WORKSHEET for Evidence-Based Review of Science for Veterinary CPCR

1. Basic Demographics

Worksheet author(s)

Ladan F. Mohammad-Zadeh	**Date Submitted for review:**

[redacted]

2. Clinical question:

In dogs and cats with cardiac arrest (P), does the use of an escalating defibrillation energy protocol (I) compared with a fixed energy protocol (C), improve outcomes (e.g. ROSC) (O)?

3. Conflict of interest specific to this question:

None

4. Search strategy (including electronic databases searched):

4a. Databases

MEDLINE via PUBMED (**April 15, 2010)**

1. defibrillation energy
2. electric countershock AND veterinary
3. defibrillation AND veterinary
4. cardiopulmonary resuscitation AND veterinary

1: 25 relevant hits of 1540 total
2: 2 relevant hits of 33 total
3: 2 relevant hits of 43 total
4: 1 relevant hits of 60 total

4b. Other sources

4c. State inclusion and exclusion criteria for choosing studies and list number of studies excluded per criterion

Inclusion criteria

Inclusion of cardiac arrest studies or cardiac arrest models with evaluation of defibrillation energy or serial shocks

Exclusion criteria

Abstracts only. Editorials. Non-ventricular fibrillation models, ex-vivo models (isolated heart models)

4d. Number of articles/sources meeting criteria for further review: 30

-Three randomized human trials were identified: Stiel et al 2007, Walsh 2004

-Twenty-seven relevant animal studies were identified:

5. Summary of evidence

Evidence Supporting Clinical Question

Good						*Clark, 2002 E* *Niemann, 2004 E* *Stiell, 2007 ABCDE* *Walker, 2003 E*
Fair						*Zhang, 2002 E*
Poor						*Clark, 2001 E* *Zhang, 2003 E*
	1	**2**	**3**	**4**	**5**	***6***
Level of evidence (P)						

A = Return of spontaneous circulation
B = Survival of event
C = Survival to hospital discharge
D = Intact neurological survival
E = Other Endpoint; Termination of VF
Italics = Non-target species studies

Evidence Neutral to Clinical question

Good			Leng , 2000 AE Murakawa, 1989 AE Walcott, 1998 E			*Berg, 2005,A* *Morrison, 2005 ABCDE* *Niemann, 2000a A,E* *Niemann, 2000b A E* *Niemann, 2003 A E* *Niemann, 2010 E* *Tang, 2001 A* *Tang, 1999 A* *Tang, 2004 A E* *Tang, 2006 A* *Walcott, 2010 A* *Wang, 2001 E* *Zhang, 2000 E*
Fair			Gelzer , 2005 E Walcott, 2002 E		Bright, 2009 B	*Tang, 2002 A* *Walcott, 2002 E*
Poor			Flaker, 1990 E			*Meany, 2011 AE* *Yamanouchi, 1999 E*
	1	**2**	**3**	**4**	**5**	***6***
Level of evidence (P)						

A = Return of spontaneous circulation
B = Survival of event
C = Survival to hospital discharge
D = Intact neurological survival
E = Other endpoint
Italics = Non-target species studies

Evidence Opposing Clinical Question

Good						
Fair						
Poor						
	1	**2**	**3**	**4**	**5**	**6**
Level of evidence (P)						

A = Return of spontaneous circulation
B = Survival of event
C = Survival to hospital discharge
D = Intact neurological survival
E = Other endpoint
Italics = Non-target species studies

6. REVIEWER'S FINAL COMMENTS AND ASSESSMENT OF BENEFIT / RISK:

The aim of this worksheet is to determine if an escalating dose defibrillation protocol versus a fixed dose protocol improves outcome in dogs and cats. With the advent of the biphasic waveform defibrillators, many investigators set out to compare biphasic fixed defibrillation protocol versus an escalating dose protocol using the traditional monophasic waveform defibrillator (Niemann 2000b, Niemann 2003, Tang 1999, Tang 2001, Wang 2001). Biphasic waveform defibrillation was as effective and more effective at termination of VF compared to monophasic waveform at lower energies. Use of biphasic waveform is also associated with less myocardial damage presumably due to lower energies used

Examining the effect of prolonged VF on defibrillation threshold was a common aspect of many studies. It was stated that for out-of-hospital arrest, the average time from arrest to application of an AED was 5 minutes, thus higher energies would be required to defibrillate VF of increasing duration. One relevant study examining this was Leng 2000 which compared the defibrillation threshold of monophasic and biphasic waveform in short duration VF (10sec) compared to prolonged duration VF (10min) using a canine model. They demonstrated that increasing the duration of VF increased the defibrillation threshold for both biphasic and monophasic waveform. Other studies show minimal or no effect on duration of VF on success in biphasic defibrillation (Tang 1999, Walcott 1999), however an increase in DFT for monophasic waveform with increasing duration of VF remained a consistent finding.

Another factor to consider when examining studies on defibrillation is the method of inducing fibrillation. Two common methods for inducing VF are via electric current or balloon occlusion of a coronary artery. Walcott 2002 demonstrated that DFT for ischemically induced VF was at least twice that of electrically induced VF. Niemann 2010 examined escalating monophasic waveform on prolonged duration VF that was electrically or

ischemically induced. The number of animals in the ischemic group requiring 360J shock was 2.5 times greater, as was the number of refibrillations.

The majority of animal studies on defibrillation are conducted using swine. Niemann 2004 was a quality study in that it not only addressed the relevant clinical question of fixed biphasic waveform (150J) versus escalating biphasic waveform (200J, 300J, 360J), but also carried out this study in an ischemic model of VF. Eighty-three percent of animals in the escalating energy group were successfully defibrillated with 3 or fewer shocks compared to 29% in the fixed dose group. Furthermore, 9 of 12 animals in the fixed dose group that failed to defibrillate were successfully defibrillated with higher energy shocks. Clark 2002 examined the success rate for defibrillation with escalating monophasic compared to escalating biphasic waveform. They demonstrated that for both monophasic and biphasic waveform the rate of defibrillation success increased when shock strength increased from 70J to 100J, but no additional success was noted at or above 200J in either group. Studied conducted in canine models is limited, many of them being fair or poor in quality and relevance and are therefore neutral to the clinical question. There is only a single case study (Bright 2009) of a dog that failed an escalating monophasic protocol that was successfully rescued with a single biphasic shock. Leng 2000 demonstrated that increased the duration of VF increased the defibrillation threshold in dogs indirectly pointing towards the possible benefits of an escalating dose strategy.

An important human study in support of the clinical question was Stiell 2007 BIPHASIC trial. It was a randomized controlled trial that demonstrated higher dose escalating biphasic protocol was superior to low dose fixed biphasic protocol at conversion of VF in multishock patients. However there was no benefit seen in terms of survival and hospital discharge.

7. Conclusion

DISCLAIMER: Potential possible wording for a Consensus on Science Statement. Final wording will differ due to other input and discussion.
CONSENSUS ON SCIENCE:

The evidence from Stiell 2007 and Niemann 2004 demonstrates that an escalating energy dose leads to higher success rates for defibrillation. However, the majority of studies in this worksheet were categorized as neutral to the clinical questions. There are findings in many of these studies that indirectly support an escalating dose strategy, such as the concept of longer duration VF having a higher defibrillation threshold. There was no evidence clearly opposing the clinical question. Taking the human and swine studies into consideration, it seems reasonable to recommend an escalating dose protocol with monophasic defibrillator. The recommended protocol using biphasic waveform defibrillators is less clear as the survival benefit of an escalating biphasic dose has not been shown.

8. Acknowledgement

none

9. Citation list

Berg RA, Samson RA, Berg MD, Chapman FW, Hilwig RW, Banville I, Walker RG, Nova RC, Anavy N, Kern KB. Better outcome after pediatric defibrillation dosage than adult dosage in a swine model of pediatric ventricular fibrillation. J Am Coll Cardiol. 2005 Mar 1;45(5):786-9.

OBJECTIVES: This study was designed to compare outcome after adult defibrillation dosing versus pediatric dosing in a piglet model of prolonged prehospital ventricular fibrillation (VF). BACKGROUND: Weight-based 2 to 4 J/kg monophasic defibrillation dosing is recommended for children in VF, but impractical for automated external defibrillator (AED) use. Present AEDs can only provide adult shock doses or newly developed attenuated adult doses intended for children. A single escalating energy sequence (50/75/86 J) of attenuated adult-dose biphasic shocks (pediatric dosing) is at least as effective as escalating monophasic weight-based dosing for prolonged VF in piglets, but this approach has not been compared to standard adult biphasic dosing. METHODS: Following 7 min of untreated VF, piglets weighing 13 to 26 kg (19 +/- 1 kg) received either biphasic 50/75/86 J (pediatric dose) or biphasic 200/300/360 J (adult dose) therapies during simulated prehospital life support. RESULTS: Return of spontaneous circulation was attained in 15 of 16 pediatric-dose piglets and 14 of 16 adult-dose piglets. Four hours postresuscitation, pediatric dosing resulted in fewer elevations of cardiac troponin T (0 of 12 piglets vs. 6 of 11 piglets, $p = 0.005$) and less depression of left ventricular ejection fraction ($p < 0.05$). Most importantly, more piglets survived to 24 h with good neurologic scores after pediatric shocks than adult shocks (13 of 16 piglets vs. 4 of 16 piglets, $p = 0.004$). CONCLUSIONS: In this model, pediatric shocks resulted in superior outcome compared with adult shocks. These data suggest that adult defibrillation dosing may be harmful to pediatric patients with VF and support the use of attenuating electrodes with adult biphasic AEDs to defibrillate children.

LOE 6 (swine), good, neutral. Prospective randomized evaluation of pediatric escalating biphasic waveform (50J-75J-86J) compared to adult escalating biphasic waveform (200J-300J-360J) on a model of prolonged VF (duration 7 min) in swine.
N=32
End point = ROSC
Both strategies achieved similar ROSC rates but pediatric dosing strategy resulted in less myocardial dysfunction and better neurologic outcome at 24hr post resuscitation.

