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ARTICLE

Energy Level and Success of Internal Defibrillation for Shockable Rhythm during Cardiopulmonary Bypass in Cardiac Surgery: A Retrospective Study

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ABSTRACT

Internal defibrillation is commonly indicated for shockable rhythm following cross-clamp removal in cardiac surgery. Low energy decreases the success rate of defibrillation but high energy can cause myocardial damage. This study aimed to determine the success rate of internal defibrillation for shockable arrhythmias after cardiac surgery.

Retrospective data of 1,424 patients who developed shockable rhythms (ventricular fibrillation or ventricular tachycardia), and required internal defibrillation after aortic cross-clamp removal during cardiac surgery, without deep hypothermic circulatory arrest technique, from August 2015 to July 2017, were reviewed.

The overall success rate of internal defibrillation in the first attempt of defibrillation was 61.5%. The success rate of the energy levels at 30, 10, and 7 Jules were 66.7, 64.9, and 61.5%, respectively. The success rate was higher in patients who had a better ejection fraction than those who failed after defibrillation. This was significantly associated with higher pH, higher bicarbonate, lower serum calcium, and lower total cardioplegic volume during cardiopulmonary bypass (CPB). Redo-valve surgery, valvular surgery, and combined coronary artery bypass graft with valvular surgery had a non-significantly lower success rate (p-value = 0.989). Incidence of failure for defibrillate patients in redo-valvular surgery, combined coronary artery bypass graft with valve surgery, adult congenital heart defect, and valvular surgery; requiring four or five shocks was non-significantly increased. Recurrent rate of ventricular fibrillation/ventricular tachycardia was 13.5%.

The success rate of internal defibrillation was not related to the dose of energy used after being weaned off CPB.

1. Introduction

During cardiac surgery, most patients require the cardiopulmonary bypass (CPB) system. For discontinuing CPB, at the end of the surgery, one of the important factors for weaning from CPB is cardiac rhythm. An organized, effective, and stable cardiac rhythm can occur spontaneously after removal of the aortic cross-clamp; however, in some cases cardiac conduction may resume electrical activity with ventricular fibrillation (VF) and/or ventricular tachycardia (VT). If VF occurs in a warm myocardium, it can increase cardiac wall tension, compromising endocardial perfusion,

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and allowing for possible subendocardial infarction.

Defibrillation is only indicated for shockable rhythms (VF, VT). Energy levels of internal defibrillation can start at 5-10 Jules [1-3], and may be increased up to 50 Jules in some patients. Defibrillation is more effective when the heart is adequately rewarmed to a general body temperature (more than 30 degrees Celsius), with the success rate at approximately 56-64% [2]. If ventricular fibrillation persists or recurs repeatedly after multiple, unsuccessful attempts of defibrillation, further management is to further warm the heart; so as to correct electrolyte abnormalities, and to begin antiarrhythmic drugs. Although, defibrillation is a life-saving procedure, the delivery of multiple high-energy shocks may be associated with myocardial damage and subsequent hemodynamic impairment [4]. Additionally, large shocks can damage cells and result in post-shock arrhythmias that may reinitiate fibrillation [1,4].

The primary objective of this study was to determine the success rates of different energy levels of internal defibrillation for VF or VT after CPB. The secondary objective was to determine the factors affecting the success of internal defibrillation.

2. Material and Methods

2.1 Study Design

This study was approved by the Local Research and Ethics Committee of the Faculty of Medicine, Prince of Songkla University (REC. 60-360-08-1). By reviewing the retrospective data from the medical records, anesthetic records, and CPB records of cardiac surgical patients in Songklanagarind Hospital, from; February 2014 to July 2017.

2.2 Participants

All patients who developed VF or VT during weaning from CPB, with a body temperature above 30°*C* were included in the study (Figure 1). The exclusion criteria were patients aged under 18-year-old and/or used the deep hypothermic circulatory arrest (DHCA) technique during surgery. The selection of each energy level and types of antiarrhythmic agents for defibrillation were determined by the decision of the attendant anesthesiologist. Repeated attempts of defibrillations were needed for unsuccessful conversions, or for recurrent episodes of shockable rhythms.

