=systolic blood pressure, NBP= diastolic blood pressure, SD=standard deviation, df=degree of freedom

Table IV Comparison of mean DBP.

Time	Forearm NIBP n=36		IABP 1 n=36		Upper arm NIBP n=36		IABP 2 n=36		F stat (df)[a]	P value[a]
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)		
Post-induction [b]										
10 minutes	60.28	10.82	59.28	12.05	54.08	11.80	60.69	11.38	2.54(3;140)	0.059
Post-insufflation										
5 minutes	74.19	19.80	73.83	17.14	66.42	18.22	74.14	18.11		
15 minutes	74.58	13.14	70.75	11.99	63.50	14.59	69.83	11.53		
30 minutes	69.42	12.44	67.08	11.32	59.47	10.13	67.81	10.70		
Average [c]	72.73	13.09	70.56	11.96	63.13	12.51	70.59	11.78	4.18(3;140)	0.007
Post- exsufflation										
15 minutes	67.67	13.39	65.81	12.14	57.53	12.75	65.39	13.35	4.35(3;140)	0.006

[a] One way ANOVA [b] Baseline DBP [c] Average DBP post-insufflations ; IABP 1: IABP reading when forearm NIBP is recorded; IABP 2:IABP reading when upper arm NIBP was recorded.
Abbreviations: NIBP=non-invasive blood pressure, IABP=invasive blood pressure, SBP=systolic blood pressure, NBP= diastolic blood pressure, SD=standard deviation, df=degree of freedom

JMSR
Journal of Medical and Surgical Research

Research Article

ISSN: 2351-8200

JMSR 2020; Vol. VII, n 1: 778- 791

Table V Comparison of mean of MAP.

Time	Forearm NIBP n=36		IABP 1 n=36		Upper arm NIBP n=36		IABP 2 n=36		F stat (df)[a]	P value[a]
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)		
Post-induction										
10 minutes	76.22	10.86	73.08	12.72	71.06	12.66	74.64	11.81	1.21 (3;140)	0.308
Post-insufflation										
5 minutes	92.69	22.55	91.67	20.38	85.83	19.96	92.36	21.77		
15 minutes	92.94	14.56	87.92	13.58	82.83	15.30	87.28	14.17		
30 minutes	89.58	14.31	83.22	11.71	79.22	12.27	84.33	12.23		
average	91.74	15.28	87.60	13.31	82.63	13.76	87.99	13.85	2.54 (3;140)	0.059
Post-exsufflation										
15 minutes	87.25	13.25	83.33	11.44	78.39	13.22	83.75	16.16	2.58 (3;140)	0.056

[a] Repeated measures ANOVA (Time & Group Interaction Effect) IABP 1: IABP reading when forearm NIBP is recorded; IABP 2:IABP reading when upper arm NIBP was recorded
NIBP=non-invasive blood pressure, IABP=invasive blood pressure, MAP=mean arterial pressure, SD=standard deviation, df=degree of freedom

DISCUSSION

Accurate non-invasive blood pressure monitoring is of clinical importance in morbidly obese patients. Various newer techniques have been developed, including the photoplethysmography method (Finapres), Vasotrac, and TRICUF. However, these techniques require special devices for monitoring, which are not routinely available in the operation theater. Studies done on these devices failed to provide clinical evidence to suggest a replacement for the conventional IABP (10, 11). For practical purposes in a limited resource setting, we use the non-invasive oscillometric technique with cuff application over the forearm to monitor the blood pressure of morbidly obese patients intra-operatively. Previous studies that compared forearm and upper arm NIBP showed inconsistent results (11-15). Based on literature search, only one study was done to compare NIBP monitoring using the oscillometric technique and IABP in morbidly obese patients who had undergone laparoscopic surgery (15). In our study, forearm cuffing was found to overestimate SBP, MAP, and DBP, while the upper arm cuffing underestimated SBP, MAP, and DBP in comparison with IABP. Leblanc et al. (15) reported similar findings with regards to SBP but not DBP. The agreement between the oscillometric technique and IABP was shown to be better for MAP readings (10), which was also observed in our study. Accurate blood pressure measurement depends on various factors, including operators, equipment, and technique of measurement. When the oscillometric technique is used, systolic blood pressure (SBP) and diastolic blood pressure (DBP) is estimated using a proprietary algorithm unique to each manufacturer, therefore, should not be considered as accurate as MAP. In addition to that, measurements with the oscillometric technique are site-dependent and will be affected by the amplitude of pressure changes detected in the cuff with its inflation and deflation (4). The discrepancy of blood pressure readings taken at different sites can be explained by the distal pulse amplification phenomenon (16) and Ohm's law. The more distal artery has a smaller diameter and therefore producing higher resistance to blood flow. This results in higher blood pressure reading when the measurement is taken at the more distal artery. The studies done using invasive techniques to monitor hemodynamic changes in morbidly obese patients during laparoscopic surgery have found MAP to be significantly raised and remained elevated throughout the pneumoperitoneum phase (17,18). This is explained by the increase in afterload due to neurohumoral effect of CO2 insufflation (17). To date, this is the only study that uses the non-invasive oscillometric technique (forearm and upper arm) in comparison to IABP to monitor blood pressure changes induced by pneumoperitoneum. Our observation revealed that the non-invasive oscillometric technique was reliable in detecting the pattern of blood pressure changes during post-induction, post- insufflations (pneumoperitoneum), and post-exsufflation phases in laparoscopic surgery. The forearm cuffing showed a

ISSN: 2351-8200
JMSR 2020; Vol. VII, n 1: 778- 791

consistent average trend of overestimating SBP, DBP, and MAP, while the upper arm cuffing showed an average trend of underestimating SBP, DBP, and MAP at various time point. However, in our study, it is not clinically feasible to measure NIBP at both the upper arm and forearm of the same limb at the same time. This may result in a discrepancy in blood pressure readings, which is a limitation in our study.

CONCLUSION

Each technique or device has its advantages and disadvantages. The risks and benefits of each technique have to be considered before they are being used. Similar patterns of changes in blood pressure were observed with IABP, upper arm, and forearm NIBP measurements at all-time points, including the phase of pneumoperitoneum. However, forearm NIBP was shown to overestimate while upper arm NIBP underestimated the IABP. Therefore, measurements using forearm and upper arm cuffing are not interchangeable intra- operatively. In conclusion, the forearm NIBP showed better agreement to IABP as compared to upper arm NIBP and may be adequate to monitor patterns of blood pressure changes during laparoscopic surgery.

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None

Conflicts of Interest:

The authors declare that they have no conflict of interest.

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JMSR 2020; Vol. VII, n 1: 778- 791

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