Bright JM, Wright BD. Successful biphasic transthoracic defibrillation of a dog with prolonged, refractory ventricular fibrillation. J Vet Emerg Crit Care (San Antonio). 2009 Jun;19(3):275-9.

OBJECTIVE: To describe a case of spontaneous ventricular fibrillation in a dog in which biphasic defibrillation was life saving. CASE SUMMARY: Ventricular fibrillation occurred in a 7-year-old female Australian Heeler during recovery from anesthesia following pacemaker implantation. Resuscitative efforts including immediate delivery of transthoracic monophasic defibrillation shocks of escalating energy and administration of vasopressors were unsuccessful. However, a single biphasic shock restored sinus rhythm despite prolonged duration of the arrhythmia. NEW OR UNIQUE INFORMATION PROVIDED: This case suggests greater efficacy of biphasic defibrillation compared with traditional monophasic defibrillation. In this dog the newer, biphasic technology was life saving after monophasic shocks failed repeatedly to terminate ventricular fibrillation.

LOE 5, fair, neutral. Case report demonstrating unsuccessful attempts at defibrillation using an escalating monophasic waveform (70J-100J-150J-200J) that was rescued with single biphasic waveform shock of 200J.
End point = ROSC

Clark CB, Zhang Y, Davies LR, Karlsson G, Kerber RE. Pediatric transthoracic defibrillation: biphasic versus monophasic waveforms in an experimental model. Resuscitation. 2001 Nov;51(2):159-63.

OBJECTIVES: The purpose of this study was to determine and compare the efficacy of biphasic and monophasic waveforms in a porcine model of pediatric defibrillation. BACKGROUND: The efficacy and safety of biphasic waveforms in children has not been established. METHODS: We initially studied 27 piglets: 12 weighed 3-6 kg ('infants'), and 15 weighed 7-12 kg ('children'). Ventricular fibrillation (VF) was induced by rapid right ventricular pacing and maintained for 15 s. Transthoracic shocks of 7-100 J energy were given using monophasic (5 ms truncated exponential) and biphasic (5 ms positive, 5 ms negative pulse, truncated exponential) waveforms. A second study of four 'infant' and four 'child' piglets utilized the same protocol but with a 10 ms instead of 5 ms monophasic truncated exponential shock waveform compared with the 10 ms biphasic waveform. RESULTS: For both biphasic and monophasic waveforms, shock success rate (termination of VF) rose steadily as energy was increased. In the first study in the 'infant' 3-6 kg group, the 10 ms biphasic waveforms were superior to 5 ms monophasic waveforms at 10, 20, and 30 J energies, and in the 'child' 7-12 kg group at 20 and 30 J energies ($P<0.05$). High success rates (>80%) were achieved by 20 J (4 J/kg) biphasic waveform shocks in the 'infant' piglets and 30 J (3 J/kg) biphasic waveform shocks in the 'child' piglets. In the second study using a 10 ms monophasic waveform, we found similar results. Pulseless electrical activity occurred in two animals following biphasic shocks and in two animals following monophasic shocks. CONCLUSIONS: Biphasic waveforms proved superior to monophasic waveforms in both infant and child models. High success rates were achieved with low-energy biphasic shocks. Biphasic waveform defibrillation is a promising advance in pediatric resuscitation.

LOE 6 (swine), poor, supportive. Prospective study evaluating monophasic and biphasic defibrillation waveforms ranging from 7 to 100J.
N=35
End point = termination of VF at 5 sec post shock
For both waveforms, success rate rose as energy increased. In the infant model the biphasic waveform shocks were superior to monophasic waveform at 10,20, and 30J and in the child model at 20 and 30J.

Clark CB, Zhang Y, Davies LR, Karlsson G, Kerber RE. Transthoracic biphasic waveform defibrillation at very high and very low energies: a comparison with monophasic waveforms in an animal model of ventricular fibrillation. Resuscitation. 2002 Aug;54(2):183-6.

The purpose of this study was to compare truncated exponential biphasic waveform versus truncated exponential monophasic waveform shocks for transthoracic defibrillation over a wide range of energies. Biphasic waveforms are more effective than monophasic shocks for defibrillation at energies of 150-200 Joules (J) but there are few data available comparing efficacy and safety of biphasic versus monophasic defibrillation at energies of <150 J or >200 J. Thirteen adult swine (weighing 18-26 kg, mean 20 kg) were deeply anesthetized and intubated. After 15 s of electrically-induced ventricular fibrillation (VF), each pig received truncated exponential monophasic shocks (10 ms) and truncated exponential biphasic shocks (5/5 ms) in random order. Energy doses ranged from 70 to 360 J. Success was defined as termination of VF at 5 s post-shock. For both biphasic and monophasic waveforms success rate rose as energy was increased. Biphasic waveform shocks (5/5 ms) were superior to 10 ms monophasic waveform shocks at the very low energy levels (at 70 J, biphasic: 80+/-9%, monophasic; 32+/-11% and at 100 J, biphasic; 96+/-3% and monophasic 39+/-11%, both $P < 0.01$). No significant differences in shock success were seen between biphasic and monophasic waveform shocks at 200 J or higher energy levels. Shock success of > 75% was achieved with 200 J (10 J/kg) for both waveforms. Pulseless electrical activity (PEA) or ventricular asystole occurred in 4 animals receiving monophasic shocks and 1 animal receiving biphasic shocks. Biphasic waveform shocks (5/5 ms) for transthoracic defibrillation were superior to monophasic shocks (10 ms) at low energy levels. Percent success increased with increasing energies. PEA occurred infrequently with either waveform

LOE 6 (swine), good, supportive. Prospective randomized evaluation of monophasic and biphasic shocks at five energy levels (70J-100J-200J-300J-360J).
N=13
End point = termination of VF at 5 sec post shock
Defibrillation success increased as energy increased for both waveforms. Biphasic shocks achieved higher success rates compared to monophasic shocks at 70J and 100J.

Flaker G, Schuder J, McDaniel W. The effect of multiple shocks on canine cardiac defibrillation. Pacing Clin Electrophysiol. 1990 Dec;13(12 Pt 1):1580-4.

To determine if multiple shocks adversely affect the success of later shocks compared with early shocks, we analyzed the success rates of initial shocks (defibrillation attempts 1-5), first half shocks (defibrillation attempts 1-20) and second half shocks (defibrillation attempts 21-40) in a canine model. Epicardial patches were placed on the right and left ventricle in 28 dogs. Ventricular fibrillation was induced by a 60-Hz shock. After 30 seconds, defibrillation was attempted using 7, 12, 13, or 18 joules with either a uniphasic or biphasic rectangular waveform. The uniphasic waveform was 5 msec in duration; the biphasic waveform was 10 msec, with the lagging 5-msec pulse one-half the amplitude of the leading 5-msec pulse. For uniphasic shocks, the right ventricular patch was positive; for biphasic shocks, the right ventricular patch was positive during the leading 5 msec of the shock and negative during the lagging milliseconds. A total of 960 fibrillation episodes were evaluated; no dog was involved in more than 40 fibrillation episodes. The success rates of defibrillation attempts 1-5, defibrillation attempts 1-20, and defibrillation attempts 21-40 were similar at 12, 13, and 18 joules. This information supports the continued use of up to 40 fibrillation trials in canine cardiac defibrillation. However, at 7 joules defibrillation attempts 21-40 were more successful than defibrillation attempts 1-5, and 1-20. With our methodology, these data are consistent with the hypothesis that low energy shocks create a "sensitizing" effect on cardiac tissue, allowing more successful defibrillation with repeated shocks.

LOE 3, poor neutral. Prospective non randomized evaluation of multiple, escalating shocks on canine defibrillation using monophasic or biphasic waveform (7J-12J-13J-18J). Success rates of the initial shocks (1-5), the first half shocks (attempts 1-20) and second half shocks (attempts 21-40)
N=28
End point = termination of VF 2.5min post shock
Higher energies did terminate VF with first attempt better than lowest energy used, but lower energies had increasing efficacy after repeated attempts compared to the highest energy used.

Gelzer AR, Moïse NS, Koller ML. Defibrillation of German shepherds with inherited ventricular arrhythmias and sudden death. J Vet Cardiol. 2005 Nov;7(2):97-107.

OBJECTIVE: To characterize defibrillation success in German shepherd (GS) dogs with inherited ventricular arrhythmias and sudden death. BACKGROUND: Ventricular tachycardia (VT) degenerates to ventricular fibrillation (VF) as the cause of death in GS dogs. To test the hypothesis that GS dogs are more difficult to defibrillate than other dogs, we sought to compare defibrillation success of induced VF in affected GS dogs to a control group of beagles. METHODS: ECG and monophasic action potential (MAP) recordings were acquired during VF and transthoracic defibrillation in anesthetized GS dogs (n=13) and normal beagles (n=7). Shock efficacy, energy requirements, VF frequency and post-defibrillation rhythms were compared between the 2 groups. RESULTS: First shock success of all episodes of VF was lower in GS dogs (10 of 18) than beagles (46 of 47) ($p<0.0001$). However, when evaluated by dog, shock success was not different between GS and beagles (7 of 13 and 6 of 7, respectively; $p=0.15$). Multiple shock success (</=3 consecutive shocks) resulted in a poorer defibrillation success of all episodes of VF in GS dogs (15 of 18) as compared to beagles (47 of 47) ($p<0.02$). Multiple shock success evaluated by dog was similar between GS (11 of 13) and beagles (7 of 7) ($p=0.11$). CONCLUSIONS: Affected GS dogs had lower defibrillation success than beagles; however, defibrillation was possible in the majority of cases.

LOE 3, fair, neutral. Prospective evaluation of defibrillation efficacy in German Shepherds with inherited ventricular arrhythmia compared to Beagles.
N=13 (GSD)
N=7 Beagle
End point = termination of VF 5 sec post shock
Greater number of shocks required to termination VF in GSD in all episodes but energy level required to terminate VF was similar to Beagles.

Leng CT, Paradis NA, Calkins H, Berger RD, Lardo AC, Rent KC, Halperin HR. Resuscitation after prolonged ventricular fibrillation with use of monophasic and biphasic waveform pulses for external defibrillation. Circulation. 2000 Jun 27;101(25):2968-74.

