Simulation study on quality of CPR between manual chest compression and mechanical chest compression devices performed in ambulance

Tuan Hairulnizam Tuan Kamauzaman, MMed (EM)[1], Johnny Ngu Tai Hock, MMed (EM)[2], Ariff Arithra, MMed (EM)[1], Abu Yazid Md Noh, MMed (EM)[1], Siti-Azrin Ab Hamid, MSc Medical Statistics (USM)[3], Junainah Nor, MMed (EM)[1]

[1]Department of Emergency Medicine, School of Medical Sciences, Universiti Sains Malaysia, Kubang Kerian, Kelantan, Malaysia, [2]Hospital Queen Elizabeth, Kota Kinabalu, Sabah, Malaysia, [3]Biostatistic and Methodology Research Unit, School of Medical Sciences, Universiti Sains Malaysia, Kubang Kerian, Kelantan, Malaysia

ABSTRACT

Background: Maintaining good quality CPR while transporting out-of-hospital cardiac arrest patients is very challenging. We aim to determine how different ambulance speed can affect the quality of chest compression performed either manually or mechanically.

Methods: This was an observational manikin-based study. A total of 96 participants as well as two types of mechanical compression devices: Lucas-2 and AutoPulse, performed one minute of continuous chest compression on BT-CPEA programmed manikin while the ambulance travelled at different speeds, i.e., idle state, 30km/hr and 60km/hr. Seven outcome variables of chest compression were measured. Performance data of different groups of compressor were compared and analysed using repeated measures analysis of variance (ANOVA).

Results: In manual chest compression, significant variation were noted among different speeds in term of average compression rate ($p<0.001$), average compression depth ($p=0.007$), fraction of adequate/insufficient compression depth and fraction of normal hands positioning with $p=0.018$, 0.022 and 0.034 respectively. Overall, AutoPulse and Lucas-2 were not affected by ambulance speed. Lucas-2 showed more consistent average compression rate, higher fraction of adequate compression depth and reduced fraction of insufficient compression depth as compared to manual compression with $p<0.001$, 0.001 and 0.043 respectively.

Conclusion: In this study we found that ambulance speed significantly affected certain aspects of manual chest compression most notably compression depth, rate and hand positioning. AutoPulse and Lucas-2 can improve these aspects by providing more consistent compression rate, depth and fraction of adequate compression depth during transport.

KEYWORDS:
Ambulance speed, chest compression, mechanical compression device, out-of-hospital cardiac arrest, prehospital care

INTRODUCTION

Incidence of out-of-hospital cardiac arrest (OHCA) is about 37 per 100,000 persons-years in Europe.[1] At the moment, the information regarding the incidence of OHCA in Malaysia and its outcome is still very limited and fragmented. Based on a study done at Hospital Kuala Lumpur in 2011, the survival rate for OHCA was only 16.8%.[2] There are various confounding factors, be it human or environmental, for the low survival rate of OHCA victims. For a primary responder to be able to transport the victims safely to the hospital while maintaining an effective cardiopulmonary resuscitation (CPR) in a mobile ambulance is indeed challenging.

A study showed that OHCA victims who had a shorter time to reach medical contact and received continuous good quality of life-support interventions during transportation had higher survival rates.[3] Emergency Medical Services usually face challenges to maintain a good quality CPR during transportation, especially when the ambulance encounters acceleration-deceleration, vehicle turning, ascending and descending slopes and uneven roads.[4] Another study showed increased CPR variabilities during ground ambulance transportation of patients in cardiac arrest when chest compressions were performed at the scene, in the ambulance and in the emergency department.[5]

Some centres advocate slow and constant ambulance speed during transportation of OHCA victim when CPR is in progress. However, a study indicates that even a constant speed of ambulance may directly affect the quality of CPR during patient transportation, factors such as increased rate and depth of chest compressions as well as no flow fraction.[6]

Mechanical compression device was first invented in the early 20's to overcome several issues encountered in CPR during ambulance transportation, including inconsistency of quality between different chest compressors, chest compressor fatigue that set in over time, and limited number of rescuers during CPR. Earliest manikin-based study done in 2007 comparing single rescuer CPR and active compression-decompression device showed that the latter was highly effective in delivering chest compressions and was not affected by the changes in a mobile environment.[7]

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Corresponding Author: Junainah Nor
Email: junainahnor@usm.my

