

Comparison of 105 μ F VS 120 μ F Capacitor for External Defibrillation

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Abstract: Sudden cardiac arrest is steeply increasing in a human population, despite rapid development in diagnostic tools in cardiac rhythm disturbance. The defibrillator is developed to control and manage such conduction rhythm abnormalities, non-medically. The efficacy of external defibrillation can be affected by multiple factors, including capacitor size accommodated in defibrillator. Despite rapid improvement in external defibrillators, there are disputes about optimal size of capacitor for defibrillation. Therefore, in this study, we tested small (105 μ F) and standard (120 μ F) size capacitors for defibrillation efficacy with a porcine model, to identify optimal size of capacitor for external defibrillator. Our study found that there was no significant difference in the waveforms (the voltage and duration in phase 1 and 2) in different setting of energy (50, 70, 100, 150 and 200 J). Furthermore, any statistical significant difference in defibrillation efficacy has not been observed in a short-term VF and long-term VF with defibrillator accommodating different size of capacitor. Our study implies that smaller difference in capacitor size may not affect the overall defibrillation efficacy.

Key words: Defibrillation, pig, DFT, external defibrillator, capacitor

INTRODUCTION

Myocardial infarction due to coronary atherosclerosis by gradual accumulation of cholesterol is steeply increased in Korea as commonly seen in western countries and is the most common cause of morbidity and mortality in human population. The most common cause of death is a sudden cardiac death caused by cardiac rhythm disturbances such as atrial fibrillation and ventricular tachyarrhythmias. Therefore, varieties of defibrillator are used to control and manage conduction rhythm abnormalities, non-medically. Although, internal type defibrillators are more commonly used in patients suffering cardiac rhythm disturbances, external type defibrillators are also used in patients suffering sudden cardiac arrest as an accommodated emergency device in Cardiopulmonary Resuscitation (CPR). This device is designed for non-special emergency crew to easily use and accommodated several monitoring patient cardiac rhythm and automatic defibrillation device (rescue shock). An external defibrillator is a device that delivers an electric shock to the heart through the chest wall. This shock helps restore the heart to a regular, healthy rhythm.

The efficacy of external defibrillation can be affected by multiple factors, such as electrode pad size

(Dalzell *et al.*, 1989; Hoyt *et al.*, 1981), shock waveform (Bardy *et al.*, 1995, 1996; Gliner *et al.*, 1995; Greene *et al.*, 1995) and sequential shocks (Kerber *et al.*, 1994). Since capacitor size can be also crucial for determining external defibrillation efficacy (Peleska *et al.*, 1966), optimizing capacitor sizes may contribute to maximizing defibrillation efficacy. Capacitor is an electrical device which can store shock energy (voltage/time; joule). Since, the time for shock delivery (τ) is directly related to the capacitor following the equation time (τ) = Resistance (R) \times Capacitance (C), shocks delivered from smaller capacitors need less time to deliver the same amount energy than shocks from larger capacitors. However, the smaller capacitors are more prone to cellular damage from high intensity shock, because they need the higher voltage to deliver the same level of energy. Also the larger capacitor requires larger space to accommodate in defibrillator, it is problematic, if it accommodates in small Implantable Cardioverter-Defibrillators (ICDs). Although, many studies tried to find optimal capacitor for defibrillation, there is still controversial for optimal capacitor for defibrillation.

Therefore, in this study, we tested 2 external types defibrillators accommodating different size of capacitor (105 and 120 μ F) to evaluate defibrillation efficacy in a pig model.

MATERIALS AND METHODS

Animals: Ten mixed breed pigs, weighing 50 kg were used in this study. All animals and testing program (including animal care, euthanasia and disposal of dead animal body) were treated by the guidelines National Research Council of the United States.

External defibrillators: Two automated biphasic external defibrillators were used for this study. Device 1 (Heart Start XL1, Phillips, USA) accommodated a 120 μF capacitor whereas, device 2 (Paramedic CU-ER1, CU-medical systems, Korea) accommodated a 105 μF capacitor.

Animal preparation: Before the studies are started, all of the animal test subjects were tested for suitability as test subjects. Blood sample was drawn from the jugular vein for complete cell count (Blood Cell Counter, Hemavet 880, USA) and biochemical tests including hepatic and cardiac function (Blood Chemistry Analyzer, Kodak, USA). The animals were evaluated for the presence of pre-existing cardiac disease through thoracic radiography and 2D (with M-mode) echocardiography (SONOACE-8900[®], Medison, Korea).

