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Verification of Reliable Blood Pressure Monitor in a Moving Ambulance during an Emergency

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Abstract:
The purpose of this study was to analyze the measurements of blood pressure and time using manual and automatic blood pressure monitors in various road conditions to verify reliable blood pressure monitor in a moving ambulance. First, the manual blood pressure monitor palpation on unpaved roads showed a systolic pressure deviation of 5 mmHg. However, the automatic blood pressure monitor showed two measurement failures, one reading failure, and the measured systolic pressure deviation was 35 mmHg. The measurement time was 102 seconds faster on average than the automatic blood pressure monitor. Second, the palpation of the manual blood pressure monitor while going over speed bumps remained constant at 130 mmHg. However, the automatic blood pressure monitor had a systolic pressure deviation of 52 mmHg. The measurement time was 61 seconds faster on average than the automatic blood pressure monitor. Finally, the manual blood pressure monitor palpation on the sharp curve road showed a systolic pressure deviation of 5 mmHg. The automatic blood pressure monitor had one reading failure and the measured systolic pressure deviation was 21 mmHg. The measurement time showed that the manual blood pressure monitor was 101 seconds faster than the automatic blood pressure monitor. As a result, in a moving ambulance during an emergency, the manual blood pressure monitor showed high reliability because the blood pressure measurement was constant and the measurement time was short.

Keywords:*Emergency, Ambulance, Manual blood pressure monitor, Automatic blood pressure monitor, Road condition*

I. Introduction

The emergency situation is the pre-hospital stage, where first aid is provided at the accident site and in the ambulance, and paramedics measure blood pressure in unstable conditions with ambient noise and while the vehicle is shaking.Ambulance services are very diverse and most roads in the city are made of asphalt.As the road develops, the speed limit increases and traffic accidents caused by the speed of drivers become more frequent.In the city center there are a lot of speed bumps on the roads and when passing through the highlands, there are also sharp curve roads with steep slopes. Local roads also have regional characteristics such as unpaved roads.

The purpose of this study is to analyze the change of blood pressure measured by manual blood pressure monitors and automatic blood pressure monitors when paramedics perform first aid and work on transporting the patient in an ambulance under various inadequate road conditions, in order to find a useful blood pressure monitor for emergency situations.The blood pressure monitors used by paramedics during the transportation of patients by ambulance can be classified into an aneroid blood pressure monitor and an automatic blood pressure monitor installed in an Automated External Defibrillator. It is difficult to accurately measure blood pressure within a shaking and noisy ambulance.Blood

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pressure that is not measured correctly can lead to misdiagnosis and improper first aid treatment.

Previous studies exist on the accuracy of blood pressure measurements according to the stability of the monitor and the changing position of the emergency department students, as well as studies on the accuracy of the manual blood pressure monitor palpatory method when conducted prior to hospital treatment inside a moving ambulance [1] [2].On the other hand, this study compared the blood pressure measurement accuracy of the manual blood pressure monitor and the automatic blood pressure monitor when used inside a moving ambulance.

Until now, there has been no research on the change rate of the manual and automatic blood pressure monitor measurement values in various road environments such as unpaved roads, speed bump roads, and sharp curve roads. Therefore, this study is to verify the reliability of blood pressure monitors used in ambulances during emergency situations based on the results of the manual blood pressure monitor and automatic blood pressure monitor under various road conditions, in order to consider the situation during the transportation of the patient by ambulance.

II. Types of Blood Pressure Monitors and Measurement Methods

2.1 Manual Blood Pressure Monitor

The manual blood pressure monitor which paramedics mainly use is aneroid [3]. In this method, the pressure is transmitted to the expanding metal bellows when the pressure of the cuff increases, and the pressure is displayed on the recording meter by the principle of the lever. The measurement methods are the auscultatory method and the palpatory method [4].

The auscultatory method inserts air into a cuff of the appropriate size wrapped around the patient's arm. The pressure in the cuff is increased by 20-30 mmHg from the point where the arterial pulse is not accelerated beyond the systolic pressure. When decompressing the cuff at a rate of 2-3 mmHg per second, the Korotkoff sounds heard through the stethoscope is divided into five phases to estimate the blood pressure. In Korotkoff phase I, the sound is heard clearly and is defined as the systolic pressure. But when the sound changes suddenly into a muffling sound, in Korotkoff phase IV, it is defined as diastolic pressure [5].