2.3 Measures

Patient demographic data included: age, gender, body mass index (BMI), comorbidities, current medications, preoperative ejection fraction (EF), preoperative congestive heart failure, left ventricular hypertrophy, American Society of Anesthesiologists (ASA) classification, and type of surgery. The intraoperative cardiopulmonary bypass data included: the success rate and level of energy for defibrillation, and the number of internal defibrillations. The factors affecting the success of internal defibrillation; such as, arterial blood gas, electrolytes, body temperature, CPB and aortic cross-clamp time, use of inotropic/vasopressor agents, antiarrhythmic agents, type of operations and recurrent VF/VT, were recorded.

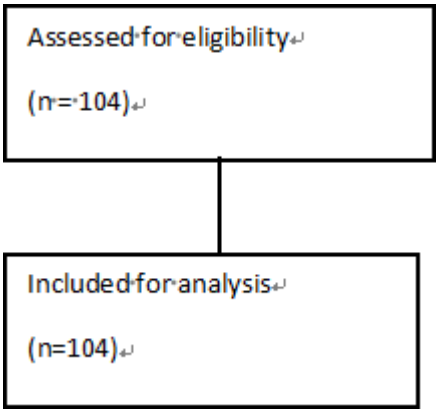

Figure 1. Flow diagram of the study

2.4 Sample Size

After reviewing the using of 7 Jules of energy level of internal defibrillation in patients who developed VT/VF during cardiac surgery in Songklanagarind Hospital, the success rate approximately was 60%. It was then used for the sample size calculation with the accepted maximum error of 0.1, and significant level of 0.05. To cover the 10% dropout rate, the sample size finally was 104 patients.

2.5 Analysis

Statistical analysis was performed using the R program (version 3.14). Patient characteristics are described as the mean, and standard deviation for the normal distribution, as the median and interquartile range (IQR) for the non-normal distribution, or absolute and relative frequencies. The comparisons between the groups were performed with the unpaired t-test for normally distributed data, or with the Mann-Whitney U test for other quantitative data; and with the Chi-squared test or Fisher exact test for qualitative variables. Univariate regression and multivariate analysis were performed to assess the association between the success of energy level and the perioperative variables. Statistical significance was considered if p-value < 0.05.

3. Results

Among a total of 1,424 patients undergoing cardiac

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surgery without DHCA technique, a hundred and four patients (7.3%) had VF/VT during weaning from CPB. The majority of patients were men (68.3%), with the mean age ± S.D. being 53.5 ±14.1 years old (range between 18-82 years of age); common current medications before surgery were diuretics (69.2%). The cardiac operations were mainly elective surgery (83.7%), and valvular heart surgery (61.5%). The types of surgeries were similar between the two groups. Baseline cardiac rhythm before surgery was normal sinus rhythm (67.3%), while pre-operative ejection fraction was 53.4 ±15%. Most patients (74%) had left ventricular hypertrophy (LVH); 34.6% of patients had a diagnosis of congestive heart failure and 16.3% patients received inotropic agents before surgery (Table 1). The pre-operative ejection fraction in patients who were successfully converted after shock (56.9 ±13.1%) was higher than those who failed after defibrillation (48.1 ±16.2%), p-value = 0.011).