Anesthesia and artificial ventilation: The animal test subject was weighed before the start of the test. The animal test subject was premedicated by atropine (0.05 mg kg^{-1} , SC) and acepromazine (0.5 mg kg^{-1}) followed by induction of anesthesia with thiopental (20 mg kg^{-1}). After tracheal intubation, the anesthesia was maintained by isoflurane with 2% concentration. The animal test subject was mechanically ventilated at a rate of 20 times min^{-1} using a volume-cycled respirator (MDS Matrix 3000, Hallowell, USA). End-tidal carbon dioxide was measured using a rapid response mainstream capnograph ($\text{CO}_2\text{SMO plus}$, Novamatrix, USA). The tidal volume was set initially at 12 mL kg^{-1} and ventilator settings were adjusted to maintain end-tidal carbon dioxide at 35 mmHg. After shaving the thorax, forefoot, hind leg and both cervical areas, the surface digital ECG (PH-1, CU Medical system, Korea) was attached and monitored throughout the study.

Catheterization for hemodynamic monitoring: After achieving surgical anesthesia, the animal test subject was maintained in asepsis by covering it with sterilized hole towel and disinfection towel. An introducer sheath (6-8 Fr Check-Flo performer[®], COOK, USA) was inserted to the right external jugular vein. In addition, the right