BACKGROUND: Survival after prolonged ventricular fibrillation (VF) appears severely limited by 2 major factors: (1) low defibrillation success rates and (2) persistent post-countershock myocardial dysfunction. Biphasic (BP) waveforms may prove capable of favorably modifying these limitations. However, they have not been rigorously tested against monophasic (MP) waveforms in clinical models of external defibrillation, particularly where rescue from prolonged VF is the general rule. METHODS AND RESULTS: We randomized 26 dogs to external countershocks with either MP or BP waveforms. Hemodynamics were assessed after shocks applied during sinus rhythm, after brief VF (>10 seconds), and after resuscitation from prolonged VF (>10 minutes). Short-term differences in percent change in left ventricular +dP/dt(max) (MP -16+/-28%, BP +9.1+/-24%; P=0.03) and left ventricular -dP/dt(max) (MP -37+/-26%, BP -18+/-20%; P=0.05) were present after rescue from brief VF, with BP animals exhibiting less countershock-induced dysfunction. After prolonged VF, the BP group had lower mean defibrillation thresholds (107+/-57 versus 172+/-88 J for MP, P=0.04) and significantly shorter resuscitation times (397+/-73.7 versus 488+/-74.3 seconds for MP, P=0.03). CONCLUSIONS: External defibrillation is more efficacious with BP countershocks than with MP countershocks. The lower defibrillation thresholds and shorter resuscitation times associated with BP waveform defibrillation may improve survival after prolonged VF arrest.

LOE 3, good, neutral. Prospective randomized evaluation of monophasic escalating (50J-100J-200J-300J-360J) versus biphasic escalating waveform (50J-70J-120J-150J-170J) on VF of 10sec and 10 min duration in dogs.
N=26
PrimaryEnd point = termination of VF at 30 sec
Secondary End point = ROSC
DFT was lower for the biphasic waveform compared to the monophasic waveform at both time points. Increasing the duration of VF raised the DFT for both waveforms. All defibrillation attempts were successful after brief VF however defibrillation failures did occur after prolonged VF. Mean ROSC occurred 90 sec faster for biphasic group compared to monophasic group.

Meaney P.A. Nadkarni V.M. Atkins D.L. Berg M.D. Samson R.A. Hazinski M.F. Berg R.A. Effect of defibrillation energy dose during in-hospital pediatric cardiac arrest. Pediatrics. 127 (1) (pp e16-e23), 2011.

OBJECTIVE: To examine the effectiveness of initial defibrillation attempts. We hypothesized that (1) an initial shock dose of 2 +/-10 J/kg would be less effective for terminating fibrillation than suggested in published historical data and (2) a 4 J/kg shock dose

would be more effective. PATIENTS AND METHODS**:** This was a National Registry of Cardiopulmonary Resuscitation prospective, multisite, observational study of in-hospital pediatric (aged <= 18 years) ventricular fibrillation or pulseless ventricular tachycardia cardiac arrests from 2000-2008. Termination of ventricular fibrillation or pulseless ventricular tachycardia and event survival after initial shocks of 2 J/kg were compared with historic controls and a 4 J/kg shock dose. RESULTS: Of 266 children with 285 events, 173 of 285 (61%) survived the event and 61 of 266 (23%) survived to discharge. Termination of fibrillation after initial shock was achieved for 152 of 285 (53%) events. Termination of fibrillation with 2 +/- 10 J/kg was much less frequent than that seen among historic control subjects (56% vs 91%; P < .001), but not different than 4 J/kg. Compared with 2 J/kg, an initial shock dose of 4 J/kg was associated with lower rates of return of spontaneous circulation (odds ratio: 0.41 [95% confidence interval: 0.21-0.81]) and event survival (odds ratio: 0.42 [95% confidence interval: 0.18-0.98]). CONCLUSIONS: The currently recommended 2 J/kg initial shock dose for in-hospital cardiac arrest was substantially less effective than previously published. A higher initial shock dose (4 J/kg) was not associated with superior termination of ventricular fibrillation or pulseless ventricular tachycardia or improved survival rates. The optimal pediatric defibrillation dose remains unknown.

LOE 6 (human) poor, neutral. Retrospective cohort study examining the optimum starting defibrillation dose for pediatric patients. Energy categories were stratified into <1J/kg, 2J/kg, 4J/kg, 6J/kg, >7J/kg with the majority of shocks delivered being in the 2J/kg and 4J/kg groups. 266 patients taken from the AHA National Registry of Cardiopulmonary Resuscitation. 283 events were evaluated for first shock success, multiple shock success, and ROSC.
N=266 with 283 events and 743 shocks
Primary end point – termination of VF
Secondary end point – ROSC and survival 20 min after ROSC
There was no significant difference in first shock or multiple shock success among the dose strata. Reduction in ROSC was seen when initial shock was 4J/kg. Although the majority of shocks delivered were biphasic waveform, posthoc analysis revealed waveform did not alter the effect of defibrillation dosage on outcomes.

Morrison LJ, Dorian P, Long J, Vermeulen M, Schwartz B, Sawadsky B, Frank J, Cameron B, Burgess R, Shield J, Bagley P, Mausz V, Brewer JE, Lerman BB; Steering Committee, Central Validation Committee, Safety and Efficacy Committee. Out-of-hospital cardiac arrest rectilinear biphasic to monophasic damped sine defibrillation waveforms with advanced life support intervention trial (ORBIT). Resuscitation. 2005 Aug;66(2):149-57.

BACKGROUND: Although biphasic defibrillation waveforms appear to be superior to monophasic waveforms in terminating VF, their relative benefits in out-of-hospital resuscitation are incompletely understood. Prior comparisons of defibrillation waveform efficacy in out-of-hospital cardiac arrest (OHCA) are confined to patients presenting in a shockable rhythm and resuscitated by first responder (basic life support). This effectiveness study compared monophasic and biphasic defibrillation waveform for conversion of ventricular arrhythmias in all OHCA treated with advance life support (ALS). METHODS AND RESULTS: This prospective randomized controlled trial compared the rectilinear biphasic (RLB) waveform with the monophasic damped sine (MDS) waveform, using step-up energy levels. The study enrolled OHCA patients requiring at least one shock delivered by ALS providers, regardless of initial presenting rhythm. Shock success was defined as conversion at 5s to organized rhythm after one to three escalating shocks. We report efficacy results for the cohort of patients treated by ALS paramedics who presented with an initially shockable rhythm who had not received a shock from a first responder (MDS: n=83; RLB: n=86). Shock success within the first three ascending energy shocks for RLB (120, 150, 200J) was superior to MDS (200, 300, 360J) for patients initially presenting in a shockable rhythm (52% versus 34%, p=0.01). First shock conversion was 23% and12%, for RLB and MDS, respectively (p=0.07). There were no significant differences in return of spontaneous circulation (47% versus 47%), survival to 24h (31% versus 27%), and survival to discharge (9% versus 7%). Mean 24h survival rates of bystander witnessed events showed differences between waveforms in the early circulatory phase at 4-10 min post event (mean (S.D.) RLB 0.45 (0.07) versus MDS 0.31 (0.06), p=0.0002) and demonstrated decline as time to first shock increased to 20 min. CONCLUSION: Shock success to an organized rhythm comparing step-up protocol for energy settings demonstrated the RLB waveform was superior to MDS in ALS treatment of OHCA. Survival rates for both waveforms are consistent with current theories on the circulatory and metabolic phases of out-of-hospital cardiac arrest.

LOE 6 (human), good, neutral. Prospective randomized evaluation of escalating biphasic (120J-150J-200J) waveform versus escalating monophasic (200J-200J-360J) waveform on out-of-hospital cardiac arrest.
N=313
Primary end point = termination of VF
Secondary end points = ROSC, 24hr survival, discharge, neurologic function
Biphasic waveform showed superior outcome for first shock success and multiple shock success but there was no difference between groups with respect to ROSC, 24hr survival, or survival to discharge.

Murakawa Y, Gliner BE, Shankar B, Thakor NV. The effect of an unsuccessful subthreshold shock on the energy requirement for the subsequent defibrillation. Am Heart J. 1989 May;117(5):1065-9.

The effect of an unsuccessful subthreshold shock on the energy requirement for the subsequent defibrillation was studied in 10 anesthetized dogs. Defibrillation was achieved with a spring catheter electrode in the superior vena cava and a patch electrode on the anteroapical ventricular wall. Success rates of defibrillation 20 seconds from the onset of ventricular fibrillation were determined at three energy levels with and without a preceding subthreshold shock. Altogether, 637 episodes of fibrillation-defibrillation were performed (63.7 +/- 6.7 per dog). Predicted energy levels for defibrillation success rates of 50% and 80% (E50 and E80) acquired from a logistic regression curve were 0.0303 +/- 0.0064 and 0.0367 +/- 0.0069 joule/gm, respectively, without subthreshold shocks. E50 and E80 with an unsuccessful subthreshold shock resulted in comparable values (E50: 0.0325 +/- 0.0041 joule/gm; E80: 0.0.380 +/- 0.0100 joule/gm). Our results suggest that an unsuccessful low-energy shock does not alter the energy requirement for subsequent defibrillation with an implantable defibrillator.

LOE 3, fair, neutral. Prospective randomized evaluation of sub-defibrillation threshold shocks on subsequent higher energy shocks delivered by internal electrode.
N=10
Primary end point= termination of VF at 10 sec
Secondary end point = ROSC
There was no appreciable effect of an unsuccessful sub DFT shock on the success rate of subsequent higher energy shocks.

Niemann JT, Burian D, Garner D, Lewis RJ. Transthoracic monophasic and biphasic defibrillation in a swine model: a comparison of efficacy, ST segment changes, and postshock hemodynamics. Resuscitation. 2000 Sep;47(1):51-8.

