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Comparing Data Analysis for Hemodynamic Monitoring in the Vigileo and LiDCORapid Models

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Abstract— **Currently, the standard method of cardiac output monitoring is to use a Swan-Ganz catheter. This catheter can lead to complications, and therefore the benefits over risks are being analyzed. In order to have a continuous monitoring of cardiac output or circulatory dynamics in a less invasive form, two different devices were developed. The first device that was developed is the Vigileo monitor (Vigileo) (Edwards Lifesciences corporation, CA, USA) and the second device is the LiDCORapid (Lidcolimited, London, UK). The comparison analysis of the cardiac output was measured between the Vigileo and LiDCORapid. A blood pressure calibrator made by BIO-TEK INSTRUMENTS called BIO-TEK601A was used for the artificial pressure source. Aortic pressure (Ao) and radial artery pressure (Rd) was obtained through the BIO-TEK601A. The CO was displayed from the data that was divided into each model, gender, age and input waveform. For statistical evaluation of the experimental data, Mann-Whitney U-test or Wilcoxon Signed rank sum test were used. The CO results from the Vigileo model were less dependent on the Ao or Rd pressure compared to the LiDCORapid model. The Vigileo was determined to have less variability with CO results compared to the LiDCORapid model.**

Index Terms— **Vigileo monitor, LiDCORapid, artificial pressure, cardiac output**

I. INTRODUCTION

Cardiac output monitoring used in the intensive care unit or operating room is helpful when controlling patients that have an unstable circulatory dynamic.1) Currently, the standard method of cardiac output monitoring is to use a Swan-Ganz catheter (Edwards Lifesciences corporation, CA, USA). Because this catheter comes with a chance of complications, its benefits over risks are being analyzed.2) Due to the complications that have developed related to Swan-Ganz catheters such as infection risk and bleeding risk3), developments have been made that allow for continuous monitoring of cardiac output or circulatory dynamics in a less invasive form. The devices developed are the Vigileo monitor (Vigileo) (Edwards Lifesciences corporation, CA, USA) and the LiDCORapid (Lidcolimited, London, UK).4)5) These machines provide information from the entire body, including the reaction to fluid optimization.6)-13)

Vigileo is a minimally invasive monitor that has an arterial pressure waveform analysis as its form of measurement. This form of measurement doesn't require calibration. It calculates the stroke volume and shows the cardiac output from the standard deviation of the arterial pressure, age, sex, height, weight and multiplies the coefficient that was calculated from the statistical treatment.14) The arterial pressure waveform that was sampled in a rate of 100Hz (100time/sec) is calculated every 20 seconds and the coefficient gets updated every minute from the standard deviation. The calculating and updating of the cardiac output is done every 20 seconds or every 5 minutes (version 4.00). With the combined use of flow track sensor, PreSep CV oximetry, arterial pressure cardiac output (AVCO) or change in one stroke volume (SVV), mixed venous oxygen saturation (SvO_2) or central venous oxygen saturation ($ScvO_2$) and other hemodynamic parameters, cardiac output can be measured continuously.

Similarly, the LiDCORapid, is a minimally invasive monitor that has the arterial pressure waveform analysis as the principle form of measurement and does not need to be calibrated. It samples the arterial pressure signal from the biological information monitor and uses its own algorithm to change the pressure signal to a waveform that shows the blood volume change. Heart rate and stroke volume can be calculated from that arterial blood volume change waveform. CF (calibration coefficient) of the individual patient is calculated by inserting the age, height, weight data and the clinical data that is registered by the nomogram that is in the algorithm. In the US and Europe, this clinical data is used and measured mainly by a Lithium dilution method. In Japan, the data from the thermo-dilution method is used. The clinical data is directly proportional to the patient's height and weight and inversely proportional to the patient's age. There are big differences in the two monitoring systems, each has its own method of interpreting the aortic pressure waveform. Therefore, different results may be obtained from each device. A simulator, which creates a stable pressure waveform, provides us with a way to analyze each device's method of obtaining cardiac output.

II. METHOD

The comparison analysis of the cardiac output was measured between Vigileo and LiDCORapid. For the artificial pressure source or simulator, a blood pressure calibrator made by BIO-TEK INSTRUMENTS called BIO-TEK601A was used. Aortic pseudo waveform (Ao) used systolic pressure 140mmHg, diastolic pressure 80mmHg and heart rates of both 90 and 120 beats per minute (bpm). Radial

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pseudo waveform (Rd) used systolic pressure 140mmHg, diastolic pressure 80mmHg and heart rate of 90 bpm. For the pressure transducer, the flow track sensor kit MHD6S made by Edwards Life Science was used. For the artery pressure waveform, the bedside monitor BSM-6000 made by Nihon Kouden was used. Circuit diagram of this experiment is shown on Fig 1.

