WORKSHEET for Evidence-Based Review of Science for Veterinary CPCR

1. Basic Demographics

Worksheet author(s)

Amy Dickinson	**Date Submitted for review:** 14. June 2011
[redacted]	

2. Clinical question:

ALS05:
In dogs and cats with cardiac arrest due to VF or pulseless VT (P), does the use of a defibrillator, or any specific defibrillation strategy (I) compared with no defibrillation (C), improve outcomes (e.g. restoration of pulse generating rhythm, ROSC, survival) (O)?

3. Conflict of interest specific to this question:

None

4. Search strategy (including electronic databases searched):

4a. Databases

-MEDLINE via PUBMED (1970 to May 2011)
Keywords:
1. cardiopulmonary resuscitation
2. cardiac arrest
3. defibrillation
4. defibrillator
5. electric countershock
6. ventricular fibrillation
7. pulseless ventricular tachycardia

-CAB abstracts (1970 to May 2011)
keywords as for Medline

4b. Other sources

-Google scholar
keywords as for medline

-VIN
keywords as for medline

- Cochrane reviews

-Review of 2010 AHA guidelines, worksheets, and cited references

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

Inclusion criteria

Clinical studies and cardiac arrest models with emphasis on target animal species (dog, cat) undergoing defibrillation for ventricular fibrillation or pulseless ventricular tachycardia during cardiac arrest were included (randomized and controlled prospective studies, retrospective studies, case series, veterinary case reports).

Exclusion criteria

Citations with abstracts only, review papers, consensus statements, editorials, individual human case reports. Non-cardiac arrest studies utilizing defibrillation (eg. cardioversion for arrhythmia) were excluded.

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

23

5. Summary of evidence

Monophasic vs Biphasic defibrillation

Evidence Supporting Clinical Question

Good			Leng 2000, BE	Bright 2009, ABCD		*Morrison 2005, E* *Schneider 2000, ADE* *Koster 2006, E* *Van Alem 2003, E* *Walker 2003, E* *Neimann 2000b, E* *Zhang 2001, E* *Tang 2001, E* *Tang 1999, E*
Fair			Lee 2008, E			*Scheatzle 1999, AE*
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

Evidence Neutral to Clinical question

Good			Leng 2000, A			*Kudenchuk 2006, ABCDE* *Niemann 2000a, AE* *Nieman 2000b, A* *Clark 2002, E* *Tang 2001 AB* *Tang 1999,AB*
Fair			Lee 2008, B			*Morrison 2005, ABCD* *Schneider 2000, BC* *Van Alem 2003,ABC*
Poor			Walcott, E			*Clark 2001, 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

One shock vs 3 stacked shocks

Evidence Supporting Clinical Question

Good						*Tang 2006, AB*
Fair						*Steen 2003, A* *Cammarata 2005, A*
Poor						*Rea 2006, ABCD* *Bobrow 2008, CD*
	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 Neutral to Clinical question

Good						*Tang 2006, DE*
Fair						
Poor						*Bobrow 2008 AB*
	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:

This worksheet was designed to determine if certain aspects of defibrillation alter outcomes in patients with ventricular fibrillation (VF) or pulseless ventricular tachycardia in dogs or cats (target species). Specific questions addressed are the use of a monophasic vs biphasic waveform defibrillator and the use of one shock vs three stacked shocks during defibrillation. In answering these questions studies in animal models (most commonly pigs), high quality randomized trials in people, experimental studies in dogs, and one case report in a dog were used to weigh the evidence and determine a consensus based on the science and overall treatment recommendations.

Monphasic vs biphasic:

This question evaluates the use of a monophasic (MP) or biphasic (BP) defibrillator in success of termination of ventricular fibrillation. Studies evaluated this question by looking at numerous end points including ROSC, termination of VF 5 seconds after shock delivery, survival to discharge, neurologic recovery, and effect of energy on myocardial function. There were a total of 18 studies included for review, 4 in the target species, 5 randomized trials in people, and 9 experimental studies in pigs.

Pigs: Porcine models of induced VF show that as the level of energy increased, the likelihood of termination of VF increased, and that the biphasic waveform was able to terminate VF at a lower energy level than monophasic (Clark 2001). Further evaluation by Clark et al in 2002 showed that biphasic shocks were more efficacious at 70 and 100J in adult pigs, but no difference was seen as energy levels increased to 200J or higher. When lower energy BP (150J) is compared to higher energy escalating MP (200-300-360J), there is no difference seen in ROSC or termination of VF in Niemann et al 2000a.

There is variable evidence regarding the result of MP vs BP defibrillation on cardiac performance. Neimann et al 2000a showed no difference in myocardial dysfunction, but Neimann 2000b showed significantly less ST segment depression with no change in rate of return of pre-VF hemodynamics. Tang et all 1999 set out to determine the difference of low energy (150J) BP vs conventional 200-300-360 MP shocks on myocardial function. This study showed no difference in ROSC or event survival, but there was less documented myocardial dysfunction with use of the BP waveform.

Zhang et all 2001 induced pre-VF left ventricular dysfunction using inhaled halothane and compared the utility of MP v BP defibrillation at lower doses (100J, 50J, 30J) and found higher successful defibrillation with the BP waveform at all energy levels in both normal and reduced LV function.