OBJECTIVE: Biphasic waveforms for transthoracic defibrillation (DF) have been tested extensively after brief (15 s) episodes of VF in animal models and in patients undergoing electrophysiologic testing. The purpose of this study was to compare the effects mono- and biphasic waveforms for DF on postdefibrillation ST segments and left ventricular pressure, markers of myocardial injury, after more extended periods of VF (30 and 90 s).
METHODS: 21 anesthetized and instrumented swine were randomized to truncated exponential monophasic or biphasic waveform DF. VF was induced electrically and 30 s later, DF with the designated waveform was attempted with a shock dose of 200 J. If unsuccessful, 300 J and then 360 J were administered if necessary. Following return to control hemodynamic values and normalization of the surface ECG, VF was again induced and, after 90 s, DF was attempted as in the 30 s VF period. CPR was not performed during VF and each animal was countershocked with only one waveform for both VF episodes. Waveforms were compared for frequency of first shock defibrillation success, surface ECG indicators of myocardial injury (ST segment changes at 10, 20, and 30 s after countershock) and time to return to pre-VF hemodynamics after successful DF, an indicator of postshock ventricular function. RESULTS: Successful first shock conversion rates at 30 and 90 s were 60 and 63% for monophasic and 64 and 82% for biphasic (NS). Biphasic DF after 30 s produced ST segment changes (measured 10 s after DF) in 1/10 animals while six of eight animals in the monophasic group showed ST segment changes (P=0.013). After 90 s of VF, ST segment changes were observed in 6/8 in the monophasic group and 2/10 in the biphasic group (P=0.054). Differences in the time to hemodynamic recovery (return to control peak left ventricular pressure) were not observed between biphasic and monophasic waveforms after 30 or 90 s of VF.
CONCLUSIONS: Monophasic and biphasic transthoracic defibrillation are equally effective in terminating VF of 30 and 90 s duration and restoring a perfusing rhythm. The biphasic waveform produced less ECG evidence of transient myocardial injury. However, there was no difference in the rate of return to control hemodynamics. ST segment changes following countershock of VF of brief duration are transient and of questionable significance.

LOE 6 (swine), good, neutral. Prospective randomized non-blinded evaluation of escalating monophasic versus escalating biphasic waveform (both 200J-300J-360J) on termination of VF of 30sec and 90sec duration.
N=21
Primary end point = Termination of VF at 30 sec post shock
No difference in efficacy in termination of VF at either time point. There was a slight advantage of biphasic waveform on myocardial dysfunction observed at 90 sec time point only but there was no difference in ROSC between groups.

Niemann JT, Burian D, Garner D, Lewis RJ. Monophasic versus biphasic transthoracic countershock after prolonged ventricular fibrillation in a swine model. J Am Coll Cardiol. 2000 Sep;36(3):932-8.

OBJECTIVE: We sought to compare the defibrillation efficacy of a low-energy biphasic truncated exponential (BTE) waveform and a conventional higher-energy monophasic truncated exponential (MTE) waveform after prolonged ventricular fibrillation (VF).
BACKGROUND: Low energy biphasic countershocks have been shown to be effective after brief episodes of VF (15 to 30 s) and to produce few postshock electrocardiogram abnormalities. METHODS: Swine were randomized to MTE (n = 18) or BTE (n = 20)

after 5 min of VF. The first MTE shock dose was 200 J, and first BTE dose 150 J. If required, up to two additional shocks were administered (300, 360 J MTE; 150, 150 J BTE). If VF persisted manual cardiopulmonary resuscitation (CPR) was begun, and shocks were administered until VF was terminated. Successful defibrillation was defined as termination of VF regardless of postshock rhythm. If countershock terminated VF but was followed by a nonperfusing rhythm, CPR was performed until a perfusing rhythm developed. Arterial pressure, left ventricular (LV) pressure, first derivative of LV pressure and cardiac output were measured at intervals for 60 min postresuscitation. RESULTS: The odds ratio of first-shock success with BTE versus MTE was 0.67 (p = 0.55). The rate of termination of VF with the second or third shocks was similar between groups, as was the incidence of postshock pulseless electrical activity (15/18 MTE, 18/20 BTE) and CPR time for those animals that were resuscitated. Hemodynamic variables were not significantly different between groups at 15, 30 and 60 min after resuscitation. CONCLUSIONS: Monophasic and biphasic waveforms were equally effective in terminating prolonged VF with the first shock, and there was no apparent clinical disadvantage of subsequent low-energy biphasic shocks compared with progressive energy monophasic shocks. Lower-energy shocks were not associated with less postresuscitation myocardial dysfunction.

LOE 6 (swine), good, neutral. Prospective randomized non-blinded evaluation of fixed dose biphasic (150J-150J-150J) and escalating monophasic (200J-300J-360J) waveform on prolonged VF (duration=5min).
N=38
Primary end point = Termination of VF immediately post shock
Secondary en point = ROSC
Although first shock success was similar between monophasic and biphasic treated groups (61% and 50% respectively), the ROSC after first shock was equally low in both groups (11% and 10% respectively).

Niemann JT, Garner D, Lewis RJ. Left ventricular function after monophasic and biphasic waveform defibrillation: the impact of cardiopulmonary resuscitation time on contractile indices. Acad Emerg Med. 2003 Jan;10(1):9-15.

Previous work has suggested that low-energy biphasic waveform defibrillation (BWD) is followed by less post-resuscitation left ventricular (LV) dysfunction when compared with higher-energy monophasic waveform defibrillation (MWD). To the best of the authors' knowledge, the effect of cardiopulmonary resuscitation (CPR) duration and total ischemia time on LV function after countershock, controlling for waveform type, has not been evaluated. OBJECTIVE: To determine the effect of CPR duration on LV function after MWD and BWD. METHODS: VF was electrically induced in anesthetized and instrumented swine. After 5 minutes of VF, the animals were randomized to MWD (n = 22) or one of two BWDs (n = 46). If countershock terminated VF but was followed by a nonperfusing rhythm, conventional manual CPR without drug therapy was performed until restoration of spontaneous circulation (ROSC), defined as a systolic arterial pressure >60 mm Hg for 10 minutes without vasopressor support. Systolic LV pressure (LVP), LV dP/dt (first derivative of pressure measured over time), and cardiac output (CO) were measured at intervals for 60 minutes postresuscitation. CPR times (times to ROSC) and hemodynamic variables for the three groups were compared. Multivariable linear regression was performed to assess the contribution of defibrillation waveform, total joules, and CPR time on LVP, LV dP/dt, and CO at 15, 30, and 60 minutes postresuscitation. RESULTS: When analyzed as groups, significant differences in median number of shocks to terminate VF, total joules, or CPR time were not observed between waveform groups. Regression analysis demonstrated that increasing CPR time was associated with a significant effect on indices of LV function at 15 and 30 minutes postresuscitation. Global LV function was not influenced by waveform type or total joules. CONCLUSIONS: Adjustment for CPR time, a determinant of total myocardial ischemia time, is necessary when defibrillation waveforms are compared for their effect on postresuscitation cardiac function and short-term outcome.

LOE 6 (swine) fair, neutral. Prospective randomized non blinded evaluation of escalating monophasic (200J-300J-360J), biphasic waveform low dose fixed (150J) and biphasic high dose (200J-300J-360J) waveform cardiac dysfunction in prolonged VF model in swine (duration 5 min).
N=68
Primary end point = termination of VF at 10 sec
Secondary end point = ROSC
No significant difference was seen between groups with respect to first shock success, ROSC, total joules delivered or CPR time.

Niemann JT, Rosborough JP, Walker RG. A model of ischemically induced ventricular fibrillation for comparison of fixed-dose and escalating-dose defibrillation strategies. Acad Emerg Med. 2004 Jun;11(6):619-24.

OBJECTIVES: Fixed- and escalating-dose defibrillation protocols are both in clinical use. Clinical observations suggest that the probability of successful defibrillation is not constant across a population of patients with ventricular fibrillation (VF). Common animal models of electrically induced VF do not represent a clinical VF etiology or reproduce clinical heterogeneity in defibrillation probability. The authors hypothesized that a model of ischemically induced VF would exhibit heterogeneous defibrillation shock strength requirements and that an escalating-dose strategy would more effectively achieve prompt defibrillation. METHODS: Forty-

six swine were randomized to fixed, lower-energy (150 J) transthoracic shocks (group 1) or escalating, higher-energy (200 J-300 J-360 J) shocks (group 2). VF was induced by balloon occlusion of a coronary artery. After 1 or 5 minutes of VF, countershocks with a biphasic waveform were administered. The primary endpoint was successful defibrillation (termination of VF for 5 seconds) with < or =3 shocks. RESULTS: VF was induced with occlusion or after reperfusion in 35 animals. Only five of 17 group 1 animals (29%, 95% CI = 10 to 56) could be defibrillated with < or =3 shocks; 15 of 18 group 2 animals (83%, 95% CI = 59 to 96) were defibrillated with < or =3 shocks ($p < 0.002$ vs. group 1). Nine of the group 1 animals (75%) that could not be defibrillated with 150-J shocks were rescued with < or =3 shocks ranging from 200 to 360 J. CONCLUSIONS: In this ischemic VF animal model, defibrillation shock strength requirements varied among individuals, and when defibrillation was difficult, an escalating-dose strategy was more effective for prompt defibrillation than fixed, lower-energy shocks.

LOE 6 (swine), good, supportive. Prospective randomized evaluation of low energy fixed dose biphasic waveform (150J) versus escalating dose biphasic waveform (200J, 300J, 360J) in an ischemic model of VF.
N=35
Primary endpoint = termination of VF at 5 sec post shock
Duration of VF = 1 min or 5 min
5/17(29%) animals using the lower energy fixed dose protocol were successfully defibrillated compared to 15/18 (83%) animals using the escalating energy protocol. Nine of 12 animals in the fixed dose group that failed defibrillation with 150J were successfully rescued with higher energy shocks. Duration of VF did not alter energy or peak current needed for successful defibrillation.

Niemann JT, Rosborough JP, Youngquist ST, Shah AP. Transthoracic defibrillation potential gradients in a closed chest porcine model of prolonged spontaneous and electrically induced ventricular fibrillation. Resuscitation. 2010 Apr;81(4):477-80.

