WORKSHEET for Evidence-Based Review of Science for Emergency Cardiac Care

Worksheet author(s)

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Clinical question.

The question originally addressed in this worksheet needed to be reformulated for proper scientific review. The original question was formulated as follows: "**In adult and pediatric patients with cardiac arrest (prehospital [OHCA], in-hospital [IHCA]) (P), does the analysis of cardiac rhythm during chest compressions (I) compared with standard care (analysis of cardiac rhythm during pauses in chest compressions) (C), improve accuracy in the diagnosis of shockable rhythms (O)?**"

The revised question (as agreed at the 2008 Fall ILCOR meting) is as follows: "**In adult and pediatric patients with cardiac arrest (prehospital [OHCA], in-hospital [IHCA]) (P), does the analysis of cardiac rhythm during chest compressions (I) compared with standard care (analysis of cardiac rhythm during pauses in chest compressions) (C), optimize the time of appropriate chest compression by avoiding unnecessary interruptions and unnecessary prolongations (O)?**"

This question is addressing: Intervention
This is a proposed new topic or revision of existing worksheet: new

Conflict of interest specific to this question

Do any of the authors listed above have conflict of interest disclosures relevant to this worksheet? No

Search strategy (including electronic databases searched).

Michael Kuiper:
Cochrane: search on automated defibrillators and analysis during chest compressions: 0 reviews
0 clinical trials
0 method studies
0 technological assessments

Medline search:
"Arrhythmias, Cardiac"[Mesh] AND "Defibrillators"[Mesh] AND "Cardiopulmonary Resuscitation"[Mesh] yielded 62 results; only one being relevant for the topic of this worksheet

Other medline search: ("Diagnosis, Computer-Assisted"[Mesh] AND "Arrhythmias, Cardiac"[Mesh]) AND "Cardiopulmonary Resuscitation"[Mesh] yielded two hits, and only one useful result. Using Mesh Headings found in already selected papers only resulted in finding the same paper; not in finding other papers.

Embase search:
exp Resuscitation/ and exp Heart Arrest/ and exp Defibrillation/ and exp Automated External Defibrillator/: 45 hits; no useable results.
exp Heart Ventricle Fibrillation/ and exp Resuscitation/ and exp Automated External Defibrillator/ yielded one result:

Other searches including terms as: "cardiac arrest" "analysis" "cardiac rhythm" "chest compression" and/ or "diagnosis" did not give any relevant results. Two searches were performed; one giving 503 hits; the second 206. All titles of found articles were screened. Combining both searches yielded 31 hits.

Most papers and abstracts were however found by manually reviewing the references of relevant articles.

Two websites were found with information on patents for a an ECG filtering technique
Tan Q: http://www.wikipatents.com/jp/2005339533.html (Tan 2005 30)
And Ruiz de Gauna: http://patentados.com/invento/metodo-para-la-deteccion-de-ritmos-cardiacos-desfibrilables.html
Both accessed in August 2009
Search was performed in 2008 and repeated in August 2009

Raúl J. Gazmuri:
PubMed: "Cardiopulmonary Resuscitation"[Majr] AND "Electrocardiography"[Majr] on September 28, 2008 (26 articles retrieved); 9 met inclusion criteria. Three (3) additional articles were retrieved by search "Related Articles" for each of the initial 9 selections. Total articles retrieved from PubMed = 12.
Additional search on October 19, 2008 for "Rhythm Analysis" retrieved 128 articles, 2 of which were relevant but had already been retrieved by the original search strategy.
The search was updated on September 23, 2009 utilizing identical strategy as above (i.e., using "Cardiopulmonary Resuscitation"[Majr] first with "Electrocardiography"[Majr] and then with "Rhythm Analysis"). Three additional articles were retrieved, all which were relevant and were incorporated in the worksheet evidence-based review.

EndNote X Master library 24Mar08: "Cardiopulmonary Resuscitation" AND "Electrocardiography" on September 28, 2008 (100 articles retrieved); no additional articles beyond those retrieved by the PubMed search were found that met inclusion criteria.
Additional search on October 19, 2008 for “Rhythm Analysis” retrieved 15 articles, 1 of which was relevant but had already been retrieved by the original search strategy.

No updated search performed on September 23, 2009 (same Master library).

Cochrane Library: "Cardiopulmonary Resuscitation" AND "Electrocardiography" on September 28, 2008 (0 articles retrieved).
Additional search on October 19, 2008 for “Rhythm Analysis” retrieved 0 articles.

Embase: "Cardiopulmonary Resuscitation" AND "Electrocardiography" on September 28, 2008 (163 articles retrieved); no additional articles beyond those retrieved by the PubMed search were found that met inclusion criteria.
Additional search on October 19, 2008 for “Rhythm Analysis” retrieved 200 articles, 2 of which were relevant but had already been retrieved by the original search strategy.