From a total of 104 patients who had VF/VT, 64 patients (61.5%) were shocked successfully, while 40 patients (38.5%) were failed after the first attempt of defibrillation. The energy used for the first attempt of internal defibrillation started at 5, 7, 10, 20, and 30 Jules (J). Most of the energy levels were 10 J (57.8%), following by 20 J(23.4%), 10 J(12.5%), 5 J(3.1%) then 30 J(3.1%). The success rates of the first attempt defibrillation at 30, 10, and 7 J were 66.7, 64.9, and 61.6%, respectively (Table 2). The use of energy levels at 5 and 20 J had lower success rates (50.0 and 55.6%). With sub-

Table 1. Demographic data of patients who received first attempt of internal defibrillation for VF/VT

Preoperative factors	Total (N = 104)	Success (n = 64)	Fail (n = 40)	p- value
Age, median ±IQR	53.5 ±14.1*	58 (47.8,65.0)	54 (37.5,59.2)	0.07
Gender, **n (%)**				1.00
male	71 (68.3)	44 (68.8)	27 (67.5)	
female	33 (31.7)	20 (31.2)	13 (32.5)	
BMI, median ±IQR	22.7 ± 4.1*	22.9 (19.8,24.9)	22.9 (20.6,25.4)	0.51
Comorbid disease, **n (%)**	33 (31.7)	22 (34.4)	11 (27.5)	0.61
diabetes	12 (11.5)	6 (9.4)	6 (15.0)	0.53
hypertension	30 (28.8)	20 (31.2)	10 (25.0)	0.64
dyslipidemia	10 (9.6)	7 (10.9)	3 (7.5)	0.74
Current medication, **n (%)**	93 (89.4)	58 (90.6)	35 (87.5)	0.74
ASA physical status, **n (%)**				0.46
3	82 (78.8)	53 (82.8)	29 (72.5)	
4	18 (17.3)	9 (14.1)	9 (22.5)	
5	4 (3.8)	2 (3.1)	2 (5.0)	
Type of surgery, **n (%)**				0.60
Elective	87 (83.7)	55 (85.9)	32 (80.0)	
Emergency	17 (16.3)	9 (14.1)	8 (20.0)	
Preoperative EF, mean ±SD	53.4 ±15	56.9 ± 13.1	48.1 ± 16.2	0.01
ECG baseline, **n (%)**				0.30
Normal sinus	70 (67.3)	39 (60.9)	31 (77.5)	
Atrial fibrillation	27 (26.0)	20 (31.2)	7 (17.5)	
Heart block	1 (1.0)	1 (1.6)	0 (0)	
Bradycardia	6 (5.8)	4 (6.2)	2 (5.0)	
Left ventricular hypertrophy	77 (74.0)	44 (68.8)	33 (82.5)	0.18
Preoperative congestive heart failure, **n (%)**	36 (34.6)	18 (28.1)	18 (45)	0.12
Preoperative use inotropic drug, n **(%)**	17 (16.3)	9 (14.1)	8 (20.0)	0.60
Norepinephrine	2 (1.9)	0 (0)	2 (5.0)	0.15
Dopamine	11 (10.6)	5 (7.8)	6 (15.0)	0.33
Dobutamine	5 (4.8)	4 (6.2)	1 (2.5)	0.65
Operations, n **(%)**				0.99
Coronary bypass graft (CABG)	11 (10.6)	7 (63.6)	4 (36.4)	
Adult congenital heart diseases	3 (2.9)	2 (66.7)	1 (33.3)	
Valvular heart surgery	64 (61.5)	39 (60.9)	25 (39.1)	
Combined CABG+ valve surgery	9 (8.7)	5 (55.6)	4 (44.4)	
Redo-valvular surgery	4 (3.8)	2 (50.0)	2 (50.0)	
Thoracic aorta surgery without DHCA	8 (7.7)	5 (62.5)	3 (37.5)	
Other (pulmonary embolectomy, myxoma removal)	5 (4.8)	4 (80.0)	1 (20.0)	

*= mean ± S.D., ASA = American Society of Anesthesiologists, BMI = body mass index, DHCA = deep hypothermic circulatory arrest, ECG = electrocardiography, EF = ejection fraction, VF = ventricular fibrillation, VT = ventricular tachycardia

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analysis from a total of 27 defibrillations of the energy level at 20 J, these occurred mainly in valvular surgery (59.3%). Failure of shock was largely found in coronary artery bypass graft (CABG) and combined CABG with valvular surgery (66.7%). However, the success rates were not significantly different in the first attempt of defibrillation among each energy level (5, 7, 10, 20, and 30 J) (p-value = 0.9).