OBJECTIVE: The purpose of this study was to measure the local electrical field or potential gradient, measured with a catheter-based system, required to terminate long duration electrically or ischaemically induced ventricular fibrillation (VF). We hypothesized that prolonged ischaemic VF would be more difficult to terminate when compared to electrically induced VF of similar duration. METHODS: Thirty anesthetized and instrumented swine were randomized to electrically induced VF or spontaneous, ischaemically induced VF, produced by balloon occlusion of the left anterior descending coronary artery. After 7 min of VF, chest compressions were initiated and rescue shocks were attempted 1 min later. The potential gradient for each shock was measured and the mean values required for defibrillation compared for the VF groups. RESULTS: The number of shocks and the shock strength required for termination of VF were not significantly different for the groups. The potential gradient of the first successful defibrillating shock was significantly greater in the spontaneous, occlusion-induced VF group (12.80+/-2.82 V/cm vs 9.60+/-2.48 V/cm, $p=0.002$). The number of refibrillations was greater in the ischaemic group than in the non-ischaemic electrical group (6+/-4 vs 1+/-1, $p<0.001$). The number of animals requiring a shock at 360J was 2.5 times greater for the ischaemic group. CONCLUSIONS: Defibrillation of prolonged VF produced by acute myocardial ischaemia requires a significantly greater potential gradient to terminate than prolonged VF induced by electrical stimulation of the right ventricular endocardium. The VF duration used in this study approximates that occurring in victims of out-of-hospital cardiac arrest. Our findings may be of clinical importance in the management of such patients.

LOE 6 (swine) good, neutral. Prospective randomized evaluation of escalating (200J-300J-360J) monophasic waveform on prolonged VF (duration 7 min) that is electrically induced or spontaneous (ischemic-induced).
N=30
Primary end point = termination of VF at 5 sec post shock
Raw data suggested shock strength as well as the number of shocks required for termination of VF was higher in spontaneous VF, it did not reach statistical significance. The number of refibrillations was greater in the ischemic group. The number of animals requiring 360J shock was 2.5 times greater for the ischemic group.

Stiell IG, Walker RG, Nesbitt LP, Chapman FW, Cousineau D, Christenson J, Bradford P, Sookram S, Berringer R, Lank P, Wells GA. BIPHASIC Trial: a randomized comparison of fixed lower versus escalating higher energy levels for defibrillation in out-of-hospital cardiac arrest. Circulation. 2007 Mar 27;115(12):1511-7.

BACKGROUND: There is little clear evidence as to the optimal energy levels for initial and subsequent shocks in biphasic waveform defibrillation. The present study compared fixed lower- and escalating higher-energy regimens for out-of-hospital cardiac arrest. METHODS AND RESULTS: The Randomized Controlled Trial to Compare Fixed Versus Escalating Energy Regimens for Biphasic Waveform Defibrillation (BIPHASIC Trial) was a multicenter, randomized controlled trial of 221 out-of-hospital cardiac arrest patients who received > or = 1 shock given by biphasic automated external defibrillator devices that were randomly

programmed to provide, blindly, fixed lower-energy (150-150-150 J) or escalating higher-energy (200-300-360 J) regimens. Patient mean age was 66.0 years; 79.6% were male. The cardiac arrest was witnessed in 63.8%; a bystander performed cardiopulmonary resuscitation in 23.5%; and initial rhythm was ventricular fibrillation/ventricular tachycardia in 92.3%. The fixed lower- and escalating higher-energy regimen cases were similar for the 106 multishock patients and for all 221 patients. In the primary analysis in multishock patients, conversion rates differed significantly (fixed lower, 24.7%, versus escalating higher, 36.6%; P=0.035; absolute difference, 11.9%; 95% CI, 1.2 to 24.4). Ventricular fibrillation termination rates also were significantly different between groups (71.2% versus 82.5%; P=0.027; absolute difference, 11.3%; 95% CI, 1.6 to 20.9). For the secondary analysis of first shock success, conversion rates were similar between the fixed lower and escalating higher study groups (38.4% versus 36.7%; P=0.92), as were ventricular fibrillation termination rates (86.8% versus 88.8%; P=0.81). There were no distinguishable differences between regimens for survival outcomes or adverse effects. CONCLUSIONS: This is the first randomized trial to compare fixed lower and escalating higher biphasic energy regimens in out-of-hospital cardiac arrest, and it demonstrated higher rates of ventricular fibrillation conversion and termination with an escalating higher-energy regimen for patients requiring multiple shocks. These results suggest that patients in ventricular fibrillation benefit from higher biphasic energy levels if multiple defibrillation shocks are required.

LOE 6 (human), good, supportive. Prospective randomized triple blinded evaluation of fixed low dose (150J-150J-150J) biphasic versus escalating high dose (200J-300J-360J) biphasic waveform on out-of-hospital cardiac arrest.
N=221
Primary end point = Termination of VF
Secondary end points = ROSC, 24hr survival, hospital discharge, neurologic function
There was no difference in first shock success at 150J and 200J. There was a benefit seen from escalating dose in multishock patients. ROSC, 24hr survival and discharge were not different between the fixed and escalating energy groups. For multishock patients, termination of VF was 82% in the escalating energy group versus 71.2% in the fixed dose group. Successful conversion in multishock patients was 36.6% with the escalating dose protocol versus 24.7% with the fixed dose protocol.

Tang W, Weil MH, Sun S, Povoas HP, Klouche K, Kamohara T, Bisera J. A comparison of biphasic and monophasic waveform defibrillation after prolonged ventricular fibrillation. Chest. 2001 Sep;120(3):948-54.

STUDY OBJECTIVE: To compare the effects of biphasic defibrillation waveforms and conventional monophasic defibrillation waveforms on the success of initial defibrillation, postresuscitation myocardial function, and duration of survival after prolonged duration of untreated ventricular fibrillation (VF), including the effects of epinephrine. DESIGN: Prospective, randomized, animal study. SETTING: Animal laboratory and university-affiliated research and educational institute. PARTICIPANTS: Domestic pigs. INTERVENTIONS: VF was induced in 20 anesthetized domestic pigs receiving mechanical ventilation. After 10 min of untreated VF, the animals were randomized. Defibrillation was attempted with up to three 150-J biphasic waveform shocks or a conventional sequence of 200-J, 300-J, and 360-J monophasic waveform shocks. When reversal of VF was unsuccessful, precordial compression was performed for 1 min, with or without administration of epinephrine. The protocol was repeated until spontaneous circulation was restored or for a maximum of 15 min. MEASUREMENTS AND RESULTS: No significant differences in the success of initial resuscitation or in the duration of survival were observed. However, significantly less impairment of myocardial function followed biphasic shocks. Administration of epinephrine reduced the total electrical energy required for successful resuscitation with both biphasic and monophasic waveform shocks. CONCLUSIONS: Lower-energy biphasic waveform shocks were as effective as conventional higher-energy monophasic waveform shocks for restoration of spontaneous circulation after 10 min of untreated VF. Significantly better postresuscitation myocardial function was observed after biphasic waveform defibrillation. Administration of epinephrine after prolonged cardiac arrest decreased the total energy required for successful resuscitation.

LOE 6 (swine), fair, neutral. Prospective randomized evaluation of escalating monophasic waveform (200J-300J-360J) and fixed biphasic waveform (150J) on ROSC and myocardial dysfunction in prolonged VF model (duration 10min).
N=20
End point = ROSC
Biphasic waveform defibrillation was as effective as escalating monophasic protocol in achieving ROSC after 10 min of VF. Myocardial dysfunction was seen in both groups but much less in the biphasic group.

Tang W, Weil MH, Sun S, Yamaguchi H, Povoas HP, Pernat AM, Bisera J. The effects of biphasic and conventional monophasic defibrillation on postresuscitation myocardial function. J Am Coll Cardiol. 1999 Sep;34(3):815-22.

OBJECTIVES: The purpose of this study was to compare the effects of biphasic defibrillation waveforms and conventional monophasic defibrillation waveforms on the success of initial defibrillation, postresuscitation myocardial function and duration of survival after prolonged ventricular fibrillation (VF). BACKGROUND: We have recently demonstrated that the severity of

postresuscitation myocardial dysfunction was closely related to the magnitude of the electrical energy of the delivered defibrillation shock. In the present study, the effects of fixed 150-J low-energy biphasic waveform shocks were compared with conventional monophasic waveform shocks after prolonged VF. METHODS: Twenty anesthetized, mechanically ventilated domestic pigs were investigated. VF was induced with an AC current delivered to the right ventricular endocardium. After either 4 or 7 min of untreated ventricular fibrillation (VF), the animals were randomized for attempted defibrillation with up to three 150-J biphasic waveform shocks or conventional sequence of 200-, 300- or 360-J monophasic waveform shocks. If VF was not reversed, a 1-min interval of precordial compression preceded a second sequence of up to three shocks. The protocol was repeated until spontaneous circulation was restored or for a total of 15 min. RESULTS: Monophasic waveform defibrillation after 4 or 7 min of untreated VF resuscitated eight of 10 pigs. All 10 pigs treated with biphasic waveform defibrillation were successfully resuscitated. Transesophageal echo-Doppler, arterial pressure and heart rate measurements demonstrated significantly less impairment of cardiovascular function after biphasic defibrillation. CONCLUSIONS: Lower-energy biphasic waveform shocks were as effective as conventional higher energy monophasic waveform shocks for restoration of spontaneous circulation after 4 and 7 min of untreated VF. Significantly better postresuscitation myocardial function was observed after biphasic waveform defibrillation.
LOE 6 (swine), good, neutral. Prospective randomized trial of escalating monophasic (200J-300J-360J) versus fixed dose biphasic (150J) waveform at two durations of VF, 4min and 7 min.
N=20
Primary end point = Termination of VF
Secondary end point = ROSC
No difference in ROSC or survival between groups. Less myocardial dysfunction was seen in the biphasic group. Higher energy was required in the monophasic group to achieve ROSC after 7min of VF compared to 4 min.

Tang W, Weil MH, Jorgenson D, Klouche K, Morgan C, Yu T, Sun S, Snyder D. Fixed-energy biphasic waveform defibrillation in a pediatric model of cardiac arrest and resuscitation. Crit Care Med. 2002 Dec;30(12):2736-41.