People: Five well designed randomized trials in people evaluated the use of MP vs BP defibrillation. Koster et al 2006 designed a study to evaluate production of an organized rhythm rather than termination of VF 5 seconds after defibrillation as definition of 'successful' defibrillation with identical energy of 200J. There was improved rate of return of organized rhythm in the biphasic group. A randomized trial by van Alem in 2003 also compared patients with out of hospital arrest with either MP or BP at 200J. There was a higher success rate for termination of VF and return to organized rhythm for 2 QRS complexes, but no difference in survival to hospital discharge.

The clinical trial by Kedenchuk et al compared MP vs BP in out of hospital arrest with identical energy protocols (200-200-360J). There was no difference in the outcomes of ROSC, termination of VF, admission to hospital, survival, or neurologic status between groups. Morrison et al compared escalating doses of MP vs escalating BP with the only difference found being a higher shock success (defined as termination of VF at 5 seconds) in the biphasic group.

Schneider et al 2000 randomized patients with out of hospital arrest to receive fixed 150J BP shocks with traditional high energy (200-360J) shocks. ROSC and cerebral performance were improved with the biphasic group, with no difference in hospital admission rate and survival to hospital discharge.

Dogs: Three experimental studies and one case report in dogs were present in the literature. Lee et al 2008 evaluated the efficacy and safety of BP in toy breed dogs less than 5kg and compared the use of MP and BP defibrillation in this toy breed population. There was a short duration of VF before defibrillation attempts compared to other experimental studies, and each dog survived 10 fib/defib events. There was less energy required for BP shocks than MP (2.24J/kg vs 3.18J/kg), as well as reduced cardiac dysfunction (echo changes and cardiac biomarkers). A dose of 2-4J/kg BP defibrillation was recommended for toy breed dogs.

An experimental study evaluating efficacy and cardiac injury following MP v BP waveforms in 26 dogs was performed by Leng et al 2000. The dogs weighed from 25-28kg. The biphasic waveform induced less cardiac dysfunction. When placed in a prolonged VF setting, the BP waveform required a lower energy for successful defibrillation (107 v 172J; approx 4J/k and 7J/kg respectively) and a shorter resuscitation time (397 v 488 seconds). There were 3 dogs in the MP group which were not successfully resuscitated with MP defibrillation but were rescued with 170 BP. Improved survival in the BP group was shown when a catheter related death was excluded from analysis.

Walcott et al 1998 evaluated two forms of biphasic defibrillators to monophasic at both 15seconds and after 5 minutes of fibrillation in 6 dogs. This study found a lower defibrillation threshold for the BP in both short and long term fibrillation but did not evaluate for other endpoints.

The case report describes a dog with prolonged spontaneous ventricular fibrillation following pacemaker implantation and medetomidine infusion. She was unresponsive to MP shocks of escalating energy (initial shock 70J, increased to 100J, 150J, and finally 200J; range of 3.4-9.9J/kg) and traditional CPR efforts. ROSC was achieved with one defibrillation attempt with biphasic defibrillator at 200J (9.9J/kg) after 12 minutes of arrest. Survival to discharge with full neurologic recovery was reported.

1 shock vs. stacked shocks:

There were a total of 5 studies (3 pig experimental model, 2 human trials) included evaluating the use of 1 shock versus a series of 3 stacked shocks in the attempt to terminate ventricular fibrillation.

Two studies in people evaluated the utility of CPR protocol changes involving 1 vs. 3 stacked shocks in out of hospital arrest. In both studies factors in addition to shock protocol (eg. time to rhythm analysis, number of post shock compressions, time to intubation, early use of drugs) were changed as well, which may interfere with the ability to determine the pure effect of change in defibrillator strategy on study endpoints. Bobrow et al showed an increase in survival to hospital discharge with use of minimally interrupted CPR and single shock. In Rea et al the patients in the treatment group were more likely to survive to hospital discharge and had improved neurologic outcome. In both studies the experimental group was compared to a historic control.

Experimental animal (pig) studies showed improved survival with a one shock protocol vs. stacked shocks (Tang et al). Additional pig studies did not address the question directly but showed that when time between CPR and defibrillation increased, successful defibrillation was not as likely, as would be seen in the case of stacked shocks vs. single shock and return to CPR efforts.

Overall the main limitation of these studies is that there are no randomized controlled trials of spontaneous disease in the target species. There were very limited studies in the target species at all, and none in dealing with the second questions of 1 vs. 3 stacked shocks. The experimental pig models utilized normal hearts with experimentally induced ventricular fibrillation which may not mimic a natural VF arrest situation in dogs or cats. All the studies in people were performed during out of hospital arrest, which is not common in the target species and again may not accurately reflect treatment timelines of VF in dogs and cats. Spontaneous VF in dogs and cats is not typical as the initial arrest rhythm, and may not respond to therapy the same as VF in people. The presence of underlying ischemic heart disease in a majority of people in the studies may also act as a confounding variable to defibrillation success. All studies used AED's for defibrillation, also not common for VF in the target species.