After the first attempt of defibrillation, forty patients (38.5%) had failure to convert VF/VT into a normal sinus rhythm. These patients required a second defibrillation, with 55% having successful shocks; eighteen patients required a third attempt, with 50% of successful defibrillation. Additionally, nine patients required a fourth attempt, with 44.4% having successful defibrillation. Five patients required a fifth attempt, with 100% having successful defibrillation at the energy levels of 20, 30 and 50 Jules (Table 2). The energy levels in the second, third, and fourth attempt were significantly increased at higher levels than those in the earlier attempt (p-value < 0.001). The energy levels of the success in the third and the fourth attempts were higher than those in the failure of defibrillation; nevertheless, they were not significantly different (p-value 0.51), (Figure 2).

Thirteen patients (0.9%) had recurrent or a second episode of VF/VT, after successful normal rhythm conversion. From the first to the third attempt of defibrillation, for the second episode of VF/VT, the energy levels in the failed attempt were higher than those in successful defibrillation; however, they were not significantly different (Figure 3). The recurrent rates of shockable rhythms were 27.3, 25, 14.1, and 12.5 %; in the CABG, redo-valve, valvular surgery, and thoracic aortic surgeries, respectively. CABG and redo-valvular surgery had recurrent rates more than other surgeries. Third recurrent episodes of VT/VF occurred in six patients (0.4%). All of these required only one attempt of defibrillation at the energy levels of 5, 20, 30, and 50 Jules to successfully convert their rhythms (Table 2).

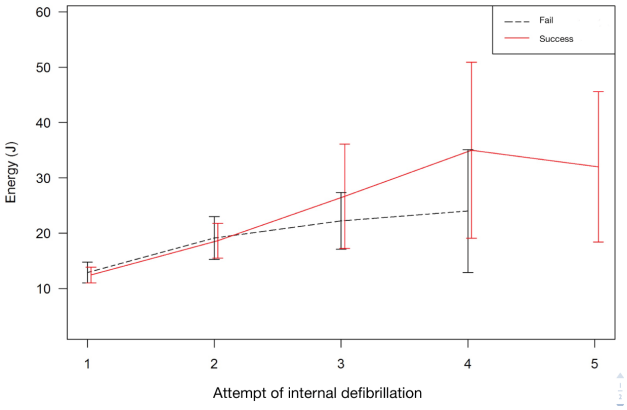

Figure 2. the energy levels for the success and failure of each attempt of defibrillation during first episode of VF/VT

Table 2. The level of energy, success, and the attempts of internal defibrillation for the first and recurrent shockable rhythms

VT/VF	Defibrillation		Energy level (Jules)					
	attempt	success n(%)	5	7	10	20	30	50
First (n=104)	first	Yes	2(50.0)	8(61.5)	37(64.9)	15(55.6)	2(66.7)	0
		no	2(50.0)	5(38.5)	20(35.1)	12(44.4)	1(33.3)	0
	second	yes	0	0	7(70.0)	11(55.0)	4(50.0)	0
		no	0	2(100)	3(30.0)	9(45.0)	4(50.0)	0
	third	yes	0	0	2(66.7)	1(16.7)	6(75.0)	1(100)
		no	0	0	1(33.3)	5(83.3)	2(25.0)	0
	fourth	yes	0	0	0	0	3(50.0)	1(100)
		no	0	0	1(100)	1(100)	3(50.0)	0
	fifth	yes	0	0	0	1(100)	3(100)	1(100)
		no	0	0	0	0	0	0
Second (recurrent) (n=13)	first	yes	0	2(100)	0	4(66.7)	1(100)	1(33.3)
		no	0	0	1(100)	2(33.3)	0	2(66.7)
	second	yes	0	0	0	1(100)	0	0
		no	0	0	0	0	2(100)	2(100)
	third	yes	0	0	0	0	2(100)	1(50.0)
		no	0	0	0	0	0	1(5.00)
	fourth	yes	0	0	0	0	0	1(100.0)
		no	0	0	0	0	0	0
Third (recurrent) (n=6)	one	yes	1(100)	0	0	2(100)	2(100)	1(100)
		no	0	0	0	0	0	0