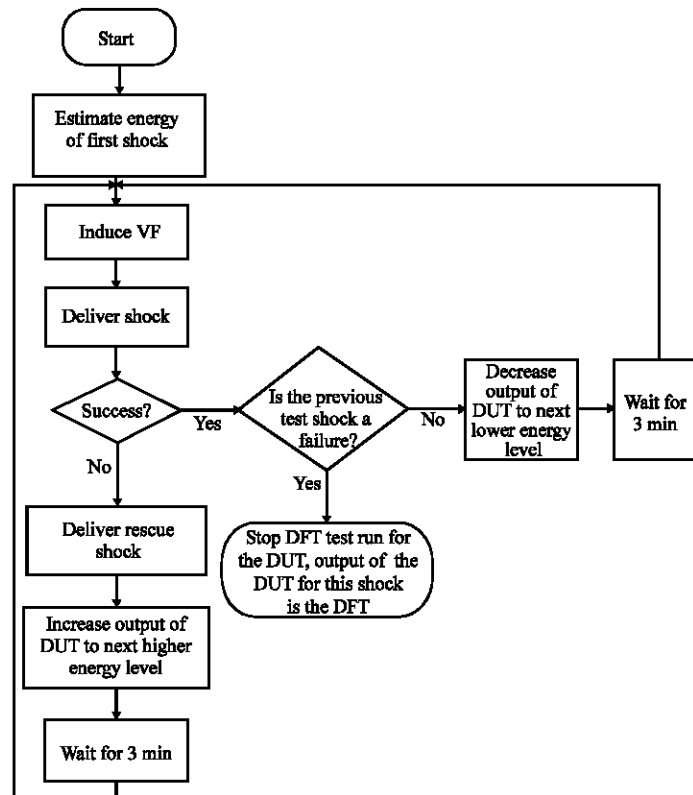


Fig. 1: Test protocol for determination of short-term defibrillation threshold

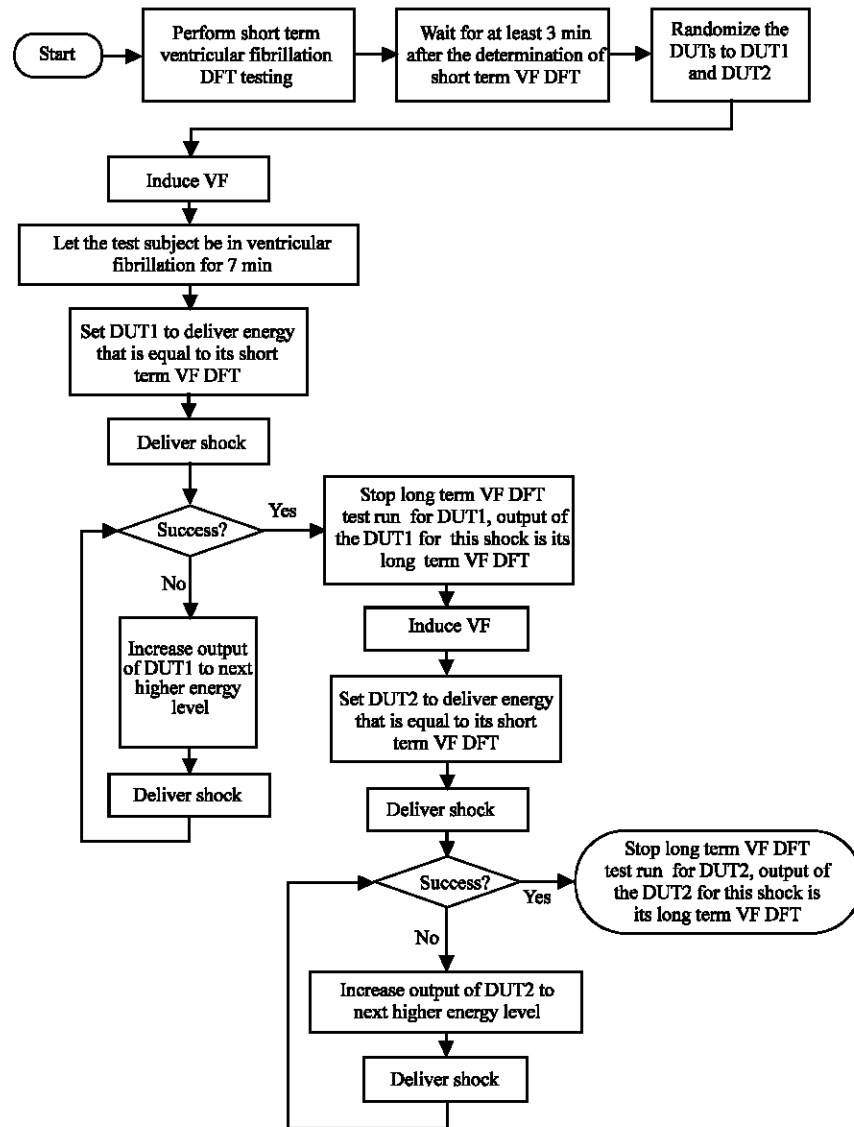


Fig. 2: Test protocol for determination of long-term defibrillation threshold

femoral region was incised and then the femoral artery and femoral vein were exposed. Using cut-down technique, an introducer sheath (4-6 Fr Check-Flo performer®, COOK, USA) was placed in the right femoral artery and a micromanometer-tipped catheter (Microtip catheter transducer SPC-350, 3-5 Fr, 120 cm, Millar instruments, USA) was advanced into the thoracic aorta. From the right external jugular vein incision, pairs of introducing sheaths (6-8 Fr Check-Flo performer®, COOK, USA) are placed and a micromanometer-tipped catheter (Microtip catheter transducer SPC-350, 3-5 Fr, 120 cm, Millar instruments; USA) was advanced into the right atrium through one of the sheaths. A balloon tipped pacing electrode (3-5 Fr, bipolar lead, Arrow international Inc., USA) was

introduced to the right ventricle through one of the sheaths to induce ventricular fibrillation under the fluoroscopic aid. The position of the pacing electrode on the right ventricle was confirmed by capture beats on the ECG monitor. The catheter position was verified by the presence of typical pressure waves and reconfirmed by autopsy at the end of each experiment.

Induction of ventricular fibrillation: Ventricular fibrillation was induced by passing an AC current of 30 mA (15 V AC 60 Hz) through the right ventricular pacing catheter for 3-6 sec using a supply unit manufactured by the research team. Ventricular fibrillation was confirmed by a fibrillation wave on the ECG monitor.

Defibrillation Threshold (DFT) test: DFT testing was performed using up-down protocol after induction of Ventricular Fibrillation (VF; using a 60 Hz current shock) (Dalzell *et al.*, 1989). DFT for short term VF was determined after 10 sec of the start of VF in 5 pigs each weighing 50 ± 1.5 kg (Fig. 1). After the determination of the defibrillation threshold, we induced the animal into VF. Let it stay in ventricular fibrillation for 7 min before delivering a shock with the same energy as the defibrillation threshold kg (Fig. 2).

DFT measurement: Digital oscilloscopes (Tektronix TDS3034B 300 MHz) are used to monitor the voltage and current of the output of each device accommodated different capacitor. The energy value is derived from the setting of the device and is verified by readings from the oscilloscope (current and voltage information plus the capacitance of the defibrillating capacitor of the device are used to compute for the delivered energy). The voltage probe of the oscilloscope is connected to the leadwires of the defibrillator pads just before the connection to the electrodes. The current probe is hooked to the leadwire. The oscilloscope traces are stored in the internal memory of the oscilloscope and transferred to a personal computer for analysis and archiving.