<u>7. Conclusion</u>

Consensus on Science statement:

Monophasic compared to biphasic waveform:
Evidence from animal trials suggests that at equivalent high doses (200J or higher) biphasic waveform is at least as efficacious as monophasic, and that biphasic may be superior in resolution of ventricular fibrillation at lower energy levels of <150J. Most studies show a reduction in myocardial dysfunction in those animals

treated with biphasic vs monophasic defibrillation. Clinical trials in people show improvements in resolution of VF and in some cases improved ROSC or other organized cardiac rhythm with use of BP over MP. No study has shown a difference in survival to discharge with either modality, but equally no evidence of harm. Limited information in the target species (dogs) supports the use of biphasic over monophasic defibrillation in both small and large breed dogs. Biphasic defibrillation appears to have a lower defibrillation threshold and produces less myocardial injury. An initial shock dose of 2-4 J/K should be considered if using biphasic, and up to 7J/kg may be needed for monophasic defibrillation in dogs. Even without clear evidence of improved survival, biphasic defibrillation appears to be superior to monophasic waveform in other endpoints and does not cause harm and should be used in transthoracic defibrillation if available.

One shock compared to three stacked shock protocols:
Evidence from experimental animal studies suggests that increased time between CPR compressions and defibrillation as occurs with stacked shocks limits defibrillation efficacy, and supports the use of a one shock protocol. Data from two human pre-post trials suggest benefit in survival to discharge and improved neurologic outcome with single shock compared to stacked shock protocol. Despite confounding multiple interventions other than defibrillation strategy in these trials the data supports the use of one shock defibrillation in VF.

Treatment recommendation:

MP v BP:
If a biphasic waveform defibrillator is available, utilize as first choice and start at a lower energy dose (2-4J/kg) in order to minimize post-shock myocardial effects. If BP is not available, utilize MP and consider beginning at a higher energy (3-7J/kg). If a monophasic defibrillation effort is not successful despite escalating therapy, switching to biphasic is recommended.

One shock vs stacked shocks:
Utilization of a one shock protocol and subsequent return to CPCR efforts with limited interruption in chest compressions.

8. Acknowledgement

9. Citation list

Monophasic vs. biphasic:

Bright JM, Wright BD. (2009). "Successful biphasic transthoracic defibrillation in a dog with prolonged, refractory ventricular fibrillation." J Vet Emerg Crit Care 19 (3):275-279.
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-case report in target species; good support ABCD

Clinical case report in target species of spontaneous ventricular fibrillation (post pacemaker implant and medetomidine infusion)
Unresponsive to MP shocks of escalating energy and other CPR efforts, but responded to single BP shock
Initial shock 70J (3.4J/kg), increased to 100 and 150J, repeat 150J, final increase to 200J (9.9J/kg)
12 minutes after arrest biphasic defibrillator used at 200J (9.9J/kg) and restored NSR
Full neurologic recovery and discharged alive.

Clark, C. B., Y. Zhang, et al. (2001). "Pediatric transthoracic defibrillation: Biphasic versus monophasic waveforms in an experimental model." Resuscitation 51(2): 159-163.
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 (pig), poor, neutral E (termination of vfib)
Evaluation of 3-6kg piglets and 7-12kg piglets to simulate infants and children
Termination of vfib improved with increased energy
BP achieved termination of vfib at lower energy than MP

Clark, C. B., Y. Zhang, et al. (2002). "Transthoracic biphasic waveform defibrillation at very high and very low energies: a comparison with monophasic waveforms in an animal model of ventricular fibrillation." Resuscitation 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 (pigs) good, neutral E (termination of vfib)
Duration of VF 15 seconds. Defibrillation success increased as energy increased for both waveforms.
Biphasic shocks achieved higher success rates compared to monophasic shocks at 70J and 100J, but no difference in efficacy at higher energies (200J or higher)

Koster, R. W., R. G. Walker, et al. (2006). "Definition of successful defibrillation." Crit Care Med 34(12 Suppl): S423-6.
OBJECTIVES: The definition of defibrillation shock "success" endorsed by the International Liaison Committee on Resuscitation since the publication of Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiac Care has been removal of ventricular fibrillation at 5 secs after shock delivery. Although this success criterion provides a direct assessment of the primary task of a shock, it may not be the only clinically useful measure of shock outcome. We evaluated a different defibrillation success criterion to determine whether it could provide additional insight into the relative performance of different defibrillation

shocks. DESIGN: A randomized study comparing monophasic and biphasic waveform shocks is reported with return of organized rhythm as the primary outcome measure of defibrillation success. PATIENTS: A total of 120 patients with out-of-hospital ventricular fibrillation as the first recorded rhythm were treated with defibrillation with automated external defibrillators. MEASUREMENTS AND MAIN RESULTS: Return of organized rhythm (two QRS complexes, <5 secs apart, <60 secs after defibrillation) was achieved in 31 monophasic shock (45%) and 35 biphasic shock (69%) patients (relative risk, 1.53, 95% confidence interval, 1.11-2.10). Logistic regression analysis revealed that shock waveform was the strongest independent predictor of return of organized rhythm (odds ratio, 4.0; 95% confidence interval, 1.67-10.0). Defibrillation success with the conventional International Liaison Committee on Resuscitation criterion was very high (91% and 98%, respectively) and not significantly different between groups. CONCLUSIONS: Return of organized rhythm proved to be a more sensitive measure of relative defibrillation shock performance than the conventional shock success criterion. Inclusion of return of organized rhythm as an end point in future clinical research could help discern more subtle defibrillation shock effects and contribute to further optimization of defibrillation technology.