The palpatory method is used when the arterial pulse is too weak to auscultate the Korotkoff sound. It is helpful to measure blood pressure when Korotkoff sounds cannot be confirmed due to the urgent situation, noisy environment, shock, etc. In addition to the stethoscope method, it can reduce the error of blood pressure measurement [6]..

2.2 Automatic Blood Pressure Monitor

Oscillometric methods are often used for automatic blood pressure monitors [7] [8]. This method determines the systolic blood pressure and the diastolic blood pressure according to the microscopic change over time of the vibration magnitude according to the pulse pressure of the cuff pressure when measuring the blood pressure [9]. Automatic blood pressure monitors are widely used because they are easy to measure with [10]. The blood pressure monitor in ambulances which is used the most in consideration of the practical situation is an AED (Automated External Defibrillator) automatic blood pressure monitor, which consists of a body and a cuff. The main body consists of a sensor for measuring blood pressure, an air pump for pressurizing the air to the cuff, a motor for operating the pump, a display screen for displaying the measurement result, and an adjustment part for controlling the monitor. The cuff consists of a hose which delivers the air pressure and an air pocket. The operation is fully automated and measures hypertension, hypotension, and pulse rate through pressurization and ventilation. However, the error rate is relatively high because of dependency on vascular characteristics such as the cuff size and the arterial stiffness [11].

2.3 Advantages and Disadvantages of Manual and Automatic Blood Pressure Monitors

Table 1 shows the advantages and disadvantages of manual and automatic blood pressure monitors. Manual blood pressure monitors are accurate and quick, but require a lot of experience and skill. Although the automatic blood pressure monitor is easy to use, it receives a lot of stimuli due to external

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factors, resulting in a decrease in accuracy and a long measurement time.

Table 1. Advantages and Disadvantages of Manual and Automatic Blood Pressure Monitors

	Manual Blood Pressure Monitor	**Automatic Blood Pressure Monitor**
Advantages	• Fast measurement time • Accurate measurement	• Can be used simultaneously for first aid treatment • Easy to use despite lack of workers • Suitable for stable patients (AED)
Disadvantages	• Stethoscope is difficult to measure when the site is noisy or the vehicle is shaking • Requires a lot of experience and skill	• When vehicle is shaking, accuracy and reliability is low • Stimulated a lot by external factors and sensitive to vibration • Measurement takes a long time

III. Experimental Condition and Method

This study was conducted from May 16th to May 17th 2017 using an aneroid manual blood pressure monitor and an automatic blood pressure monitor installed in an Automated External Defibrillator (AED). The experiment was conducted by paramedics travelling by ambulance in various road conditions. Blood pressure was measured five times at five minute intervals with a manual blood pressure monitor and an automatic blood pressure monitor (automated external defibrillator) to compare and analyze accuracy and timing of the two monitors according to road condition.

3.1 Experimental Condition

While the ventilator and air conditioner are running inside the ambulance similar to simulate the usual noise of the real life situation, the blood pressure is measured five times at five minute intervals using the palpatory method with a manual blood pressure monitor (aneroid) inside the ambulance. Blood pressure was also measured five times at five minute intervals with an automatic blood pressure monitor (AED) to verify the usefulness of the blood pressure monitor during the ambulance transfer by checking the measurement time and the change rate of blood pressure measurement on the monitor. The subjects of this study were three men in their thirties with standard builds and normal blood pressure (120/80). The blood pressure and driving were measured and operated by a female nurse, a second emergency medical technician, and a driver.

The manual blood pressure monitor consists of an aneroid cuff, a pressure gauge (300 mmHg), an air pressure pump, an exhaust valve, and a stethoscope. Automated external defibrillators used as automatic blood pressure monitors are effective because they are able to simultaneously measure vital signs such as pulse rate and respiratory rate. As shown in Table 2, a rechargeable battery is used as the power source and the weight is below 8.5 kg.

Table 2. Specification of Automated External Defibrillator (AED)

Power Source	**Component**	**Monitor**	**Method of Use**	**Time of Use**	**Weight**
AC power source, rechargeable battery	System unit, EDG cable, vital sign measuring instrument, printer	5-11 inches	Turn on the upper power section	90 minutes (approx.)	Below 8.5 kg

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As shown in Table 3, the ambulance used in the experiment is mainly an ambulance arranged in the fire station, which is convenient for passing through a narrow residential street. The ambulance, which has a seating capacity of five people, has a total width of less than 2 m and a total height of less than 2.5 m, which means it is maneuverable.