OBJECTIVE: For adults, 150-J fixed-energy, impedance-compensating biphasic truncated exponential (ICBTE) shocks are now effectively used in automated defibrillators. However, the high energy levels delivered by adult automated defibrillators preclude their use for pediatric patients. Accordingly, we investigated a method by which adult automated defibrillators may be adapted to deliver a 50-J ICBTE shock for pediatric defibrillation. DESIGN: Prospective, randomized study. SETTING: A university-affiliated research institution. SUBJECT: Domestic piglets. INTERVENTIONS: We initially investigated four groups of anesthetized mechanically ventilated piglets weighing 3.8, 7.5, 15, and 25 kg. Ventricular fibrillation was induced with an AC current delivered to the right ventricular endocardium. After 7 mins of untreated ventricular fibrillation, a conventional manual defibrillator was used to deliver up to three 50-J ICBTE shocks. If ventricular fibrillation was not reversed, a 1-min interval of precordial compression preceded a second sequence of up to three shocks. The protocol was repeated until spontaneous circulation was restored, or for a total of 15 mins. In a second set of experiments, we evaluated a 150-J biphasic adult automated defibrillator that was operated in conjunction with energy-reducing electrodes such as to deliver 50-J shocks. The same resuscitation protocol was then exercised on piglets weighing 3.7, 13.5, and 24.2 kg. MEASUREMENTS AND MAIN RESULTS: All animals were successfully resuscitated. Postresuscitation hemodynamic and myocardial function quickly returned to baseline values in both experimental groups, and all animals survived. CONCLUSION: An adaptation of a 150-J biphasic adult automated defibrillator in which energy-reducing electrodes delivered 50-J shocks successfully resuscitated animals ranging from 3.7 to 25 kg without compromise of postresuscitation myocardial function or survival.

LOE 6 (swine) fair, neutral. Prospective randomized evaluation of fixed biphasic waveform (50J machine and 150J machine modified to deliver 50J) on prolonged VF (duration 7 min) in piglets over a range of sizes (range 3.8 – 25kg).
N=20
End point = ROSC
All animals achieved ROSC. Middle sized animals (7.5kg and 15kg) required fewer shocks for successful defibrillation, 1.8, compared to smallest animals, 3.2 shocks and largest animals, 5.2 shocks.

Tang W, Weil MH, Sun S, Jorgenson D, Morgan C, Klouche K, Snyder D. The effects of biphasic waveform design on post-resuscitation myocardial function. J Am Coll Cardiol. 2004 Apr 7;43(7):1228-35.

OBJECTIVES: This study examined the effects of biphasic truncated exponential waveform design on survival and post-resuscitation myocardial function after prolonged ventricular fibrillation (VF). BACKGROUND: Biphasic waveforms are more effective than monophasic waveforms for successful defibrillation, but optimization of energy and current levels to minimize post-resuscitation myocardial dysfunction has been largely unexplored. We examined a low-capacitance waveform typical of low-energy application (low-energy biphasic truncated exponential [BTEL]; 100 microF, < or =200 J) and a high-capacitance waveform typical of high-energy application (high-energy biphasic truncated exponential [BTEH]; 200 microF, > or =200 J). METHODS: Four

groups of anesthetized 40- to 45-kg pigs were investigated. After 7 min of electrically induced VF, a 15-min resuscitation attempt was made using sequences of up to three defibrillation shocks followed by 1 min of cardiopulmonary resuscitation. Animals were randomized to BTEL at 150 J or 200 J or to BTEH at 200 J or 360 J. RESULTS: Resuscitation was unsuccessful in three of the five animals treated with BTEH at 200 J. All other attempts were successful. Significant therapy effects were observed for survival ($p = 0.035$), left ventricular ejection fraction ($p < 0.001$), stroke volume ($p < 0.001$), fractional area change ($p < 0.001$), cardiac output ($p = 0.044$), and mean aortic pressure ($p < 0.001$). Hemodynamic outcomes were negatively associated with energy and average current but positively associated with peak current. Peak current was the only significant predictor of survival ($p < 0.001$). CONCLUSIONS: Maximum survival and minimum myocardial dysfunction were observed with the low-capacitance 150-J waveform, which delivered higher peak current while minimizing energy and average current.

LOE 6 (swine) good, neutral. Prospective randomized evaluation of fixed energy low capacitance biphasic waveform (150J or 200J) and high capacitance biphasic waveform (200J or 360J).
BTEL – low energy biphasic waveform
BTEH – high energy biphasic waveform
N=20, 5 animals in each of 4 groups; BTEL 150J, BTEL 200J, BTEH 200J, BTEL 360J
End point = termination of VF at 5 sec post shock
Both BTEL strategies resulted in termination of VF and survival of all patients and was associated with less myocardial dysfunction. BTEL patients required fewer shocks to achieve ROSC, although this did not reach significance.

Tang W, Snyder D, Wang J, Huang L, Chang YT, Sun S, Weil MH. One-shock versus three-shock defibrillation protocol significantly improves outcome in a porcine model of prolonged ventricular fibrillation cardiac arrest. Circulation. 2006 Jun 13;113(23):2683-9.

BACKGROUND: The success of resuscitation with a 1-shock versus the conventional 3-shock defibrillation protocol was investigated subject to the range of treatment variation imposed by automated external defibrillators (AEDs). METHODS AND RESULTS: Ventricular fibrillation was induced in 44 domestic pigs. After 7 minutes of untreated VF, animals were randomized among 4 groups representing all combinations of the 1- versus 3-shock protocol and 2 different AED regimens (AED1, AED2). Because few AEDs support a 1-shock protocol, manual defibrillators were used to replicate the AED treatment regimen: electrical waveform, dose sequence, and cardiopulmonary resuscitation (CPR) interruption intervals. Initial shock(s) were delivered, followed by 60 seconds of CPR, and the treatment was repeated until resuscitation was successful or for 15 minutes. The 1-shock protocol was associated with improved outcome, reducing CPR interruptions from 45% to 34% of total resuscitation time ($P=0.019$) and increasing survival from 64% to 100% ($P=0.004$). Survival was 91% for AED1 versus 36% for AED2 ($P=0.024$) with a 3-shock protocol but was increased to 100% for both by adoption of a 1-shock protocol. Improvements in postresuscitation left ventricular ejection fraction and stroke volume were observed with AED1 compared with AED2 (difference of means, 15% and 28% of baseline respectively, $P<0.001$) regardless of defibrillation protocol. CONCLUSIONS: Adoption of a 1-shock versus a 3-shock resuscitation protocol improved survival and minimized outcome differences imposed by variations in AED design and implementation. When a conventional 3-shock defibrillation protocol was used, however, the choice of AED had a significant impact on resuscitation outcome

LOE 6 (swine), good neutral. Prospective randomized evaluation of two biphasic AED models in 1 shock versus 3 consecutive shock protocol in prolonged VF, duration 7 min.
AED 1, low capacitance, fixed dose 150J; AED 2, high capacitance, escalating dose 200J-300J-360J
N=44
End point = termination of VF at 5 sec post shock
One shock protocol reduced CPR interruptions from 45% to 34% of total resuscitation time and incrased survival from 64% to 100%. Survival was better with AED 1 compared to AED 2 when three shock protocol was used, but this increased to 100% for both groups when 1 shock protocol was adopted. For the same shock protocol AED1 produced less myocardial dysfunction than AED 2.

Walcott GP, Melnick SB, Killingsworth CR, Ideker RE. Comparison of low-energy versus high-energy biphasic defibrillation shocks following prolonged ventricular fibrillation. Prehosp Emerg Care. 2010 Jan-Mar;14(1):62-70.

INTRODUCTION: Since the initial development of the defibrillator, there has been concern that, while delivery of a large electric shock would stop fibrillation, it would also cause damage to the heart. This concern has been raised again with the development of the biphasic defibrillator. OBJECTIVE: To compare defibrillation efficacy, postshock cardiac function, and troponin I levels following 150-J and 360-J shocks. METHODS: Nineteen swine were anesthetized with isoflurane and instrumented with pressure catheters in the left ventricle, aorta, and right atrium. The animals were fibrillated for 6 minutes, followed by defibrillation with either low-energy ($n = 8$) or high-energy ($n = 11$) shocks. After defibrillation, chest compressions were initiated and continued until return

of spontaneous circulation (ROSC). Epinephrine, 0.01 mg/kg every 3 minutes, was given for arterial blood pressure < 50 mmHg. Hemodynamic parameters were recorded for four hours. Transthoracic echocardiography was performed and troponin I levels were measured at baseline and four hours following ventricular fibrillation (VF). RESULTS: Survival rates at four hours were not different between the two groups (low-energy, 5 of 8; high-energy, 7 of 11). Results for arterial blood pressure, positive dP/dt (first derivative of pressure measured over time, a measure of left ventricular contractility), and negative dP/dt at the time of lowest arterial blood pressure (ABP) following ROSC were not different between the two groups (p = not significant [NS]), but were lower than at baseline. All hemodynamic measures returned to baseline by four hours. Ejection fractions, stroke volumes, and cardiac outputs were not different between the two groups at four hours. Troponin I levels at four hours were not different between the two groups (12 +/- 11 ng/mL versus 21 +/- 26 ng/mL, p = NS) but were higher at four hours than at baseline (19 +/- 19 ng/mL versus 0.8 +/- 0.5 ng/mL, p < 0.05, groups combined). CONCLUSION: Biphasic 360-J shocks do not cause more cardiac damage than biphasic 150-J shocks in this animal model of prolonged VF and resuscitation.

LOE 6 (swine), fair, neutral. Prospective randomized non-blinded evaluation of either fixed low energy biphasic waveform (150J) or fixed high energy biphasic waveform (360J) on prolonged VF model (duration 6 min).
N=19
End point = ROSC
Both first shock success and first-two-shock success was significantly greater for 360J group (11/11, 100%) versus 150J (5/8, 62%), however similar number reached the primary end point of ROSC and survival at 4 hr post resuscitation (62%). There was no difference in troponin I levels between groups in the post resuscitation period.