LOE 6 (human), good, support E (return of organized rhythm not ROSC)
120 patients with out of hospital cardiac arrest, randomized/blinded to mono or biphasic defibrillation, given via AED's.
200J first shock for both waveforms
Improved return of organized rhythm with biphasic vs mono (69 v 45%)

Kudenchuk, P. J., L. A. Cobb, et al. (2006). "Transthoracic Incremental Monophasic Versus Biphasic Defibrillation by Emergency Responders (TIMBER): A randomized comparison of monophasic with biphasic waveform ascending energy defibrillation for the resuscitation of out-of-hospital cardiac arrest due to ventricular fibrillation." Circulation 114(19): 2010-2018.
BACKGROUND - Although biphasic, as compared with monophasic, waveform defibrillation for cardiac arrest is increasing in use and popularity, whether it is truly a more lifesaving waveform is unproven. METHODS AND RESULTS - Consecutive adults with nontraumatic out-of-hospital ventricular fibrillation cardiac arrest were randomly allocated to defibrillation according to the waveform from automated external defibrillators administered by prehospital medical providers. The primary event of interest was admission alive to the hospital. Secondary events included return of rhythm and circulation, survival, and neurological outcome. Providers were blinded to automated defibrillator waveform. Of 168 randomized patients, 80 (48%) and 68 (40%) consistently received only monophasic or biphasic waveform shocks, respectively, throughout resuscitation. The prevalence of ventricular fibrillation, asystole, or organized rhythms at 5, 10, or 20 seconds after each shock did not differ significantly between treatment groups. The proportion of patients admitted alive to the hospital was relatively high: 73% in monophasic and 76% in biphasic treatment groups (P=0.58). Several favorable trends were consistently associated with receipt of biphasic waveform shock, none of which reached statistical significance. Notably, 27 of 80 monophasic shock recipients (34%), compared with 28 of 68 biphasic shock recipients (41%), survived (P=0.35). Neurological outcome was similar in both treatment groups (P=0.4). Earlier administration of shock did not significantly alter the performance of one waveform relative to the other, nor did shock waveform predict any clinical outcome after multivariate adjustment. CONCLUSIONS - No statistically significant differences in outcome could be ascribed to use of one waveform over another when out-of-hospital ventricular fibrillation was treated.

LOE 6 (human), good, neutral ABCDE
168 patients, out of hospital vfib cardiac arrest, prospective randomized, blinded trial of monophasic (200-200-360J) vs biphasic (200-200-360J)
No stat difference for termination of vfib (82% mono vs 88% bi); ROSC 26 v 34%
No difference in admission to hospital (73% v 76%), survival (34 v 41%) or discharge home/good neuro (23 v 24%)

Lee SG, Moon HS, et al. (2008) "The efficacy and safety of external biphasic defibrillation in toy breed dogs." J Vet Emerg Crit Care 18(4): 362-369.
Objective: To evaluate the efficacy and safety of biphasic (BP) defibrillation in toy breed dogs (<5 kg of body weight). Design: Prospective, clinical experimental study. Setting: Veterinary teaching hospital.
Animals: Five dogs (pilot study) and 10 dogs (comparison study of biphasic versus monophasic defibrillation).
Measurements and main results: The efficacy of defibrillation was compared by estimating E80 (80% probability of successful defibrillation) after biphasic (BP) and monophasic (MP) defibrillations. The E80 for BP defibrillation was 7.24 _ 1.33 J (2.24 _ 0.41 J/kg) and 10.24 _ 1.34 J (3.18 _ 0.12 J/kg) for MP defibrillation. BP waveform required 30% less shock energy for a successful defibrillation. In order to compare the safety of defibrillation, we evaluated changes in cardiac biomarkers, electrocardiogram, echocardiographical left ventricular index, and aortic pressure during and after BP and MP defibrillation. All dogs treated by either BP or MP defibrillation survived. Pulseless electrical activity occurred in 2 of 5 dogs during MP defibrillation. The levels of cardiac biomarkers were elevated and sustained for longer periods in the MP defibrillation group. Electrocardiographic changes (e.g., QT prolongation, the time to return to an isoelectric ST segment after shocks) were more severe and longer in the MP defibrillation group. In addition, overall left ventricular cardiac performance was severely depressed in the MP group compared with the BP group.

Conclusion: Our findings suggest that BP defibrillation is more effective and safer than MP defibrillation. We determined the acceptable shock energy to be 2–4 J/kg for toy breed dogs.

LOE 3 (experimental in target species), fair, support E (less myocardial effects in BP), neutral B
Pilot study evaluating safety of BP in toy breeds <5kg- 80% successful defib with 2.78J/kg; further study of MP v BP with 10 dogs, 5 in each group. 10 fib/defib events for each dog. Short duration vfib before defibrillation attempted.
All dogs survived all 10 events
Less energy required for BP shock than MP to terminated fibrillation (2.24J/kg v 3.18J/kg)
Reduced cardiac dysfunction in BP vs MP dogs for cardiac biomarkers and echo changes
Showed BP defib safe in toy breeds, and likely more effective, recommend energy to be 2-4J/kg for toy breed dogs