Table 3. Specification of Ambulance

Model	Gross Weight	Seating Capacity	Tire	Width	Height	Engine Power	Length
Hyundai Grand Starex	2,595 kg	5 people	215/70 R/16	1920 mm	2400 mm	175/3600	5150 mm

Table 4 shows the specific conditions of the experiment location. In order to evaluate the change rate of blood pressure measurement in a moving ambulance, the ambulance drove at a constant speed of 20 km/h on unpaved roads because it is impossible to test an automatic blood pressure monitor at 40 km/h on unpaved roads. When driving on speed bump roads and sharp curve roads, the ambulance drove according to the speed limit at a constant speed of 40 km/h. To increase the reliability of the experiment, the experiment was repeated a total of five times.

Table 4. Experiment Location

Location	Type of Road	Road Condition	Driving Method	Speed Bumps	Driving Speed
Hwarang-ro, Seongbuk-gu, Seoul, Republic of Korea	Unpaved road (sports field)	Soil	Drive straight then repeat curve	None	20 km/h
Hoegi-ro, Seongbuk-gu, Seoul, Republic of Korea	Speed bump road (flatland)	One way road, four straight-line curve sections	Drive measurement section 5 times	7 places, height of 7-9 cm	40 km/h
Bugaksan-ro, Seongbuk-gu, Seoul, Republic of Korea	Sharp curve road (slope)	One way road, four curve sections	Drive measurement section 5 times	4 places	40 km/h

3.2 Experiment Method

The experiment confirmed the change rate of each blood pressure measurement while the ambulance was running. The initial blood pressure measurement had a preparation time of around 15 seconds because of the time spent winding the cuff around the subject's arm.

Inside the moving ambulance, the manual blood pressure monitor was operated while the patient was sitting comfortably in a seat with their arm equal to the height of the heart. In order to improve the accuracy of the experiment, paramedics with practical experience and skill were selected because they can understand the experiment which uses a manual blood pressure monitor and automatic blood pressure monitor. The palpation was measured using a manual blood pressure monitor. The cuff was wrapped around the upper arm of the subject and the systolic blood pressure was measured in the radial artery using the palpatory method five times at five minute intervals during the ambulance ride. The measurer,

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who was located next to the subject, recorded the systolic blood pressure through the pulse of the wrist artery using a cuff wrapped around the subject's arm.

In the measurement of the automatic blood pressure monitor, the subject wore a seat belt while lying on a bed with his arm equal to the height of his heart, his back relaxed, and his head slightly lifted. The cuff was wrapped around the left upper arm and the systolic and diastolic blood pressures were measured by pressing the start button. The blood pressure was measured five times during the ambulance ride and the change rate was analyzed.

IV. Experiment Results and Discussion

4.1 Unpaved Roads

Table 5 shows the results of blood pressure measurements on unpaved roads. When the palpation was recorded in a moving ambulance, the maximum value shown was a systolic pressure of 130 mmHg, which was shown four times, and the minimum value was a systolic pressure of 125 mmHg, shown once. The results of the automatic blood pressure monitor in the moving ambulance were a maximum value of 152/99 mmHg and a minimum value of 117/80 mmHg, and there were also two measurement failures and one reading failure appeared. The manual blood pressure monitor had a maximum deviation of 5 mmHg and the automatic blood pressure monitor had a maximum deviation of 35 mmHg. The accuracy of the manual blood pressure monitor was higher. Therefore, the results are statistically significant.

The average blood pressure measurement time in the moving ambulance was 15.00 seconds for the manual blood pressure monitor and 117.00 seconds for the automatic blood pressure monitor. The measurement time for the manual blood pressure monitor was 102 seconds faster on average.