VF = ventricular fibrillation, VT = ventricular tachycardia

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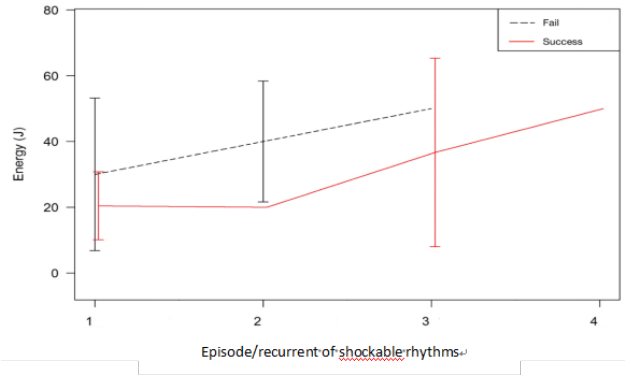

Figure 3. the energy levels for the success and failure of defibrillation in first and recurrent VF/ VT

The anti-arrhythmic agents were required in 63.5% of the total patients who developed shockable rhythms. These were usually administered during multiple attempts of defibrillation, or for recurrent VT/VF. Lidocaine (43%) was most frequently used, and the least (25%) was amiodarone. Lidocaine combined with magnesium, amiodarone combined with magnesium, and amiodarone combined with lidocaine were given in 15.2, 6.1, and 3.0%, respectively: triple medications were administered in 16.7%. Lidocaine was commonly used in the dose range of 50-120 milligrams, with the dose range of magnesium being 1-2 grams, and amiodarone was administered in the dose of 150-300 milligrams.

During CPB, the patients received inotropic/vasopressor agents, which consisted mainly of epinephrine (68.3%). The CPB and aortic cross-clamp time were 146.2 ±58.6 and 105.8 ±46 minutes, respectively. Both of these were not significantly different between the successful group and the failed group. During CPB, the higher serum bicarbonate (22.4 & 21.7, p-value =0.009), lower serum calcium (1.08 ± 0.06 & 1.11 ± 0.07, p-value = 0.02), and lower total cardioplegic volume (2250 & 3050, p-value = 0.006) significantly increased with the success of the first attempt at defibrillation (Table 3).

Table 3. The cardiopulmonary bypass data of patients who received first attempt of internal defibrillation for their first VF/VT.