Leng, C. T., N. A. Paradis, et al. (2000). "Resuscitation after prolonged ventricular fibrillation with use of monophasic and biphasic waveform pulses for external defibrillation." Circulation 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 (experiemental in target species); good, support BE (less countershock induced cardiac dysfunction and reduced resuscitation time), neutral A
Randomized prospective non-blinded trial evaluating mono vs biphasic defibrillation after 10s and 10 min of vfib
26 dogs
Biphasic induced less countershock induced cardiac dysfunction
Lower defibrillation thresholds with biphasic in prolonged vfib (107 v 172 p=0.04)
3 of 13 dogs after 10 min vfib failed 360J mono but were successfully rescued with BP of 170J; only 1/13 failed BP but were rescued with MP at 360J
Time to ROSC shorter for BP (397 v 488 seconds, p=0.03)
Trend toward improved survival with BP, significant if catheter related hemorrhage death removed

Morrison, L. J., P. Dorian, et al. (2005). "Out-of-hospital cardiac arrest rectilinear biphasic to monophasic damped sine defibrillation waveforms with advanced life support intervention trial (ORBIT)." Resuscitation 66(2): 149-157.
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 stepup 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 5 s 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, 200 J) was superior to MDS (200, 300, 360 J) 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 24 h (31% versus 27%), and survival to discharge (9% versus 7%). Mean 24 h 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), fair, support E, neutral ABCD
Prospective randomized non-blinded
Escalating dose monophasic (200-200-360) vs escalating biphasic (120-150-200J)
Higher shock success (termination of vfib) with biphasic vs mono (55 v 44%)
No difference in ROSC or survival to discharge

Niemann, J. T., D. Burian, et al. (2000a). "Monophasic versus biphasic transthoracic countershock after prolonged ventricular fibrillation in a swine model." Journal of the American College of Cardiology 36(3): 932-938.
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 (pig), good, neutral AE (termination of vfib, hemodynamic variables)
Prospective randomized comparison of MP (200-300-360) vs BP (150-150-150)
5min of Vfib, n=38 pigs
Termination of vfib equally effective with MP v BP
Most had manual CPR after defibrillation in order to restore a perfusing rhythm (ROSC)- no difference with MP or BP
Lower energy shocks not associated with less myocardial dysfunction

Niemann, J. T., D. Burian, et al. (2000b). "Transthoracic monophasic and biphasic defibrillation in a swine model: a comparison of efficacy, ST segment changes, and postshock hemodynamics." Resuscitation 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 (pigs) good, support E (ST segment changes less severe with BP group), neutral A
Escalating MP vs BP in induced vfib in pigs, defibrillation 30 and 90s, no CPR

No difference in defibrillation success or ROSC
Less myocardial injury (via ST seg depression) in BP group but no difference in rate of return of hemodynamics

Scheatzle, M. D., J. J. Menegazzi, et al. (1999). "Evaluation of biphasic transthoracic defibrillation in an animal model of prolonged ventricular fibrillation." Academic Emergency Medicine 6(9): 880-886.
Objectives: To determine whether a biphasic defibrillation waveform (BDW) would produce a superior rate of converting prolonged ventricular fibrillation (VF) into a perfusing rhythm and delay the occurrence of asystole and/or pulseless electrical activity (PEA) during the resuscitation attempt, when compared with a monophasic defibrillation waveform (MDW). Methods: The authors performed a prospective, randomized, blinded experiment using an established swine model of prolonged VF. Thirty-four mixed-breed domestic swine (mean mass 22.9 kg) were sedated (ketamine/xylazine), anesthetized (isoflurane), and intubated. Aortic and femoral venous catheters were placed. ECG was monitored continuously. The animals were shocked into VF (3-s, 100-mA, 60- Hz shock), and were untreated for 8 minutes. Advanced Cardiac Life Support (ACLS) began with i minute of standardized (Thumper) chest compressions and ventilation. The animals were randomized to treatment with either BDW or MDW. Standard ACLS protocols were followed. The energy sequence was 2.5 J/kg first, 3.5 J/kg second, and 4.5 J/kg for all subsequent shocks. Outcome variables were time to event of asystole/PEA, return of spontaneous circulation (ROSC), and one-hour survival. Data were analyzed with two-tailed Fisher's exact test and Kaplan-Meier survival plots (alpha = 0.05). Results: ROSC occurred more frequently in the BDW group (7/17) compared with the MDW group (1/17); p = 0.04. Survival analysis showed that the BDW significantly delayed the occurrence of asystole/PEA during the resuscitation attempt when compared with the MDW; log-ranked p = 0.02. Onehour survival rates (5/17 BDW and 1/17 MDW, p = 0.17) did not differ. Conclusions: BDW resulted in a superior rate of ROSC and delay in the occurrence of asystole/PEA during the resuscitation attempt when compared with MDW.

LOE 6 (pigs) fair, support AE (delayed occurrence of asystole/PEA during resuscitation attempt)
Prospective randomized blinded MP v BP defib in swine model
N=34, duration of vifb 8 minutes, followed by 1min of chest compressions then defibrillation at equal rates (2.5j/kg, then 3.5, then 4.5J/kg)
ROSC more frequent in BP
Reduced occurrence of PEA/asystole during resuscitation in BP group

Schneider, T., P. R. Martens, et al. (2000). "Multicenter, randomized, controlled trial of 150-J biphasic shocks compared with 200- to 360-J monophasic shocks in the resuscitation of out-of-hospital cardiac arrest victims." Circulation 102(15): 1780-1787.
Background - In the present study, we compared an automatic external defibrillator (AED) that delivers 150-J biphasic shocks with traditional high-energy (200- to 360-J) monophasic AEDs. Methods and Results - AEDs were prospectively randomized according to defibrillation waveform on a daily basis in 4 emergency medical services systems. Defibrillation efficacy, survival to hospital admission and discharge, return of spontaneous circulation, and neurological status at discharge (cerebral performance category) were compared. Of 338 patients with out-of-hospital cardiac arrest, 115 had a cardiac etiology, presented with ventricular fibrillation, and were shocked with an AED. The time from the emergency call to the first shock was 8.9+/-3.0 (mean+/-SD) minutes. Conclusions - The 150-J biphasic waveform defibrillated at higher rates, resulting in more patients who achieved a return of spontaneous circulation. Although survival rates to hospital admission and discharge did not differ, discharged patients who had been resuscitated with biphasic shocks were more likely to have good cerebral performance.