Table 5. Comparison of Blood Pressure Monitors on Unpaved Roads

Test Number	Vehicle State	Vehicle Speed(km/h)	Manual Blood Pressure Monitor		Automatic Blood Pressure Monitor		Note
			Palpation (mmHg)	Measurement Time (seconds)	Automated Electronic Defibrillator (mmHg)	Measurement Time (seconds)	
1	Moving	20	125	15	Measurement Failure	230	Wrapped cuff
2	Moving	20	130	15	Reading Failure	95	
3	Moving	20	130	15	Measurement Failure	130	
4	Moving	20	130	15	152/99	40	
5	Moving	20	130	15	117/80	90	
Average	**-**	**20**	**129.00**	**15.00**	**-**	**117.00**	

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Figure. 1 is a set of images showing an automatic blood pressure monitor (AED) error occurrence. Figure. 1 (a) shows the measurement failure screen and Figure. 1 (b) shows the reading failure screen. During the ambulance ride, the highest blood pressure measurement recorded was 129 mmHg with the manual blood pressure monitor and 152/99mmHg with the automatic blood pressure, so there was a big difference. The measurement time was 15 seconds with the manual blood pressure monitor and 117.00 seconds with the automatic blood pressure monitor, which means there was a difference of over one minute. The automatic blood pressure monitor showed three measurement and reading failures when the ambulance was moving at 20 km/h speed. The results confirm that the reliability is low due to the large rate of change of the measured values in the case of conditions with lots of vibration such as driving on unpaved roads. Therefore, when measuring blood pressure with an automatic blood pressure monitor, it should be measured under the most stable condition possible. In order to increase the accuracy of the blood pressure measurement, it is necessary to prevent the error of the automatic blood pressure monitor by measuring with a manual blood pressure monitor.

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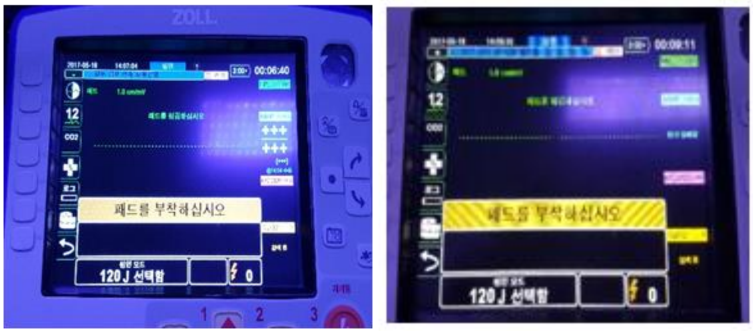

Measurement Failure Screen

Reading Failure Screen

Figure. 1. Automatic Blood Pressure Monitor (AED) Error Occurence Images
(a) Automatic Blood Pressure Monitor Measurement Failure Screenb) Automatic Blood Pressure Monitor Reading Failure Screen

4.2 Speed Bump Road

Table 6 compares the blood pressure monitor measurements on a road with speed bumps. In all of the five tests, the palpation was constant at a systolic air pressure of 130 mmHg, so the average systolic air pressure was 130 mmHg. The automatic blood pressure monitor showed a highest reading of 152/80 mmHg and a lowest reading of 100/78 mmHg inside the moving ambulance. The maximum systolic pressure deviation of the automatic blood pressure monitor was 52 mmHg, which was higher than that of the manual blood pressure monitor, so the manual blood pressure monitor was more accurate. This result shows statistical significance.

The analysis of the blood pressure measurement time showed that the manual blood pressure monitor had an average measurement time of 15 seconds for measuring palpation and the automatic blood pressure monitor had an average measurement time of 76 seconds. The manual blood pressure monitor was 61 seconds faster on average than the automatic blood pressure monitor when being used inside a moving ambulance in unstable conditions.

Table 6. Comparison of Blood Pressure Monitors on Speed Bump Roads

Test Number	**Vehicle State**	**Vehicle Speed(km/h)**	**Manual Blood Pressure Monitor**		**Automatic Blood Pressure Monitor**		**Note**
			Palpation (mmHg)	**Measurement Time (seconds)**	**Automated Electronic Defibrillator (mmHg)**	**Measurement Time (seconds)**	
1	Moving	40	130	15	148/78	50	
2	Moving	40	130	15	114/79	60	
3	Moving	40	130	15	100/78	90	Wrapped cuff
4	Moving	40	130	15	152/80	90	
5	Moving	40	130	15	105/76	90	
Average	**-**	**40**	**130.00**	**15.00**	**-**	**76.00**	