Statistical analysis: A paired t-test was done using software packages (Minitab ver 14, Minitab inc, USA). If $p < 0.05$, we considered the result was statistically significant.

RESULTS AND DISCUSSION

Comparison of the voltage and current of the output of both devices in different setting of energy: No significant difference in the voltage and current of the output from both devices in different setting of energy (50, 70, 100, 150 and 200 J) was observed (Fig. 3). Digital oscilloscopes (Tektronix TDS3034B 300 MHz) are used to monitor the voltage and current of the output of the DUT.

Determine DFT during short-term VF: The mean DFT energy in 2 devices was determined in 5 pigs weighing around 50 kg. The DFTs per body weight (kg) in device 1 and 2 during the short-term VF were 2.08 and 2.28 J kg^{-1} , respectively (Table 1).

Determine DFT during long-term VF: The DFTs per body weight (kg) in device 1 and 2 during the long-term VF were 2.48 and 2.60 J kg^{-1} , respectively (Table 2).

Statistical analysis: In statistical comparisons for evaluating the difference between 2 devices

accommodated different size of capacitor, no statistical difference was observed in both of short-term VF and long-term VF (Table 3). In statistical comparisons for evaluating, the difference between short and long duration VF for each device, no statistical difference was observed between short-term VF and long-term VF for each device (Table 4).

The efficacy of defibrillation can be affected by the voltage required for defibrillation, the energy required for defibrillation, cellular injuries by high intensity shock and the amount of time required to charge the capacitor (Windecker *et al.*, 1999). Previous studies suggested that a capacitance of $90 \mu\text{F}$ or even less might be better than the $140\text{-}150 \mu\text{F}$ capacitance, since the smaller capacitance might require less energy when a short duration waveform is used. Therefore, smaller capacitor is generally accommodated in ICDs. However, defibrillation with smaller capacitance requires significantly more voltage, even though the energy is the same or moderately decreased, since according to the equation given above a smaller C requires a larger V for the capacitor to contain the same amount of energy (Ideker *et al.*, 2001). Since, some evidence suggests that detrimental effects of shock, such as electroporation, are more closely related to peak shock voltage than shock energy (Al-Khadra *et al.*, 2000; Tung, 1995), the shock from defibrillator with a smaller capacitance may be more likely to cause damage, even though they are the same or slightly lower energy than shocks from defibrillator with a standard size capacitance ($120 \mu\text{F}$ capacitor). Recent study found that, while the larger capacitors markedly reduced the voltage required for defibrillation, they either did not significantly change or only slightly increased the energy required for defibrillation (Brugada *et al.*, 2001). However, a bigger capacitor is not always better, because the bigger capacitor requires the bigger space for accommodation (Ideker *et al.*, 2001). In efforts of finding optimal size of capacitor for external defibrillator, although we tested small and standard size capacitors for defibrillation efficacy, no significant difference in the waveforms (the voltage and duration in phase 1 and 2) generated from device having either $105 \mu\text{F}$ or $120 \mu\text{F}$ capacitor in different setting of energy (50, 70, 100, 150 and 200 J) was observed. Furthermore, any statistical significant difference in defibrillation efficacy in device having either $105 \mu\text{F}$ or $120 \mu\text{F}$ capacitor has not been observed in a short-term VF and long-term VF. These results imply that the smaller difference in capacitor size may not significantly affect the overall defibrillation efficacy, as observed in previous studies. Since we used the same leadwire (the main determinant for resistance) for minimizing variables, our study suggested that smaller