LOE 6 (human), good, support ADE, neutral BC
Prospective randomized clinical trial monophasic escalating dose(200-360J) vs fixed biphasic dose (150J) via AED
Up to 3 consecutive shocks given
115 patients with vfib of cardiac origin analyzed (of 338 with out of hospital cardiac arrest)
More patients with ROSC (81 v 52%), good cerebral performance with biphasic
No difference with hospital admission, survival to discharge (33 v 27%)
Not powered to show difference in survival

Tang, W., M. H. Weil, et al. (1999). "The effects of biphasic and conventional monophasic defibrillation on postresuscitation myocardial function." Journal of the American College of Cardiology 34(3): 815-822.
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 (pigs), good support E, neutral AB
Escalating MP (200,300,360J) v BP (150,150,150J) after 4 or 7 minutes untreated vfib
No difference in ROSC or survival, less myocardial dysfunction with biphasic

Tang, W., M. H. Weil, et al. (2001). "A comparison of biphasic and monophasic waveform defibrillation after prolonged ventricular fibrillation." Chest 120(3): 948-954.
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 (pigs), good, support E, neutral AB
Prospective, swine model of vfib; 10min untreated Vfib before defibrillation
Used escalating doses of MP (200,300,360J) or standard BP (150, 150, 150J) shocks (up to 3 in series)
No difference in ROSC or initial survival
Less myocardial dysfunction with BP

van Alem, A. P., F. W. Chapman, et al. (2003). "A prospective, randomised and blinded comparison of first shock success of monophasic and biphasic waveforms in out-of-hospital cardiac arrest." Resuscitation 58(1): 17-24.
BACKGROUND: Evidence suggests that biphasic waveforms are more effective than monophasic waveforms for defibrillation in out-of-hospital cardiac arrest (OHCA), yet their performance has only been compared in un-blinded studies. METHODS AND RESULTS: We compared the success of biphasic truncated exponential (BTE) and monophasic damped sine (MDS) shocks for defibrillation in OHCA in a prospective, randomised, double blind clinical trial. First responders were equipped with MDS and BTE automated external defibrillators (AEDs) in a random fashion. Patients in ventricular fibrillation (VF) received BTE or MDS first shocks of 200 J. The ECG was recorded for subsequent analysis continuously. The success of the first shock as a primary endpoint was removal of VF and required a return of an organized rhythm for at least two QRS complexes, with an interval of <5 s, within 1 min after the first shock. The secondary endpoint was termination of VF at 5 s. VF was the initial recorded rhythm in 120 patients in OHCA, 51 patients received BTE and 69 received MDS shocks. The success rate of 200 J first shocks was significantly higher for BTE than for MDS shocks, 35/51 (69%) and 31/69 (45%), P=0.01. In a logistic regression model the odds ratio of success for a BTE shock was 4.01 (95% CI 1.01-10.0), adjusted for baseline cardiopulmonary resuscitation, VF-amplitude and time between collapse and first shock. No difference was found with respect to the secondary endpoint, termination of VF at 5 s (RR 1.07 95% CI: 0.99-1.11) and with respect to survival to hospital discharge (RR 0.73 95% CI: 0.31-1.70). CONCLUSION: BTEwaveform AEDs provide significantly higher rates of successful defibrillation with return of an organized rhythm in OHCA than MDS waveform AEDs.

LOE 6 (human), fair, supportive E , neutral ABC
Prospective randomized double blind trial of first shock success with 200J mono or biphasic AED; n=120
Defined success as return of organized rhythm (primary endpoint), higher with biphasic vs mono (69 v 45%)
No difference in survival to hospital admission, discharge, or ROSC
Not powered to show difference in patient outcome

Walcott, G. P., S. B. Melnick, et al. (1998). "Relative efficacy of monophasic and biphasic waveforms for transthoracic defibrillation after short and long durations of ventricular fibrillation." Circulation 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 crosscirculation. 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 (experimental study in target species), poor, neutral E (termination of vfib)
Prospective study comparing 2 forms of biphasic defibrillation to monophasic at 15sec and 5 min of fibrillation
Lower defibrillation thresholds found with biphasic defib vs monphasic but did not evaluate for success of defibrillation, only energy level required.

Walker, R. G., S. B. Melnick, et al. (2003). "Comparison of six clinically used external defibrillators in swine." Resuscitation 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 impedancecompensation 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 manufacturerprovided doses.