The simulations settings were height of 160 cm, weight of 60 kg and body surface area of 1.62m^2. The measurement was performed at the ages of 80, 70, 60, 50, 40 and 30 for both male and female. For Vigileo the required field of height, weight, age and gender, were entered. The required fields of height, weight, and age were entered for LiDCORapid. Verification was done on the cardiac output (l/min) (CO). This CO was displayed from the data that was divided into each model, sex, age and input waveform. The value of CO was measured 3 min after the experiment started. For statistical evaluation of the experimental data, Mann-Whitney U-test or Wilcoxon Signed rank sum test were used. Differences at $P < 0.05$ were considered significant (Table 1).

Fig 1 Circuit diagram of the experimental system

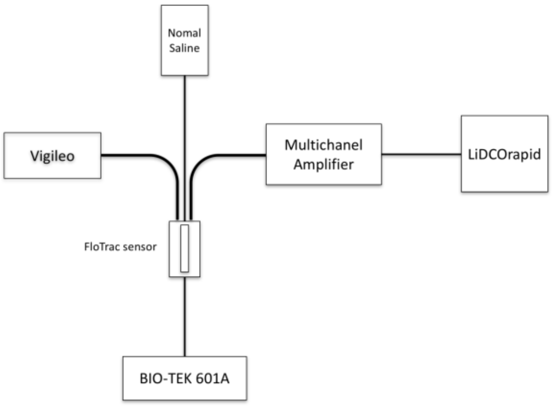

Table 1 Method of each tables

	Method	Unit	Statistical analysis
1	Comparison of CO was obtained between the two models	l/min	N/A
2	Comparison of CO between genders	N/A	Man-Whitney U test
3	Comparison of CO due to age	l/min	
4	Comparison of CO on input waveform LiDCORapid Ao (90 beats): Rd (90 beats)	N/A	Wilcoxon Signed rank sum test
5	Comparison of Stroke Volume in beats (Ao)	Ml	N/A
6	Comparison of CO due to systemic vascular resistance value.	System Vascular Resistance (SVR) = (Mean arterial pressure – right arterial pressure) / (CO x 79.92) Normal value 800 – 1200 (dyne*sec*cm^{-5})	N/A
7	Comparison of CO was made on the effect that difference in heart rate has on vascular resistance value	dyne*sec*cm^{-5}	N/A

III. RESULT

With all ages, CO in Ao and Rd at LiDCORapid measured higher than Vigileo. Note difference in CO between male and female as evidenced by P value of 0.0313. When both the heart rates are the same and AO and Rd input waveforms are used in borth models, the Vigileo didi not show significant difference in CO (p=0.552) while the LiDCORapid showed significant difference in CO (p=0.0021) (Table 2). LiDCORapid measured higher than Vigileo (Table 3).

The comparison of Stroke Volume in ml for heart rates of 90 and 120 bpm is shown. (Table 4). In the Vigileo, except for a 30-year-old men, stroke volume decreased at 120 beats. However, 120 beats for age of 60, 70, 80 years old in LiDCORapid showed less stroke volume compared to the Vigileo. In the comparison of vascular resistance value, Vigileo the vascular resistance Ao value was normal for the 30 years old and 40 years old male at 120 beats/min. In female, all other vascular resistance values were abnormal.

For LiDCORapid, the vascular resistance Ao value was normal for 30 year olds at 90 beats/min, the vascular resistance Ao value was normal for ages 30 – 50 at 120 beats/min. The Radial vascular resistance was abnormal across the board (Table 5).

The effect that difference in heart rate has on vascular resistance value (Table 6) (Subtracting the 120bpm result from the 90bpm result).

Both model results showed a decrease in vascular resistance with an increase in heart rate from 90 beats to 120 beats, because according to the formula, blood pressure= (Heart rate x stroke volume) x vascular resistance (Elasticity) when the blood pressure is constant, and an increase in heart rate the vascular resistance decreases.

This verification was done by measuring the CO of LiDCORapid and Vigileo by using pressure calibrator BIO-TEK 601A. But the actual pressure waveform that can be obtained was not constant, it is difficult to compare with clinical use. When the two models were compared, only Vigileo had a comparison between gender because Vigileo had to have height, weight, age, and gender entered but LiDCORapid only needs height, weight, and age.