However, there is still lack of evidence on patient outcome in OHCA after using different mechanical devices and manual compression in mobile environments especially when considering the speed of ambulances. Different devices have their pros and cons. AutoPulse has the advantage of giving circumferential compression for victims of different sizes based on chest circumferential diameter. Slight delay may occur in commencing chest compression due to the time taken by the machine to analyse and calculate the correct compression depth. Whereas Lucas-2 is set according to AHA BLS guideline for adult CPR. Some concerns arise regarding safety and efficiency in relatively small or big sized victims. Clear evidence showing improved patient outcome by using these mechanical compression devices in OHCA in term of survival and neurological function is still lacking.[8]

Emergency Medical Services in Malaysia has yet to recommend mechanical compression devices as the standard equipment in all prehospital respond teams. On the other hand, 2015 American Heart Association Guidelines for adult Basic Life Support (BLS) recommends that mechanical compression device may be a reasonable alternative to conventional CPR in specific settings in which the delivery of high quality CPR may be challenging or dangerous for the provider (e.g., limited rescuers available, prolonged CPR, CPR during hypothermic cardiac arrest, CPR in moving ambulance, CPR in the angiography suite, and CPR during preparation for Extracorporeal CPR).

Therefore, in this observational manikin-based study, we aimed to evaluate the effect of the speed of ambulance on the quality of chest compression performed by the two different types of mechanical devices and manual chest compression. We hope that the findings of the study will serve as a useful and an informative guide in making recommendations on how to improve our prehospital CPR.

MATERIALS AND METHODS

The study was performed with the approval of the Universiti Sains Malaysia (USM) Research Ethical Committee. The study was a prospective, manikin-based observational study conducted in Heath Campus, USM.

Participants in this study were selected from paramedics and doctors working in the Emergency Department (ED) as well as final year medical students from USM. A total of 96 participants were recruited for this study. The name list of the final year medical students were obtained, with prior permission, from the Dean of School of Medical Sciences, USM while those of the paramedics and doctors were obtained from the head of ED, Hospital USM. The participants were randomly selected from their group designation list (paramedic, doctor and student) by using Microsoft Excel RANDBetween function. The selected participants who did not consent or fulfil the criteria of this study were replaced by randomly selected names from the name list until the target sample size was achieved. Participants without a minimum BLS training, having injury or had difficulty in performing CPR, or unable to complete the task were excluded.

Study Protocol

All participants were told to perform one minute of continuous chest compression on a manikin according to 2015 American Heart Association (AHA) Guidelines for CPR: (1) compression rate 100-120/min, (2) depth of compression 5-6cm, (3) allow full chest recoil and (4) minimize compression interruption. Continuous chest compression was done in the rear compartment of an ambulance. The ambulance was operated with warning lights. Chest compression at a stationary state was performed with the engine of the ambulance kept on but the vehicle was in the idle state. Chest compression and data recording were started after the ambulance had achieved the targeted speed and each speed was maintained at ± 5km/hr range. GPS was used to monitor the ambulance speed. Participants did not support themselves with any structures in the ambulance while performing chest compression.

The trial started with 3 different groups of chest compressors, who were the medical students, paramedics and medical officers, followed by two mechanical compression devices namely AutoPulse and Lucas-2. One minute of manual chest compression was performed on the manikin right after the ambulance achieved each targeted velocity: idle state, 30km/hr and 60km/hr. To avoid the effect of compressor fatigue on the quality of CPR, participants were given 15 minutes of rest between trials. On the other hand, mechanical chest compression devices were applied correctly on the manikin based on the instruction manual. Continuous compression mode was selected and ran right after the ambulance achieved the targeted velocity. The ambulance run was repeated three times for each variable for each mechanical device. At the end of the trials, performance data was transferred from manikin to personal computer via blue-tooth and the results were summarized using a compatible software.

Research Tool

A programmed ACLS simulation manikin, CPR Evaluation Simulator BT-CPEA was used for the CPR performance evaluation. It is capable of measuring average compression rate, average compression depth, total hands-off time, fraction of adequate relaxation, and fraction of correct hands positioning. The manikin was strapped on a rigid spinal board that was secured on the ambulance stretcher. We used a van-based Mercedes-Benz Sprinter L2 H2 4x4 (Type B Ambulance) with a coil-spring-type suspension in this study. GPS was used to monitor ambulance speed to ensure that it travelled within ±5km/hr of the target speed.