Perioperative factors	The first attempt of defibrillation			Univariate analy sis	Multivariate analysis	
	Total (N = 104)	Success (n = 64)	Fail (n = 40)	p-value	OR (95% CI)	p-value
Cardiopulmonary bypass time (mins), median ±IQR	146.2 ±58.6*	132 (106.2,166.2)	145.5 (113.2,182.5)	0.58	-	-
Aortic cross clamp time (mins), mean ±SD	105.8 ±46	103.4 ± 42.8	109.6 ± 51.2	0.51	-	-
Intraoperative inotropic drug, n (%)	103 (99.0)	63 (98.4)	40 (100.0)	1.00	-	-
- Epinephrine	71 (68.3)	42 (65.6)	29 (72.5)	0.61	-	-
- Norepinephrine	46 (44.2)	27 (42.2)	19 (47.5)	0.74	-	-
- Dopamine	18 (17.3)	11 (17.2)	7 (17.5)	1.00	-	-
- Dobutamine	29 (27.9)	18 (28.1)	11 (27.5)	1.00	-	-
- Milrinone	16 (15.4)	7 (10.9)	9 (22.5)	0.19	-	-
Body temperature, n (%)						
Nasopharyngeal, median ±IQR	36.9 ±1.1*	37.2 (36.7,37.4)	37.3 (36.8,37.6)	0.11	-	-
Rectal, median ±IQR	35.8 ±1.3*	36 (35.1,36.4)	36.2 (35.6,36.8)	0.17	-	-
Mean arterial pressure (mmHg), median ±IQR	52.2 ±13*	50.5 (44,62)	50.5 (40,56)	0.12	-	-
ABG, median ±IQR						
- pH	7.4 ±0.1*	7.4 (7.4,7.4)	7.4 (7.3,7.4)	0.04	-	-
- PaO_2	267.8 ±81.2*	270.5 (83.7)	263.4 (77.9)	0.67	-	-
- $PaCO_2$	37 ±3.9*	36.9 (4.1)	37.1 (3.5)	0.85	-	-
- HCO_3^-	22 ±2.2*	22.4 (21.2,23.7)	21.7 (20.4,22.6)	0.01	1.2(1.0-1.5)	0.03
Electrolytes, median ±IQR						
- Sodium	135.8 ±5.3*	135.1 (4.9)	136.8 (5.8)	0.13	-	-
- Potassium	4.4 ±0.6*	4.4 (0.6)	4.3 (0.5)	0.25	-	-
- Chloride	106.3 ±4.3*	107 (104,109)	107 (103.8,110.2)	0.42	-	-
- Calcium	1.1 ±0.1*	1.1 (0.1)	1.1 (0.1)	0.02	0.0003(0-0.3)	0.02
Total cardioplegic volume (mL), median ±IQR	2810.6 ±1387*	2250 (2000,2850)	3050 (2075,4125)	0.01	0.9996 (0.9993-0.9999)	0.01
Time from last cardioplegia to VF/VT (mins), median ±IQR	45.2 ±44.1*	25.5 (17.8,77.8)	24 (15.5,53.5)	0.563	-	-

*= mean ±S.D., ABG= arterial blood gas

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4. Discussion

The energy levels of the internal defibrillation for VF/VT, occurring during the weaning CPB, in this study varied from 5, 7, 10, 20, and 30 J; with a success rate of 50, 61.5, 64.9, 55.6, and 66.7%, respectively, for the first attempt of defibrillation. The success rates of our study showed nonlinear correlation with the level of energy used for defibrillations. Kerber et al, administered 5, 10, and 20 J of shocks, and reported the successes at 56% of 5 J shocks, 70% of 10 J shocks, and 80% of 20 J of shocks [5]. Carol et al, used 5, 7.5, 10, 20, 30 J shocks, and demonstrated that the success rates were 56% of 5 J, 59% of 7.5 J, 64% of 10 J, 85% of 20 J, and 100% of 30 J of shocks [4]. Although, our success rate at the high energy level of 20 J and 30 J were lower than in the previous study [2]; the study by Carol et al, showed that an energy level above 2.5 J had a plateau defibrillation success rate of 50-60% [4], similar to our results. Schuder et al also reported a nonlinear correlation for transthoracic defibrillation shock with success [6]. An increasing level of the shock strength, above an optimal range, can decrease the success of defibrillation. Several studies have demonstrated that an increase in post-shock arrhythmias can be a possible cause of unsuccessful defibrillation [1,2]. High energy shocks might produce contractile abnormalities as well as post-shock arrhythmias, caused by ultrastructural damage in the mitochondria of the myocardium [2]. This might explain our lower success rates at 20 and 30 J shocks in the first attempt.

A sub-analysis of the success rate at 20 J, from a total of 27 shocks, which was not better than the lower energy, showed that it was mostly used in valvular surgery (59.3%). However, most of the failed shocks occurred in CABG, and combined valve with CABG surgery (66.7%). A possible etiology for the redevelopment of VF/VT would be a coronary air embolism, which is more likely during open-heart surgery than coronary artery or close heart surgery. Additionally, the presence of coronary artery disease also decreases the VF threshold; especially when a rapid heart rate is associated with coronary occlusion [2].