Comparing the model with the cardiac output, in every field LiDCORapid showed a higher value than Vigileo. In comparison of gender showed that at every age male had a higher CO value than females. It's predicted that there has to be a correction factor made because there is gender difference in CO with Vigileo. Also, comparing age, both instruments showed that as the age decreased the CO number was shown to be higher.

This is because Vigileo uses the standard deviation of the arterial pressure that has been measured continuously (mmHg) to derive Khi (x. The Khi (x) and arterial pressure waveform (mmHg) are converted to an arterial blood volume waveform. Khi has the algorithm that analyzes large vessel compliance, arterial waveform's skewness and kurtosis that was estimated from patient's demographic characteristics patient's pulse, standard deviation of average arterial pressure. The LiDCORapid algorithm converts the arterial pressure waveform (mmHg) to arterial blood volume waveform (mL) considering vessel compliance. After an autocorrelation processing of arterial blood volume waveform from the nomogram it decides the calibration coefficient.

Next, the comparison of cardiac output and heart rate, from the relation of CO= stroke volume x HR, the prediction was that an increase in heart rate results in an increase in cardiac output, but the Vigileo did not show this proportional relationship. LiDCORapid did show this proportional relationship. This may suggest that heart rate may cause changes in vascular resistance. Therefore, it can be said that LiDCORapid shows that with an increase in heart rate there is an increase in CO. (Table 2 and 4)

Table 2 Comparison of cardiac output (CO) between two models (l/mim), (aortic pressure (Ao), radial artery pressure (Rd)), (Beats/min (bpm)), (Male(M), Female(F))

Age	Gender	Vigileo (l/mim)			LiDCORapid (l/mim)		
		Ao		Rd	Ao		Rd
		90bpm	120bpm	90bpm	90bpm	120bpm	90bpm
80	M	2.2	2.6	2	2.8	3.7	2.6
	F	1.9	2	1.6			
70	M	3.1	3.6	3.1	4.1	5.3	3.7
	F	2.4	2.6	2.4			
60	M	3.8	4.6	3.8	4.9	6.4	4.4
	F	2.8	3.3	2.9			
50	M	4.7	5.9	4.8	5.7	7.6	5.4
	F	3.5	4.1	3.4			
40	M	5.1	6.7	5.1	6	8	5.7
	F	3.9	4.8	3.9			
30	M	6	8	6.3	6.7	9	6.4
	F	4.7	5.9	4.5			

Note difference in CO between male and female as evidenced by P value of 0.0313. When both the heart rates are the same and AO and Rd input waveforms are used in borth models, the Vigileo didi not show significant difference in CO (p=0.552) while the LiDCORapid showed significant difference in CO (p=0.0021).

Table 3 Compare LiDCORapid/Vigileo (aortic pressure (Ao), radial artery pressure (Rd)), (Beats/min (bpm)), (Male (M), Female (F))

Age	Gender	LiDCORapid/Vigileo		
		Ao		Rd
		90 bpm	120 bpm	90 bpm
80	M	127.3%	142.3%	130.0%
	F	147.4%	185.0%	162.5%
70	M	132.3%	147.2%	119.4%
	F	170.8%	203.8%	154.2%
60	M	128.9%	139.1%	115.8%
	F	175.0%	193.9%	151.7%
50	M	121.3%	128.8%	112.5%
	F	162.9%	185.4%	158.8%
40	M	117.6%	119.4%	111.8%
	F	153.8%	166.7%	146.2%
30	M	111.7%	112.5%	101.6%
	F	142.6%	150.8%	142.2%
Average		141.0%	156.4%	133.9%
Overall average		143.7%		

Table 4 Comparison of Stroke Volume in beats (aortic pressure (Ao)) (ml) (Beats/min(bpm)), (Male(M), Female(F))

Age	Gender	Vigileo (ml)		LiDCOrapid (ml)	
		90bpm	120bpm	90bpm	120bpm
80	M	24.4	21.7	31.1	*30.8*
	F	21.1	16.7		
70	M	34.4	30.0	45.6	*44.2*
	F	26.7	21.7		
60	M	42.2	38.3	54.4	*53.3*
	F	31.1	27.5		
50	M	52.2	49.2	63.3	63.3
	F	38.9	34.2		
40	M	56.7	55.8	66.7	66.7
	F	43.3	40.0		
30	M	*66.7*	*66.7*	74.4	75.0
	F	52.2	49.2		

Table 5 Comparison of vascular resistance value (dynes/sec/cm^5), (aortic pressure(Ao), radial artery pressure(Rd)), (Beats/min(bpm)), (Male(M), Female(F))