Walcott GP, Melnick SB, Chapman FW, Jones JL, Smith WM, Ideker RE. Relative efficacy of monophasic and biphasic waveforms for transthoracic defibrillation after short and long durations of ventricular fibrillation. Circulation. 1998 Nov 17;98(20):2210-5.

BACKGROUND: Recently, interest has arisen in using biphasic waveforms for external defibrillation. Little work has been done, however, in measuring transthoracic defibrillation efficacy after long periods of ventricular fibrillation. In protocol 1, we compared the efficacy of a quasi-sinusoidal biphasic waveform (QSBW), a truncated exponential biphasic waveform (TEBW), and a critically damped sinusoidal monophasic waveform (CDSMW) after 15 seconds of fibrillation. In protocol 2, we compared the efficacy of the more efficacious biphasic waveform from protocol 1, QSBW, with CDSMW after 15 seconds and 5 minutes of fibrillation. METHODS AND RESULTS: In protocol 1, 50% success levels, ED50, were measured after 15 seconds of fibrillation for the 3 waveforms in 6 dogs. In protocol 2, defibrillation thresholds were measured for QSBW and CDSMW after 15 seconds of fibrillation and after 3 minutes of unsupported fibrillation followed by 2 minutes of fibrillation with femoral-femoral cross-circulation. In protocol 1, QSBW had a lower ED50, 16.0+/-4.9 J, than TEBW, 20.3+/-4.4 J, or CDSMW, 27.4+/-6.0 J. In protocol 2, QSBW had a lower defibrillation threshold after 15 seconds, 38+/-10 J, and after 5 minutes, 41.5+/-5 J, than CDSMW after 15 seconds, 54+/-19 J, and 5 minutes, 80+/-30 J, of fibrillation. The defibrillation threshold remained statistically the same for QSBW for the 2 fibrillation durations but rose significantly for CDSMW. CONCLUSIONS: In this animal model of sudden death and resuscitation, these 2 biphasic waveforms are more efficacious than the CDSMW at short durations of fibrillation. Furthermore, the QSBW is even more efficacious than the CDSMW at longer durations of fibrillation.

LOE 3, fair neutral. Prospective randomized evaluation of monophasic waveform compared to two biphasic waveforms (truncated exponential and quasi-sinusoidal) to determine DFT in dog model at two different VF durations, 15 sec and 5min.
N=6
End point = termination of VF 30 sec post shock
Lower DFT seen for both biphasic waveforms compared to monophasic waveform. DFT for monophasic waveform increased in prolonged VF model but remained nearly unchanged for the biphasic waveforms.

Walcott GP, Killingsworth CR, Smith WM, Ideker RE. Biphasic waveform external defibrillation thresholds for spontaneous ventricular fibrillation secondary to acute ischemia. J Am Coll Cardiol. 2002 Jan 16;39(2):359-65.

OBJECTIVES: The goal of this study was to determine if the defibrillation threshold (DFT) after spontaneous ventricular fibrillation (VF) secondary to acute ischemia differs from the DFT for electrically induced VF in the absence of ischemia in anesthetized, closed-chest dogs and pigs. BACKGROUND: The efficacy of external defibrillators has been tested mainly in animals and humans using E-VF, yet external defibrillators are often used in patients to halt S-VF. METHODS: Protocol 1: biphasic truncated exponential (BTE) waveform shocks were delivered through electrodes placed in an anterior-anterior (A-A) position (left and right lateral thorax) in nine dogs. After measuring the E-VF DFT, acute ischemia was induced with an angioplasty balloon in either the left anterior descending or left circumflex coronary artery, and the S-VF DFT was determined. Protocol 2: in a group of 12 pigs, the E-VF DFT and S-VF DFT were determined for electrodes in the A-A position and in the anterior-posterior position (A-P). Protocol 3: the E-VF DFT was determined in seven pigs. Then up to three shocks 1.5x the E-VF DFT were delivered to S-VF. If defibrillation did not occur, a step-

up protocol was used until defibrillation occurred. RESULTS: Protocol 1: the DFT for E-VF was 65 +/- 28 J (mean +/- SD) compared with 226 +/- 97 J for S-VF, $p < 0.05$. Protocol 2: the DFT was 152 +/- 58 J for E-VF and 315 +/- 123 J for S-VF for A-A electrodes. The DFT was 100 +/- 43 J for E-VF and 206 +/- 114 J for S-VF for A-P electrodes. Protocol 3: 11/37 shocks of strength 1.5x E-VF DFT (182 +/- 40 J) stopped the arrhythmia. The episodes of S-VF not halted by these shocks required energy levels of up to 400 J for defibrillation. CONCLUSIONS: External defibrillation of S-VF induced by acute ischemia requires significantly more energy than VF induced by 60-Hz current in the absence of ischemia. A safety margin >1.5x the DFT for electrically induced VF may be necessary in BTE external defibrillators to defibrillate S-VF.

LOE 3 and 6 (swine) fair, supportive. Prospective evaluation of biphasic DFT for electrically induced versus spontaneous (ischemic induced) VF.
N=9 dog
N=19 pig
End point = termination of VF at 30 sec post shock
Spontaneous VF has higher DFT compared to electrically induced VF.

Walker RG, Melnick SB, Chapman FW, Walcott GP, Schmitt PW, Ideker RE. Comparison of six clinically used external defibrillators in swine. Resuscitation. 2003 Apr;57(1):73-83.

BACKGROUND: External defibrillation has long been practiced with two types of monophasic waveforms, and now four biphasic waveforms are also widely available. Although waveforms and clinical dosing protocols differ among defibrillators, no studies have adequately compared performance of the monophasic or the biphasic waveforms. This is the first study to compare defibrillation efficacy among biphasic external defibrillators, and does so as part of a study comparing all commonly available waveforms using their respective manufacturer-provided and clinically used doses. METHODS AND RESULTS: Efficacy of six waveforms was tested in 852 short-duration ventricular fibrillation episodes in 14 swine. Protocol 1: 200-J monophasic damped sine (MDS) and monophasic truncated exponential (MTE) shocks were compared to 150-J biphasic shocks in six swine at the low-impedance of these animals. Protocol 2: Four commercially available biphasic defibrillators were compared using their respective manufacturer-recommended dose protocols in eight swine at low and simulated high-impedance. At low-impedance, all biphasic shocks achieved near-perfect success, while efficacy was significantly lower for MDS (67%) and MTE (30%) shocks. In protocol 2, first-shock success rates of the four biphasic defibrillators were uniformly high (97, 100, 100, and 94%) for low-impedance shocks, and decreased for high-impedance shocks (62, 92, 82, and 64%). There were statistically significant differences in efficacy among devices. CONCLUSIONS: Commonly used MDS and MTE waveforms provide markedly dissimilar efficacies. Despite impedance-compensation schemes in biphasic defibrillators, impedance has an impact on their efficacy. At high-impedance, modest efficacy differences exist among clinically available biphasic defibrillators, reflecting differences in both waveforms and manufacturer-provided doses.

LOE 6, good, supportive. Prospective randomized comparison of different waveform and energy protocols on VF and efficacy with varying impedance in swine model.
N=14
Protocol 1 = comparison of two monophasic waveforms with biphasic waveform
Protocol 2 = comparison of four biphasic waveforms with differing energy protocol

a. *Fixed dose 150J-150J-150J*
b. *High dose escalating 200J-300J-360J*
c. *Low-High-High*
d. *Low dose escalating 120J-150J-200J*

No difference in shock efficacy noted in low impedance model. With high impedance model, escalating high dose was more effective at termination of VF within three shocks.

Wang HE, Menegazzi JJ, Lightfoot CB, Callaway CW, Fertig KC, Sherman LD, Hsieh M. Effects of biphasic vs monophasic defibrillation on the scaling exponent in a swine model of prolonged ventricular fibrillation. Acad Emerg Med. 2001 Aug;8(8):771-80.

OBJECTIVE: Mathematical analyses of ventricular fibrillation (VF) have resulted in the derivation of a measure termed the scaling exponent (ScE) that characterizes the duration of VF and probability of defibrillation success. The purpose of this study was to compare the effects of biphasic defibrillation waveform (BDW) and monophasic defibrillation waveform (MDW) rescue shocks on ScE in a swine model of prolonged VF. METHODS: Utstein guidelines for the laboratory study of cardiopulmonary resuscitation were followed. Twenty mixed-breed domestic swine (mass range 20.5-26.8 kg) were instrumented and randomized to receive either MDW or BDW rescue shocks. Ventricular fibrillation was induced and untreated for a nonintervention interval of 8 minutes. Rescue shocks were delivered at 8, 10, and 12 minutes of elapsed VF time. The energy sequence for the three MDW shocks was 70, 100, and

150 J (approximately 3, 4, and 6 J/kg). All BDW shocks were delivered at 50 J (approximately 2.5 J/kg). Only VF was shocked. Chest compressions and drugs were not provided. Rhythm analysis and ScE calculation were performed offline. Continuous and discontinuous linear regression models were fit to plots of ScE vs time. Defibrillation success and progression of ScE slope were analyzed using Fisher's exact test, paired t-tests, and repeated-measures analysis of variance (ANOVA). RESULTS: Baseline characteristics were similar for both groups. Successful termination of VF occurred on the first rescue shock in 1 of 10 (10%) in the MDW group and 3 of 10 (30%) in the BDW group; this difference was not statistically significant (p = 0.58). No other defibrillation successes were observed. No animals achieved return of spontaneous circulation. The ScE values during the protocol progressed from 1.330 (95% CI = 1.287 to 1.373) to 1.724 (95% CI = 1.603 to 1.845) for MDW and 1.338 (95% CI = 1.261 to 1.415) to 1.639 (95% CI = 1.530 to 1.745) for BDW. Both groups showed a trend toward increasing ScE values with successive rescue shocks. Repeated-measures ANOVA using both continuous and discontinuous models demonstrated no difference in overall ScE slope progression between study groups. CONCLUSIONS: Mode of defibrillation waveform (BDW vs MDW) does not appear to impact ScE trends. Additional studies must be performed to better evaluate the clinical implications of this finding.