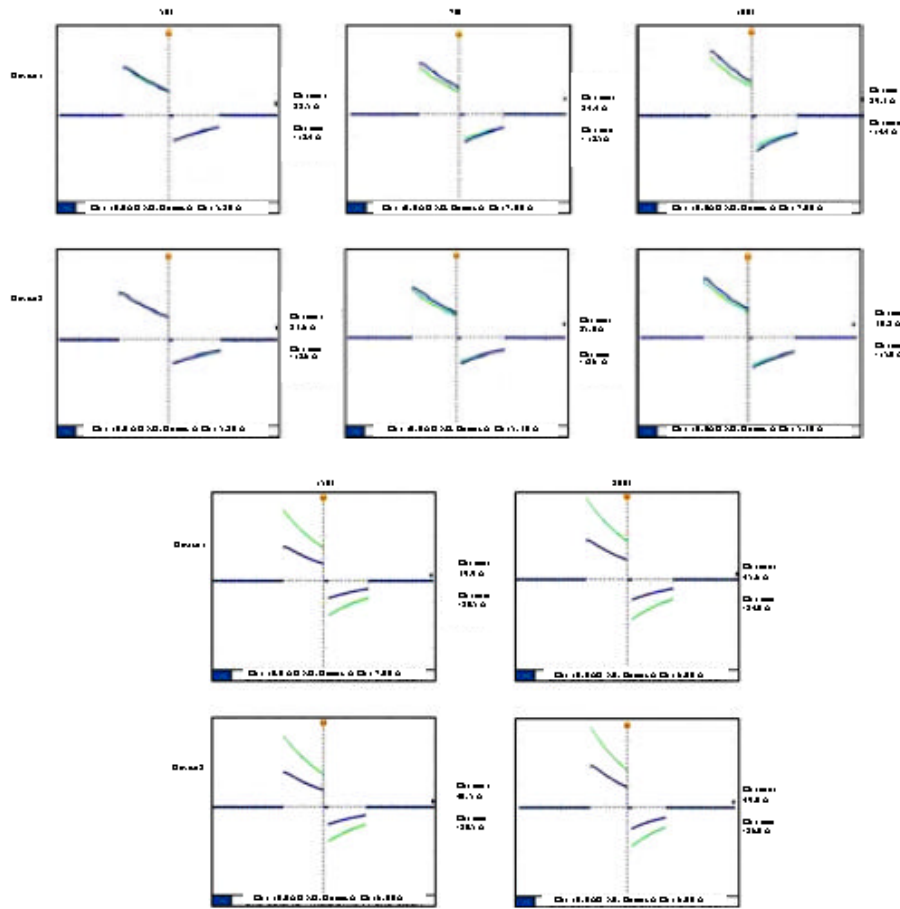


Fig. 3: Comparison of oscillation wave after shock applied in different setting of energy in two devices accommodated 120 and 105 μF capacitors

Table 1: Determination of Defibrillation Threshold (DFT) during short-term Ventricular Fibrillation (VF)

DFT energy	Pig					Mean (kg)	SD
	1	2	3	4	5		
Body weight (kg)	49.5	48.5	50.5	51.5	50.0	50.0	1.12
Device 1	100	70	150	150	100	114	0.701
Device 2	100	70	100	150	100	104	0.576

[§]Device 1 accommodated 120 μF capacitor, whereas device 2 accommodated 105 μF capacitor

Table 2: Determination of Defibrillation Threshold (DFT) during long-term Ventricular Fibrillation (VF)

DFT energy	Pig					Mean (kg)	SD
	1	2	3	4	5		
Body weight (kg)	49.5	48.5	50.5	51.5	50	50	1.12
Device 1	100	100	150	150	150	130	0.548
Device 2	70	100	150	150	150	124	0.743

[§]Device 1 accommodated 120 μF capacitor, whereas device 2 accommodated 105 μF capacitor

size of capacitor can be accommodated in defibrillator without significant decrement of defibrillation efficacy, although, the safety issue related to high intensity shocks

Table 3: Statistical result from a paired t-test for evaluating the difference between 2 devices accommodated 120 and 105 μF capacitor, respectively, during short-term Ventricular Fibrillation (VF) and long-term VF

Type of experiment	Device	Mean	SD	t	p-value [§]
Short-term VF	1	114.00 [*]	35.07	-1.000	0.374
	2	104.00	28.81		
Long-term VF	1	130.00	27.39	-1.000	0.374
	2	124.00	37.15		

[§]If $p < 0.05$, we consider the result is statistically significant; ^{*}Unit is Joule (J)

Table 4: Statistical result from a paired t-test for evaluating the difference between short and long-term Ventricular Fibrillation (VF) for each device accommodated 120 and 105 μF capacitor, respectively

Device	Type of experiment	Mean	SD	t	p-value [§]
1	Short-term VF	114.00 [*]	35.07	-1.55	0.195
	Long-term VF	130.00	27.39		
2	Short-term VF	104.00	28.81	-1.29	0.266
	Long-term VF	124.00	37.15		

[§]If $p < 0.05$, we consider the result is statistically significant; ^{*}Unit is Joule (J)

generated by defibrillators accommodating different size of capacitors still requires clarifying. Therefore, further

studies should be directed to reveal the difference in the safety of high intensity shocks generated by defibrillators accommodated different size of capacitors.

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