Age	Gender	Vigileo (dynes/sec/cm^5)			LiDCORapid (dynes/sec/cm^5)		
		aortic pressure Ao		Rd	Ao		Rd
		90bpm	120bpm	90bpm	90bpm	120bpm	90bpm
80	M	3633	3074	3996	2854	2160	3074
	F	4206	3996	4995			
70	M	2578	2220	2578	1949	1508	2160
	F	3330	3074	3330			
60	M	2103	1737	2103	1631	1249	1816
	F	2854	2422	2756			
50	M	1700	1355	1665	1402	(1052)	1480
	F	2283	1949	2351			
40	M	1567	*1193*	1567	1332	*999*	1402
	F	2049	1665	2049			
30	M	1332	*999*	1269	*1193*	(888)	1249
	F	1700	1355	1776			

Table 6 The effect that difference in heart rate has on vascular resistance value

(Subtracting the 120bpm result from the 90bpm result) (aortic pressure(Ao), radial artery pressure(Rd)), (Beats/min(BPM)), (Male(M), Female(F))

Age	Gender	Vigileo (dynes/sec/cm^5)			LiDCORapid (dynes/sec/cm^5)		
		Ao			Ao		
		90bpm	120bpm	VR	90bpm	120bpm	VR
80	M	3636	3077	559	2857	2162	695
	F	4211	4000	211			
70	M	2581	2222	358	1951	1509	442
	F	3333	3077	256			
60	M	2105	1739	366	1633	1250	383
	F	2857	2424	433			
50	M	1702	1356	346	1404	(1053)	351

	F	2286	1951	334			
40	M	1569	*1194*	375	1333	*1000*	333
	F	2051	1667	385			
30	M	1333	*1000*	333	*1194*	*889*	305
	F	1702	1356	346			

IV. DISCUSSION

In comparing the input waveform, Vigileo didn't have any difference in Ao and Rd. From this, it can be concluded that Vigileo is looking at the same cardiac output even if there is a waveform difference due to different measuring sources (Ao and Rd). It is able to view the skewness and kurtosis of the aortic waveform. LiDCORapid converts Ao and Rd pressure waveform to arterial blood volume waveform and evaluates each waveform as separate entities.

In general, the radial artery waveform gets sharper than the aortic pressure waveform with the same blood pressure but blood volume that is being outputted from the heart is the same. In the results Vigileo predicted a large difference between gender and age but minimal differences were shown in the overall Ao and Rd waveform. According to the results of the research Vigileo is not concerned at what point the arterial waveforms are calculated. LiDCORapid has the radial artery as a premise for the measurement condition. It has a difference in male and female gender input waveforms. As the results showed that the graphed Ao pressure was higher than the Rd arterial pressure.

In the comparison of body vascular resistance value, the value that was in the reference value was 120beats of Ao from male and as the age got older the value became higher. For LiDCORapid it was 30 years old with 90 beats of Ao and Ao of120 beats of 30,40,50 years old. Each data result showed that Vigileo vascular resistance was higher. Both model showed that the effect of difference in heart rate on vascular resistance value became higher as the subject got older.

In this research the comparison of each model, verification of the accuracy of the analysis of the numerical value (CO) cannot be assured since a simulator was used. Therefore, no conclusion can be drawn determining which model was closest to the clinical value. Vigileo derives its data from different arterial sources, the results obtained are the same, and can be seen as very useful in the OR or ICU where different pressure sources may be needed. LiDCORapid derives its information from one heartbeat. This quick device response can assist practitioners in providing a method for rapid reaction to change in patient condition. Also, because LiDCORapid doesn't need to enter gender information and only looks at change in age, analyzing the same blood pressure waveform as the age got higher CF became smaller causing SV value to become smaller and CO value to also become smaller. That change is according to the LiDCORapid concept of their algorithm. LiDCORapid results are predicted to be obtained according to the law of V=IR.

V. LIMITATIONS

The study was performed on a simulation model. It could provide more validity if the models were used on real patients in the ICU and OR settings to ensure the accuracy.

VI. CONCLUSION

We found that each model was not closest to the clinical value, because the verification of the accuracy of the analysis of the numerical value (CO) couldn't be assured due to the use of the simulator. Vigileo seems to be useful in the OR or the ICU where different pressure sources may be needed due to its consist CO results derived from different arterial sources. LiDCORapid derives its information from one heart beat (obtained according to the Ohm's law) therefore, the LiDCORapid is useful in the cardiac unit or ICU.

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