Two mechanical compression devices commonly used in the prehospital care were used in this study, namely AutoPulse (2005) and Lucas-2 (2014). AutoPulse is an automated, portable, battery-powered compression device composed of a constricting band and half backboard that is intended to be used as an adjunct to CPR during advanced cardiac life support. It measures chest size and resistance before it delivers the unique combination of thoracic and cardiac chest compression. The compression depth and force varies per patient. The chest displacement equals a 20% reduction in the anterior-posterior chest depth. It runs in a 30:2, 15:2 or continuous compression mode, which is user-selectable, at a rate of 80 compressions per minute. Whereas Lucas-2 is a chest compression system which includes a base unit with a back plate, carrying bag, patient straps, stabilization strap, suction cups, and one rechargeable lithium polymer battery. The operator can choose to deliver 30:2 compression-to-ventilation ratio or continuous CPR. Compression is delivered via piston with suction cup that allows chest recoil during decompression. Lucas-2 can deliver a compression rate of 102±2 per minute and a compression depth of 53±2mm which is strictly adhered to AHA adult BLS 2015 guideline.

Study Location
The study took place at an identified jogging track within the USM campus. The length of the identified road was approximately 1.8km long, straight and in good condition.

Outcome Variables
Average compression rate (compression/min), average compression depth (mm), fraction of adequate/insufficient/excessive compression depth (%), fraction of adequate chest relaxation (%) and fraction of normal hand positioning (%) were measured when manual chest compression and mechanical compression by two different types of devices were performed in the ambulance travelling at 0km/hr, 30km/hr and 60km/hr.

Statistical Analysis
Data was entered and analysed using IBM SPSS version 23.0. Numerical data were presented as mean (standard deviation) or median (interquartile range) based on normality of distribution. Categorical data were presented as frequency and percentage. Predefined outcome variables at an idle state, 30km/hr and 60km/hr were compared using repeated measure ANOVA. General linear model contrasts were tested for cases which did not show overt linearity. A p-value of less than 0.05 is considered to represent statistical significance at a 95% confidence interval.

RESULTS

Of the 96 participants, 32 were doctors, 32 paramedics and 32 medical students. The mean (SD) age of participants was 26.1±3.6 years old. Among the participants, 53.6% were males and 43.8% were females. All of them had received a minimum of BLS training while 28.1% of them had received advanced cardiac life support training. Forty-point six percent received their last training in the last 6 months, 18.8% within a year while 40.6% received training more than a year ago. Thirty-three-point three percent participants had no experience working in the ED and they were all medical students, 30.2% had worked less than 2 years, 27.1% had worked for 2 to 5 years while 9.4% had worked more than 5 years. Mean (SD) height of participants was 1.63m±0.09m while mean (SD) weight of participants was 61.11kg±13.36kg. Mean (SD) body mass index (BMI) for all participants was 22.96±4.10kgm^{-2}.

The mean of all outcome variables measured during manual and mechanical compression in the ambulance travelling at 0km/hr, 30km/hr and 60km/hr are summarized in Table I. Table II shows all the pairwise comparisons among different ambulance speed. We found a strong relationship between ambulance speed and the quality of manual chest compression. It showed a linear relationship between ambulance speed and average compression rate. As the speed of ambulance increased, the average compression rate also increased, and statistical significance was noted when the ambulance speed reached 60km/hr (p=0.001). Average compression depth decreased in a linear trend notably as soon as the speed of ambulance reached 30km/hr (p=0.007) and 60km/hr (p=0.016). The fraction of correct hands positioning during chest compression showed a significant decrease at 30km/hr (p=0.034). Other outcome variables such as hands-off time and the fraction of adequate relaxation did not show any statistical significance up till the speed of 60km/hr. Performance by Lucas-2 and AutoPulse did not show any statistically significant differences in all outcome variables.

Table III shows a pairwise comparison between the human group, AutoPulse and Lucas-2. Among those, three outcome variables showed a significant difference when the human group was compared with Lucas-2 and AutoPulse. These variables were average compression rate, fraction of adequate depth and fraction of insufficient compression depth. The effect of ambulance speed on average compression rate was more significant in the human group as compared to AutoPulse and Lucas-2 with p<0.001 and p=0.038, followed by the fraction of adequate compression depth with p=0.030 and p<0.001, and fraction of insufficient compression depth with p=0.028 and p=0.043. There were two outcome variables wherein only human group and AutoPulse had a significant difference. They were average compression depth and fraction of adequate chest relaxation with p=0.022 and 0.020.