LOE 6 (swine), fair, neutral. Prospective randomized evaluation of monophasic escalating dose (70-100-150J) compared to fixed biphasic waveform (50J) in swine model of prolonged VF (duration 8 min).
N=20
End point = termination of VF 20 sec post shock
First shock success was similar for monophasic and biphasic groups (1/10 and 3/10 respectively) and none of the remaining subjects converted to an organized rhythm with a second or third rescue shock in either group.

Yamanouchi Y, Brewer JE, Donohoo AM, Mowrey KA, Wilkoff BL, Tchou PJ. External exponential biphasic versus monophasic shock waveform: efficacy in ventricular fibrillation of longer duration. Pacing Clin Electrophysiol. 1999 Oct;22(10):1481-7.

Ventricular fibrillation (VF) duration may be a factor in determining the defibrillation energy for successful defibrillation. Exponential biphasic waveforms have been shown to defibrillate with less energy than do monophasic waveforms when used for external defibrillation. However, it is unknown whether this advantage persists with longer VF duration. We tested the hypothesis that exponential biphasic waveforms have lower defibrillation energy as compared to exponential monophasic waveforms even with longer VF duration up to 1 minute. In a swine model of external defibrillation (n = 12, 35 +/- 6 kg), we determined the stored energy at 50% defibrillation success (E50) after both 10 seconds and 1 minute of VF duration. A single exponential monophasic (M) and two exponential biphasic (B1 and B2) waveforms were tested with the following characteristics: M (60 microF, 70% tilt), B1 (60/60 microF, 70% tilt/3 ms pulse width), and B2 (60/20 microF, 70% tilt/3 ms pulse width) where the ratio of the phase 2 leading edge voltage to that of phase 1 was 0.5 for B1 and 1.0 for B2. E50 was measured by a Bayesian technique with a total often defibrillation shocks in each waveform and VF duration randomly. The E50 (J) for M, B1, and B2 were 131 +/- 41, 57 +/- 18,* and 60 +/- 26* with 10 seconds of VF duration, respectively, and 114 +/- 62, 77 +/- 45,* and 72 +/- 53* with 1 minute of VF duration, respectively (*P < 0.05 vs M). There was no significant difference in the E50 between 10 seconds and 1 minute of VF durations for each waveform. We conclude that (1) the E50 does not significantly increase with lengthening VF durations up to 1 minute regardless of the shock waveform, and (2) external exponential biphasic shocks are more effective than monophasic waveforms even with longer VF durations.

LOE 6 (swine), poor, neutral. Prospective evaluation of DFT with monophasic or biphasic waveform on short duration (10 sec) or longer duration (1min) VF.
N=12
End point = Termination of VF
There was a decreased DFT with biphasic waveform compared to monophasic waveform at both time points. There was no different in DFT within the biphasic group at 10 sec or 1 min.

Zhang Y, Clark CB, Davies LR, Karlsson G, Zimmerman MB, Kerber R. Body weight is a predictor of biphasic shock success for low energy transthoracic defibrillation. Resuscitation. 2002 Sep;54(3):281-7.

BACKGROUND: Transthoracic impedance and current flow are determinants of defibrillation success with monophasic shocks. Whether transthoracic impedance, either independently or via its association with body weight, is a determinant of biphasic waveform shock success has not been determined. METHODS AND RESULTS: We studied 22 swine, weighing 18-41 kg. After 15 s of ventricular fibrillation, each pig received transthoracic truncated exponential biphasic shocks (5/5 ms), 70-360 J. Shock success was strongly associated individually with body weight, leading-edge transthoracic impedance and current at low energy levels (70 and 100 J, all P<0.001). Multiple logistic regression analysis showed a significant association of body weight with shock success after adjusting for the effect of leading-edge impedance (odds ratio of success for 1 kg decrease in weight at 70 J was 1.29, 95% CI:

1.05-1.59, P=0.02; and at 100 J was 1.30, 95% CI: 1.14-1.49, P<0.0001). The same result was observed after adjusting for the effect of leading-edge current. At 150 J or higher energy levels, no significant association was observed.
CONCLUSIONS: Body weight is a determinant of shock success with biphasic waveforms at low energy levels in this swine model.

LOE 6 (swine), fair, supportive. Prospective randomized evaluation of effect of body weight on defibrillation success using biphasic waveform. Random sequence of shocks delivered at energies of 70J,100J, 150J, 200J, 300J, 360J.

N=22
End point = termination of VF at 5 sec post shock
The data suggests that increasing success in defibrillation is seen with increasing energies, however the random sequence of shock energies cannot demonstrate the effect of lower energies of previous shocks on subsequent, higher energy shocks. There was an association between more successful defibrillation and lower body weight patients at energies 70J and 100J.

Zhang Y, Karlsson G, Davies LR, Coddington WJ, Kerber RE. Biphasic and monophasic transthoracic defibrillation in pigs with acute left ventricular dysfunction. Resuscitation. 2001 Jul;50(1):95-101.

OBJECTIVE: Our purpose was to compare biphasic versus monophasic shock success for VF termination in a porcine model of acute left ventricular (LV) dysfunction. BACKGROUND: For the termination of ventricular fibrillation (VF), transthoracic biphasic waveform shocks achieve higher success rates than monophasic shocks. However, the effectiveness of biphasic versus monophasic defibrillation in a setting of left ventricular dysfunction has not been reported. METHODS: In 23 open-chest adult swine (15-25 kg), LV dysfunction [> or =25% decline in cardiac output (CO)] was induced by continuous inhalation of halothane (1-1.75%). Each pig randomly received transthoracic biphasic and monophasic shocks at three energy levels (30, 50 and 100 J) in two conditions: baseline and LV dysfunction. Halothane effect on left ventricular size and contraction was measured by echocardiography in three additional swine. RESULTS: With halothane, pigs demonstrated a decline in CO (baseline 4.16+/-0.19, halothane 2.72+/-0.19 l/min, P<0.01), mean arterial pressure (baseline 107.2+/-3.5, halothane 80.1+/-3.4 mmHg, P<0.01) and increased left ventricular end-diastolic pressure (baseline 6.4+/-0.9, halothane 12.7+/-0.8 mmHg, P<0.01). LV diameters increased and fractional shortening fell. During baseline, biphasic shocks achieved significantly greater success (termination of VF) compared to monophasic waveforms (100 J: biphasic 83.3+/-9.5 versus monophasic 38.9+/-9.5%, P<0.01; 50 J: biphasic 67.1+/-8.8 versus monophasic 11.8+/-5.7%, P<0.01; 30 J: biphasic: 31.9+/-6.4 versus monophasic 0+/-0%, P<0.01). The superiority of the biphasic waveform to terminate VF was retained during LV dysfunction at all energy levels (100 J: biphasic 78.3+/-7.3 versus monophasic 37.5+/-8.1%, P<0.01; 50 J: biphasic 65.5+/-11.5 versus monophasic 11.7+/-5.9%, P<0.01; 30 J: biphasic: 40.6+/-8.0 versus monophasic 3.1+/-3.1%, P<0.01). Within both waveforms, there were no significant differences in percent shock success at any energy level comparing baseline with LV dysfunction. CONCLUSION: In this porcine model of acute LV dysfunction, biphasic waveform shocks were not only superior to monophasic waveform shocks for termination of VF during baseline, but retained superiority to monophasic waveform shocks when LV dysfunction was present.
LOE 6 (swine), good, neutral. Prospective randomized non-blinded evaluation of monophasic versus biphasic waveform on normal animals and animals with halothane induced LV dysfunction.
N=23
End point = termination of VF at 5 sec post shock
Biphasic waveform superior to monophasic waveform at termination of VF under healthy conditions and with the presence of LV dysfunction.

Zhang Y, Ramabadran RS, Boddicker KA, Bawaney I, Davies LR, Zimmerman MB, Wuthrich S, Jones JL, Kerber RE. Triphasic waveforms are superior to biphasic waveforms for transthoracic defibrillation: experimental studies. J Am Coll Cardiol. 2003 Aug 6;42(3):568-75.

OBJECTIVES: Our objective was to evaluate the efficacy of triphasic waveforms for transthoracic defibrillation in a swine model. BACKGROUND: Triphasic shocks have been found to cause less post-shock dysfunction than biphasic shocks in chick embryo studies. METHODS: After 30 s of electrically induced ventricular fibrillation (VF), each pig in part I (n = 32) received truncated exponential biphasic (7.2/7.2 ms) and triphasic (4.8/4.8/4.8 ms) transthoracic shocks. Each pig in part II (n = 14) received biphasic (5/5 ms) and triphasic shocks (5/5/5 ms). Three selected energy levels (50, 100, and 150 J) were tested for parts I and II. Pigs in part III (n = 13) received biphasic (5/5 ms) and triphasic (5/5/5 ms) shocks at a higher energy (200 and 300 J). Although the individual pulse durations of these shocks were equal, the energy of each pulse varied. Nine pigs in part I also received shocks where each individual pulse contained equal energy but was of a different duration (biphasic 3.3/11.1 ms; triphasic 2.0/3.2/9.2 ms). RESULTS: Triphasic shocks of equal duration pulses achieved higher success than biphasic shocks at delivered low energies: <40 J: 38 +/- 5% triphasic vs. 19 +/- 4% biphasic ($p < 0.01$); 40 to <50 J: 66 +/- 7% vs. 42 +/- 7% ($p < 0.01$); and 50 to <65 J: 78 +/- 4% vs. 54 +/- 5% ($p < 0.05$). Shocks of equal energy but different duration pulses achieved relatively poor success for both triphasic and biphasic

waveforms. Shock-induced ventricular tachycardia (VT) and asystole occurred less often after triphasic shocks. CONCLUSIONS: Triphasic transthoracic shocks composed of equal duration pulses were superior to biphasic shocks for VF termination at low energies and caused less VT and asystole.

LOE 6 (swine), poor, supportive. Prospective randomized evaluation comparing biphasic and triphasic defibrillation (50J-100J-150J) in swine.
N=14
End point = termination of VF at 5sec post shock
Increasing shock efficacy was seen with increasing energy. Shocks were provided in random order, not necessarily in escalating succession. Triphasic waveform was more effective at termination of VF throughout all energies tested.