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4.3 Sharp Curve Roads

Table 7 shows the blood pressure monitor measurement results for inside a moving ambulance on a sharp curve road. The palpation measurements recorded with the manual blood pressure monitor ranged from a minimum value of 120 mmHg, which was recorded four times, to a maximum value of 125 mmHg, recorded once. The highest value recorded with the automatic blood pressure monitor was 126/83 mmHg and the lowest value was 105/64 mmHg. There was also one reading failure with the automatic blood pressure monitor, so the blood pressure measurement could not be known. A malfunction of the sensor seems to have been caused when the ambulance passed through a sudden turn on a sharp curve road and went over a speed bump. The blood pressure measurement of palpation had a deviation of 5 mmHg. It was determined that the reason for this was because the measurement was difficult to center on a sudden turn because it was difficult for the person measuring to stay balanced, and it was also difficult to accurately detect the pulse of the radial artery. The maximum deviation of the automatic blood pressure monitor was 21 mmHg, so the accuracy of the manual blood pressure monitor was higher than the automatic blood pressure monitor. This result is statistically significant.

The average blood pressure measurement time inside the moving ambulance was 15 seconds for the manual blood pressure monitor and 116.00 seconds for the automatic blood pressure monitor. It can be seen that the manual blood pressure monitor is 101 seconds faster on average than the automatic blood pressure monitor when used in an unstable situation while driving.

Based on these results, it can be seen that it is difficult to cope with an emergency when the manual blood pressure monitor is not used because there is a great difference in the measurement time between the two monitors when they are used inside a moving ambulance. In addition, when the pump is used to correctly use the manual blood pressure monitor, if the cuff pressure is too low, the systolic blood pressure cannot be accurately measured. On the other hand, too much pressure may cause unnecessary pain and irritation to the patient. It seems to be necessary to have a proper technique for applying pressure of 20-30 mmHg from the point where the pulse of the upper arm and radial artery cannot be detected.

Table 7. Comparison of Blood Pressure Monitors on Sharp Curve Roads

Test Number	**Vehicle State**	**Vehicle Speed(km/h)**	**Manual Blood Pressure Monitor**			**Automatic Blood Pressure Monitor**		**Note**
			Auscultation (mmHg)	**Palpation (mmHg)**	**Measurement Time (seconds)**	**Automated Electronic Defibrillator (mmHg)**	**Measurement Time (seconds)**	
1	Moving	40	-	120	15	115/72	180	Wrapped cuff
2	Moving	40	-	120	15	110/68	80	
3	Moving	40	-	125	15	Reading Failure	90	
4	Moving	40	-	120	15	105/64	150	
5	Moving	40	-	120	15	126/83	80	
Average	-	**40**	-	**121.00**	**15.00**	-	**116.00**	

V. Conclusions

The purpose of this study was to analyze blood pressure measurement and measurement time using manual and automatic blood pressure monitors on unpaved roads, speed bump roads and sharp curve roads in order to verify the reliability of blood pressure monitors while in a moving ambulance. The results of the experiment are as follows.

Unpaved Roads

The palpation measurements from the manual blood pressure monitor showed a systolic pressure deviation of 5 mmHg. The automatic blood pressure monitor showed two measurement failures and one reading failure during the ambulance operation and the deviation of the systolic pressure during the measurement was 35 mmHg, so the automatic blood pressure monitor was less accurate. It is considered that the unsteady state of the unpaved road caused noise and vibration in the ambulance, which caused malfunction of the blood pressure monitor sensor. The measurement time is 102 seconds faster than the manual blood pressure monitor.

Speed Bump Roads

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The acceleration during the ambulance driving of the manual blood pressure monitor was constant at 130 mmHg. The automatic blood pressure monitor had a deviation of 52 mmHg in systolic pressure during an ambulance. This seems to be due to the fact that the noise and vibration of the ambulance caused by the speed bumps is larger than the unpaved road. The measurement time was found to be 61 seconds faster than the manual blood pressure monitor.

Sharp Curve Roads

Acceleration during manual ambulatory ambulance was measured with a systolic pressure deviation of 5 mmHg. The automatic blood pressure monitor had one reading failure while driving the ambulance, and the measured systolic pressure deviation was 21 mmHg. The reason for this is that the sensor malfunctioned due to the shaking of the vehicle body during a sudden turn. The measurement time was 101 seconds faster than the manual blood pressure monitor.

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