In another sub-analysis to compare both the mechanical compression devices, we noticed that the AutoPulse and Lucas-2 showed significant statistical differences in three outcome variables. They were average compression depth, fraction of adequate compression depth and fraction of insufficient compression depth with p=0.019, p<0.001 and p<0.001 respectively. In term of fraction of excessive compression depth and fraction of normal hand positioning, we found no statistical significance among the three groups. Figure 1 further shows the estimated marginal means of average compression rate, average compression depth, and fraction of normal hand positioning among the three groups.

DISCUSSION

This is a follow-through study that evaluates the effects of ambulance speed on the quality of manual chest compression in a more detailed manner while comparing it with mechanical compression. Results of this study clearly showed that the speed of ambulance can affect many aspects of manual chest compression. We found a strong link between the speed of ambulance and manual compression rate which were both increased in a linear trend. The compression rate of 120/min generated the largest blood flow then it declined with a further increased rate.9 The increased compression rate could be associated with the adrenaline rush and therefore increased sympathetic response of the compressors. This was one of the features which was almost negligible in both mechanical compression devices.

Table I: Mean of all outcome variables

	Type of compressor	Speed of ambulance Mean (SD)		
		Idle	30km/hr	60km/hr
Average compression rate (/min)	Manual	122.23(16.2)	124.65(14.37)	127.79(14.36)
	Lucas-2	107(1)	104.67(2.08)	104.67(3.06)
	AutoPulse	94.67(1.53)	98(8.89)	82.67(1.53)
Average compression depth (mm)	Manual	49.41(7.26) 53(0)	47.68(8.12)	47.49(8.64)
	Lucas-2	53(0)	52.67(0.58)	53.33(0.58)
	AutoPulse	38.67(2.89)	36(1)	35.67(0.58)
Fraction of adequate compression depth (%)	Manual	47.4(33.01)	38.86(38.85)	37.21(32.57)
	Lucas-2	99.7(0.52)	98.47(1.19)	98.7(0.52)
	AutoPulse	0(0)	0(0)	0(0)
Fraction of insufficient compression depth (%)	Manual	42.92(38.08)	52.2(38.16)	51.47(40.12)
	Lucas-2	1.3(0.52)	0.3(0.52)	1.2(1.51)
	AutoPulse	100(0)	100(0)	100(0)
Fraction of excessive compression depth (%)	Manual	9.7(20.21)	8.94(21.09)	8.94(21.09)
	Lucas-2	0(0)	0(0)	0(0)
	AutoPulse	0(0)	0(0)	0(0)
Fraction of adequate chest relaxation (%)	Manual	97.32(13.65)	99.08(5.51)	99.17(2.85)
	Lucas-2	95.63(1.43)	97.73(1.10)	97.8(2.99)
	AutoPulse	84.87(1.40)	82.13(8.78)	97.4(2.71)
Fraction of normal hand positioning (%)	Manual	74.92(33.23)	67.17(35.26)	70.03(33.54)
	Lucas-2	93.77(1.10)	92.8(2.72)	90.43(3.49)
	AutoPulse	70.47(31.54)	20.33(12.48)	11.3(8.19)

Numerical values in table: mean (standard deviation)

Table II: Pairwise comparison among different speed of ambulance

	Velocity (km/hr)	Human		Lucas-2		AutoPulse	
		MD (95% CI)	p-value*	MD (95% CI)	p-value*	MD (95% CI)	p-value*
Average compression rate (/min)	0 vs. 30	-2.417	0.202	2.333	0.951	3.333	1
	0 vs. 60	-5.562	0.001	2.333	0.889	12	0.061
	30 vs. 60	-3.146	0.010	0.001	1	15.333	0. 221
Average compressiondepth (mm)	0 vs. 30	1.729	0.007	0.333	1	2.677	0.809
	0 vs. 60	1.917	0.016	-0.333	1	3	0.565
	30 vs. 60	0.188	1	0.333	1	-0.667	1
Fraction of adequate compression depth (%)	0 vs. 30	8.543	0.018	1.233	0.265	0	0
	0 vs. 60	10.191	0.011	1	0.583	0	0
	30 vs. 60	1.648	1	-0.233	1	0	0
Fraction of insufficient compression depth (%)	0 vs. 30	-9.273	0.022	-0.9	0.793	0	0
	0 vs. 60	-8.55	0.066	-1	0.583	0	0
	30 vs. 60	0.723	1	-0.1	1	0	0
Fraction of excessive compression depth (%)	0 vs. 30	0.758	1	0	0	0	0
	0 vs. 60	-1.366	1	0	0	0	0
	30 vs. 60	-2.124	0.945	0	0	0	0
Fraction of adequate chest relaxation (%)	0 vs. 30	-1.754	0.365	-2.1	0.791	2.733	1
	0 vs. 60	-1.848	0.443	-2.167	0.938	-12.533	0.099
	30 vs. 60	-0.094	1	-0.067	1	-15.267	0.020
Fraction of normal hand positioning (%)	0 vs. 30	7.743	0.034	0.967	1	50.133	0.477
	0 vs. 60	4.878	0.162	3.333	0.506	59.167	0.221
	30 vs. 60	-2.865	0.826	2.367	1	9.033	0.778