LOE 6 (pig), good, support E
Prospective randomized comparison of 6 defibrillators (2MP, 4BP)
Efficacy for MP defib less than for BP at low impedance

Zhang, Y., G. Karlsson, et al. (2001). "Biphasic and monophasic transthoracic defibrillation in pigs with acute left ventricular dysfunction." Resuscitation 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 (pigs), good, support E (termination of VF)
Prospective randomized non-blinded MP vs BP defibrillation in porcine model of LV dysfunction
Compared defibrillation success at 100J, 50J, 30J either MP v BP
Higher success with BP v MP at all energy levels
Higher rate of success of defibrillation continued with presence of LV dysfunction (induced by halothane)

1 shock vs stacked shocks:

Bobrow, B. J., L. L. Clark, et al. (2008). "Minimally interrupted cardiac resuscitation by emergency medical services for out of hospital cardiac arrest." JAMA 299(10): 1158-65.
CONTEXT: Out-of-hospital cardiac arrest is a major public health problem. OBJECTIVE: To investigate whether the survival of patients with out-of-hospital cardiac arrest would improve with minimally interrupted cardiac resuscitation (MICR), an alternate emergency medical services (EMS) protocol. DESIGN, SETTING, AND PATIENTS: A prospective study of survival-to-hospital discharge between January 1, 2005, and November 22, 2007. Patients with out-of-hospital cardiac arrests in 2 metropolitan cities in Arizona before and after MICR training of fire department emergency medical personnel were assessed. In a second analysis of protocol compliance, patients from the 2 metropolitan cities and 60 additional fire departments in Arizona who actually received MICR were compared with patients who did not receive MICR but received standard advanced life support. INTERVENTION: Instruction for EMS personnel in MICR, an approach that includes an initial series of 200 uninterrupted chest compressions, rhythm analysis with a single shock, 200 immediate postshock chest compressions before pulse check or rhythm reanalysis, early administration of epinephrine, and delayed endotracheal intubation. MAIN OUTCOME MEASURE: Survival-to-hospital discharge. RESULTS: Among the 886 patients in the 2 metropolitan cities, survival-to-hospital discharge increased from 1.8% (4/218) before MICR training to 5.4% (36/668) after MICR training (odds ratio [OR], 3.0; 95% confidence interval [CI], 1.1-8.9). In the subgroup of 174 patients with witnessed cardiac arrest and ventricular fibrillation, survival increased from 4.7% (2/43) before MICR training to 17.6% (23/131) after MICR training (OR, 8.6; 95% CI, 1.8-42.0). In the analysis of MICR protocol compliance involving 2460 patients with cardiac arrest, survival was significantly better among patients who received MICR than those who did not (9.1% [60/661] vs 3.8% [69/1799]; OR, 2.7; 95% CI, 1.9-4.1), as well as patients with witnessed ventricular fibrillation (28.4% [40/141] vs 11.9% [46/387]; OR, 3.4; 95% CI, 2.0-5.8).
CONCLUSIONS: Survival-to-hospital discharge of patients with out-of-hospital cardiac arrest increased after implementation of MICR as an alternate EMS protocol. These results need to be confirmed in a randomized trial.

LOE 6 (human), poor (retrospective controls), support CD, neutral AB
Out of hospital arrest before and after minimally interrupted cardiac resuscitation protocols put in place (including use of 200 uninterrupted chest compressions, single shock, immediate post shock compressions before pulse check or rhythm analysis, early admin of epi, delayed endotracheal intubation)
*Survival to discharge 4/218 (1.8%) vs 36/668 (5.4%) OR 3.0 (1.1-8.9)*stat sig*
*Survival of witnessed VF 2/43 (4.7) vs 23/131 (17.6) OR 8.6 (1.8-42.0)*stat sig*
ROSC 34/218 (15.6) vs 154/668 (23.1) OR 1.3 (0.8-2.0)
Survival to admission 35/218 (16.1) vs 113/668 (16.9) OR 0.8 (0.5-1.2)
Not clear if purely use of 1 shock vs stacked led to larger survival vs combination of changes set forth in new protocols.

Cammarata, G., M. H. Weil, et al. (2006). "Challenging the rationale of three sequential shocks for defibrillation." Resuscitation 69(1): 23-7.
The 2000 guidelines for cardiopulmonary resuscitation (CPR) recommend up to three sequential shocks for persistent ventricular fibrillation (VF). We hypothesized that the time consumed for repetitive rhythm analyses and recharging of the capacitor

compromises the success of the second and third shock of each sequence. In 60 domestic pigs, VF was electrically induced and untreated for 7 min. After 1 min of CPR, which includes precordial compression and ventilation, up to three sequential shocks were delivered. All animals were resuscitated. For purposes of the present study we determined the outcomes of the first, the second, and the third shock of each sequence during attempted defibrillation. Our criterion of success was the restoration of spontaneous circulation (ROSC). Forty-eight of the 60 animals (80%) attained ROSC after the first shock, 9/60 (15%) after the second shock, and only 3/60 (5%) after the third shock. In confirmation of the earlier observations, ROSC was highly predictive when the coronary perfusion pressure (CPP) exceeded 12 mmHg and end-tidal CO(2) (ETCO(2)) exceeded 11 mmHg. However, these criteria were never achieved after the second shock. The present study supports the rationale of delivering only a single shock, or at the most two shocks, prior to resuming chest compression, to re-establish the threshold levels of CPP and ETCO(2) before delivery of a subsequent electrical shock.