The incidences of failure of the fourth or fifth defibrillations in redo-valvular surgery, combined CABG with valve surgery, adult CHD, and valvular surgery were greater than in the patients with CABG, thoracic aortic surgery, and other surgeries. Especially, in redo-valvular and adult CHD surgeries, which were less likely to succeed from defibrillation. Carol et al, reported the difficulty to defibrillate patients with valvular heart disease as well [4]. Incidence of failure to defibrillate patients with valvular heart disease with the second or third shock was greater than in patients with coronary artery disease. The favorable effect of valve surgery on left ventricular loading conditions might reduce proarrhythmic stress and stretch as well as being associated with proarrhythmic risk. Coronary artery disease, structural heart disease, and left ventricular dysfunction were among the factors that predisposed malignant ventricular arrhythmia. Also, cardiac surgery exposes the patients with a substrate for ventricular arrhythmia to various arrhythmic triggers; such as, ischemia, reperfusion injury, hemodynamic changes, and electrolyte shifts that could lead to ventricular arrhythmia; especially acute ischemia or reperfusion injury [7].

Chapman et al, demonstrated that left ventricular hypertrophy (LVH) was significantly correlated with the defibrillation threshold [8]. However, Kerber et al, found that the LVH did not elevate defibrillation energy requirements [9]. From our results, the success rates insignificantly correlated with the LVH of the patients. However, ejection fraction (EF) can predict the success of the shock in the first attempt. This was lower in patients with failed shock (48.1%) than in the successful shock group (56.9%) (p-value = 0.011). So, higher EF was significantly associated with higher successful shocks in the first attempt.

Defibrillation during the states of acid-base imbalance has been influenced by the effect of derangements on the ventricular fibrillation threshold. In an animal study, acid-base abnormalities did not elevate defibrillation energy requirements; whereas, hypoxia reduced the energy needed to defibrillate [9]. Therefore, pH and blood gas alterations did not significantly affect the normal defibrillation threshold [10]. Higher bicarbonate levels significantly increased the success rate in the first attempt of shock in our clinical trial, but this different value was very scarce in the clinical setting.

Electrolytes, such as serum potassium, play an important role in the evoked potential generation for cardiac conduction. From the previous study, the success of defibrillation was associated with high serum potassium and coronary perfusion pressure at the first shock, and could correctly predict the outcome in 78% of the first shock [2]. Similar to our results, serum potassium and mean arterial pressure in successful shocks were higher than in the failed shocks, in the first attempt; but they were not significantly different.

VF or VT occasionally persists, and defibrillation needed to be repeated. In this case, the conventional strategy is to administer lidocaine, magnesium, and various anti-arrhythmic agents, and then repeat defibrillation. However, multiple repeated defibrillations

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not only increase the risk of myocardial damage and reduce cardiac function, but may also attenuate the fibrillation threshold [11]. Lidocaine and magnesium are generally the common drugs of choice in many hospitals; this includes our institute.

There are some limitations in this study. First of all, it is a retrospective design. No uniform protocol of the energy level and antiarrhythmic drugs is applied for internal defibrillation within our hospital. Secondly, the blood gas determinations in the majority of the patients were not obtained at the exact time of developing VF/VT. Instead, they were before the occurrence of VF/VT, and after the therapy (defibrillation) in many cases. Finally, the numbers of patients for each energy level were too small; especially at 5, 7, and 30 J levels, when compared with the level at 10 and 20 J. Future prospective studies of internal defibrillation may resolve these uncertainties.

5. Conclusions

The success rate of internal defibrillation did not significantly correlate to the dose of energy at the levels from 7 to 30 J after weaning off cardiopulmonary bypass. However, it was significantly related to the preoperative ejection fraction, and relatedly converted to intraoperative acidosis, serum calcium, and cardioplegic volume.

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