MD (95% CI): mean difference 95% confidence interval; vs.: versus.
*Repeated Measures ANOVA

Contrary to a previous study, our study demonstrated a linear decrease in average compression depth with the increasing speed of ambulance.[6] There was a significant decline of average compression depth at ambulance speed of 30 and 60km/hr. Inadequate compression depth is not favourable during CPR as it renders the CPR ineffective. The confined compartment in the ambulance and constant vibration during transportation are two strong factors associated with the instability on an ambulance.[10,11] Adequate compression depth is not only vital in achieving good venous return from compressed thoracic vessels but also improves coronary blood flow.[12] According to the findings of some studies, instability due to inertia during speed changes may negatively impact the quality of chest compressions performed during CPR in a moving environment. As such, the environment in a moving ambulance results in a lower percentage of chest compressions that achieve adequate depth, compared to chest compressions performed on an unmoving ground.[13,14]

Table III: Pairwise comparison among different group of compressors

	GROUP	Mean Difference (95% CI)	p-value*
Average compression	Human vs. Autopulse	33.11	0.001
rate (per minute)	Human vs. Lucas-2	19.44	0.038
	Lucas-2 vs. Autopulse	13.67	0.611
Average compression	Human vs. Autopulse	11.413	0.022
depth (mm)	Human vs. Lucas-2	-4.809	0.755
	Lucas-2 vs. Autopulse	16.222	0.019
Fraction of adequate	Human vs. Autopulse	41.156	0.030
compression depth	Human vs. Lucas-2	-57.8	0.001
(%)	Lucas-2 vs. Autopulse	98.956	0.001
Fraction of insufficient	Human vs. Autopulse	-51.135	0.028
compression depth	Human vs. Lucas-2	47.932	0.043
(%)	Lucas-2 vs. Autopulse	-99.06	0.001
Fraction of excessive	Human vs. Autopulse	9.902	0.994
compression depth	Human vs. Lucas-2	9.902	0.994
(%)	Lucas-2 vs. Autopulse	0	1
Fraction of adequate	Human vs. Autopulse	10.388	0.020
chest relaxation	Human vs. Lucas-2	1.466	1
(%)	Lucas-2 vs. Autopulse	8.922	0.273
Fraction of normal hand	Human vs. Autopulse	36.674	0.115
positioning	Human vs. Lucas-2	-21.626	0.656
(%)	Lucas-2 vs. Autopulse	58.3	0.055