LOE 6 (pig), fair, supportive A
Electrically induced vfib, untreated for 7 minutes
Evaluated ability of each shock in subsequent defibrillation efforts to obtain ROSC
Did not specificially compare single shock to stacked shock protocol for ROSC
1 shock: 80% ROSC, 2 shocks: 15%, 3rd shock 5%
Cornonary perfusion pressure not obtained to adequate level for 2nd and 3rd shocks (average 17mmHg before first shock, 9 before 2nd, 6 before 3rd)
Pig model under anes with no ischemic heart disease

Rea, T. D., M. Helbock, et al. (2006). "Increasing use of cardiopulmonary resuscitation during out-of-hospital ventricular fibrillation arrest: survival implications of guideline changes." Circulation 114(25): 2760-5.
BACKGROUND: The most recent resuscitation guidelines have sought to improve the interface between defibrillation and cardiopulmonary resuscitation; the survival impact of these changes is unknown, however. A year before issuance of the most recent guidelines, we implemented protocol changes that provided a single shock without rhythm reanalysis, stacked shocks, or postdefibrillation pulse check, and extended the period of cardiopulmonary resuscitation from 1 to 2 minutes. We hypothesized that survival would be better with the new protocol. METHODS AND RESULTS: The present study took place in a community with a 2-tiered emergency medical services response and an established system of cardiac arrest surveillance, training, and review. The investigation was a cohort study of persons who had bystander-witnessed out-of-hospital ventricular fibrillation arrest because of heart disease, comparing a prospectively defined intervention group (January 1, 2005, to January 31, 2006) with a historical control group that was treated according to previous guidelines of rhythm reanalysis, stacked shocks, and postdefibrillation pulse checks (January 1, 2002, to December 31, 2004). The primary outcome was survival to hospital discharge. The proportion of treated arrests that met inclusion criteria was similar for intervention and control periods (15.4% [134/869] versus 16.6% [374/2255]). Survival to hospital discharge was significantly greater during the intervention period compared with the control period (46% [61/134] versus 33% [122/374], P=0.008) and corresponded to a decrease in the interval from shock to start of chest compressions (28 versus 7 seconds). Adjustment for covariates did not alter the survival association. CONCLUSIONS: These results suggest the new resuscitation guidelines will alter the interface between defibrillation and cardiopulmonary resuscitation and in turn may improve outcomes.

LOE 6 (human), poor (retrospective controls) support ABCD
Bystander witnessed out of hospital Vfib arrest because of heart disease
Compared prospectively defined group to historical controls before protocol changes
Control period n=374, study period n=134
Survival to hospital discharge greater during intervention period (46% vs 33%, p=0.008)
Also showed significant improvement to hospital admission (survival of event) and discharge to home (neurologic recovery).
Unclear if due to other changes in protocol or one vs stacked shocks, improvement in CPR due to care givers being observed.

Steen, S., Q. Liao, et al. (2003). "The critical importance of minimal delay between chest compressions and subsequent defibrillation: a haemodynamic explanation." Resuscitation 58(3): 249-58.
Outcome after prehospital defibrillation remains dire. The aim of the present study was to elucidate the pathophysiology of cardiac arrest and to suggest ways to improve outcome. Ventricular fibrillation (VF) was induced in air-ventilated pigs, after which ventilation was withdrawn. After 6.5 min of VF, ventilation with 100% oxygen was initiated. In six pigs (group I), defibrillation was the only treatment carried out. In another six pigs (group II), mechanical chest compression-decompression CPR (mCPR) was carried out for 3.5 min followed by a 40-s hands-off period before defibrillation. If unsuccessful, mCPR was resumed for a further 30 s before a second or a third, 40-s delayed, shock was given. In a final six pigs (group III) mCPR was applied for 3.5 min after which up to three shocks (if needed) were given during on-going mCPR. Return of spontaneous circulation (ROSC) occurred in none of the pigs in group I (0%), in 1 of six pigs in group II (17%) and in five of six pigs in group III (83%). During the first 3 min of VF arterial blood was transported to the venous circulation, with the consequence that the left ventricle emptied and the right ventricle became

greatly distended. It took 2 min of mCPR to establish an adequate coronary perfusion pressure, which was lost when the mCPR was interrupted. During 30 s of mCPR coronary perfusion pressure was negative, but a carotid flow of about 25% of basal value was obtained. In this pig model, VF caused venous congestion, an empty left heart, and a greatly distended right heart within 3 min. Adequate heart massage before and during defibrillation greatly improved the likelihood of return of spontaneous circulation (ROSC).

LOE 6 (pig), fair, support A
Most of study does not evaluate this question- compares hands off CPR time with ability to successfully defibrillate not 1 shock vs stacked shocks. Group 3 had continuous CPR for 3.5 minutes then defibrillation, 4/5 ROSC on first defibrillation event. Only 1/6 (17%) had ROSC after 40seconds of hands off time between CPR and defibrillation.

Tang, W., D. Snyder, et al. (2006). "One-shock versus three-shock defibrillation protocol significantly improves outcome in a porcine model of prolonged ventricular fibrillation cardiac arrest." Circulation 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 (pigs), good, support AB, neutral DE
Prospective randomized study evaluating one vs three stacked shock in pigs
Induced vfib in 44 pigs, duration of vfib 7 minutes
1 shock protocol improved survival from 64% to 100%; all survived >72h with no differences in neuro scores in each group of survivors
No difference in myocardial dysfunction when comparing 1 shock vs stacked shocks