CI: confidence interval; vs.: versus.
*Repeated Measures ANOVA

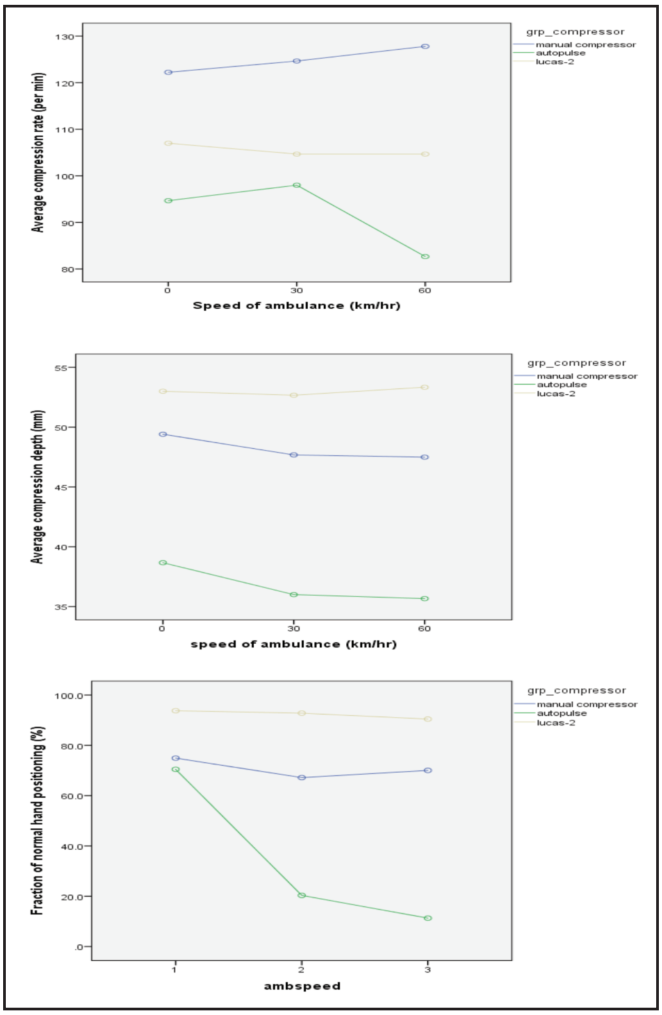

Fig. 1: Estimated marginal means of average compression rate (/min), average compression depth (mm), and fraction of normal hand positioning (%) at ambulance speed of 1) 0km/hr, 2) 30km/hr and 3) 60km/hr

Our fraction of normal hands positioning also showed a significant reduction in the human group when the speed of ambulance reached 30km/hr. Our results showed that even a slight increase in the speed of the ambulance can lead to an increased instability of chest compression. Abnormal hands positioning during chest compression renders not only ineffective CPR but also increases the risk of chest, cardiac and visceral organ injury.[15,16]

A similar test was repeated on AutoPulse and Lucas-2, however, both devices did not show any significant differences in their performance at three different speeds. When compared to both compression devices, we noted major disadvantages of manual chest compression were on the compression rate and compression depth. We noticed that there was a constant increase in the average compression rate in the human group as the speed of ambulance increased, while both mechanical compression devices were not affected. We also noticed that there was a constant decrease in the average compression depth in the human group which was not seen in both mechanical compression devices. While inconsistent performance of humans can be explained by the influence of various physical and physiological factors, both mechanical compression devices clearly have shown their superiority in giving continuous and consistent chest compression at all times regardless of the speed of ambulance. In this study, the fraction of normal hands positioning was of no difference when comparing both mechanical compression devices. We hypothesized that the clear effect of ambulance speed on hand positioning cannot be fully demonstrated due to the short duration of continuous chest compression in our study.

Sub analysis of both mechanical compression devices showed some variability mainly in term of compression depth. However, we need to bear in mind that both mechanical compression devices work in different ways and principles.

We think that we should exclude few variables namely fraction of adequate/inadequate/excessive compression depth for AutoPulse machine as it is designed in such a way that it generates circumferential compression based on chest circumference of the patients rather than a direct compression depth of 5-6 cm as proposed by AHA BLS adult.

A previous study showed that the quality of chest compression when performed on the ground is affected by gender and BMI.[17] Our study, however, was unable to demonstrate a clear association between various physiological factors, for instance, height, BMI, gender and age of the participants with the quality of chest compressions when performed on a moving ambulance. Similar negative results were also seen when looking into the associations between level of training, duration from the last training, and years of working experience in the prehospital care with the quality of chest compressions when performed on a moving ambulance.

CONCLUSION

Certain aspects of manual CPR can be affected by the speed of the ambulance. In this study, we demonstrated that the average compression rate, compression depth and fraction of normal hands positioning were affected by different ambulance speed. Whereas the quality of CPR of both mechanical compression devices were not affected by the speed of the ambulance. This condition, in which both mechanical compression devices were not affected by the speed of ambulance puts up a strong recommendation on utilizing mechanical compressions devices as mandatory equipment in OHCA, to ensure continuous high-quality CPR which can improve the patient survival.

LIMITATION OF STUDY

We intended to extend our study by increasing the speed of ambulance to 90km/hr but this was abandoned due to safety issues and unavailability of suitable study location. Another limitation of this study was the duration of chest compression performed. The reason we set only one minute of chest compression was to avoid other factors like compressor fatigue from affecting the quality of CPR. We hypothesized that if we prolonged the duration of chest compression, we may be able to demonstrate an adverse effect of ambulance speed on certain aspects like duty cycle and hand positioning. However, we feel that the primary goal of chest compression should be focused on generating adequate cardiac output, coronary and cerebral perfusion, and outcomes which are measurable by specially designed manikins.

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