- State inclusion and exclusion criteria

Inclusion:
Studies reporting analysis of ECG rhythms obtained during chest compression (“corrupted ECG”) in humans or in animal models of cardiac arrest in which the analysis included an approach to remove the artifact produced by chest compression and a comparison with the ECG rhythm obtained without chest compression (“uncorrupted ECG”). The “corrupted ECG” could be an actual recording of ECG during chest compression or a previously recorded “uncorrupted ECG” processed to incorporate CPR artifacts.
Exclusion:
Studies of ECG rhythm analysis with CPR artifact but without a proper comparator.

Number of articles/sources meeting criteria for further review:
21 articles met criteria for further review:
(Aase 2000 1440; Achleitner 2001 61; Amann 2001 77; Langhelle 2001 279; Eftestøl 2002 2270; Husøy 2002 1287; Eilevstjønn 2004 131; Klotz 2004 2203; Ruiz de Gauna 2005 175; Aramendi 2007 115; Berger 2007 145; Li 2007 131; Li 2008 198; Neurauter 2008 453; Rheinberger 2008 130; Ruiz de Gauna 2008 271; Tan 2008 S409; Irusta 2009 1229; Irusta 2009 1052; Werther 2009 1301; Werther 2009 320)

Summary of evidence

Evidence Supporting Clinical Question

Good					**(Aramendi 2007 115) E** ***(Berger 2007 145) E*** **(Eilevstjønn 2004 131) E** **(Irusta 2009 1229) E** **(Irusta 2009 1052) E** **(Ruiz de Gauna 2008 271) E** **(Tan 2008 S409) E** **(Werther 2009 1301) E**
Fair					**(Li 2008 198) E** **(Li 2007 131) E**
Poor					
	1	**2**	**3**	**4**	**5**
Level of evidence					

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

Evidence Neutral to Clinical question

Good					
Fair					
Poor					
	1	**2**	**3**	**4**	**5**
Level of evidence					

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

Evidence Opposing Clinical Question

Good					
Fair					
Poor					
	1	**2**	**3**	**4**	**5**
Level of evidence					

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

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

The question originally addressed in this worksheet needed to be reformulated for proper scientific review. The original question was formulated as follows: "**In adult and pediatric patients with cardiac arrest (prehospital [OHCA], in-hospital [IHCA]) (P), does the analysis of cardiac rhythm during chest compressions (I) compared with standard care (analysis of cardiac rhythm during pauses in chest compressions) (C), improve accuracy in the diagnosis of shockable rhythms (O)?**"
The revised question (as agreed at the 2008 Fall ILCOR meting) is as follows: "**In adult and pediatric patients with cardiac arrest (prehospital [OHCA], in-hospital [IHCA]) (P), does the analysis of cardiac rhythm during chest compressions (I) compared with standard care (analysis of cardiac rhythm during pauses in chest compressions) (C), optimize the time of appropriate chest compression by avoiding unnecessary interruptions and unnecessary prolongations (O)?**"

The rationale for this change is as follows:
The original question focused on the ability of an intervention; namely, analysis of the ECG rhythm obtained during chest compression (using some tool to remove compression artifacts), to improve the accuracy in the diagnosis of a shockable ECG rhythm. Accordingly, the comparator would be the ECG rhythm analysis in the absence of compression artifacts. Accuracy is a measure of the ability to correctly classify shockable and non-shockable rhythms and can be quantitatively defined as:
Accuracy (%) = [true shockable rhythms + true non-shockable rhythms]/[true shockable rhythms + false shockable rhythms + false non-shockable rhythms + true non-shockable rhythms]. 100% accuracy means all shockable and all non-shockable rhythms are correctly classified (i.e., sensitivity 100%, positive predictive value 100%, specificity 100%, negative predictive value 100%).
Implied in the analysis of accuracy is the presence of a "gold standard," which in this setting would be the accuracy of the ECG signal measured in the absence of chest compression with adjudication of shockable and non-shockable ECG rhythms by an AED or visually by a trained observer. However, this "gold standard" is also the comparator (i.e., "the analysis of cardiac rhythm during pauses in chest compressions") such that the accuracy of the comparator would be already 100%, limiting the accuracy of the intervention to accuracy equal or less than that of the comparator and therefore rendering the question unanswerable.
To make the question answerable and relevant, it was reformulated asking whether ECG analysis during chest compression applying some method to remove compressions artifacts optimizes the time of appropriate chest compression by avoiding unnecessary interruptions and unnecessary prolongations (O)? As reformulated, the question addresses the very purpose for removing ECG compression artifacts.
Wherever possible the effect of the intervention to remove ECG artifacts and correctly classify shockable and non-shockable rhythms was evaluated by measuring: 1) specificity = [true non-shockable rhythms]/[true non-shockable rhythms + false shockable rhythms], 2) sensitivity = [true shockable rhythms]/[true shockable rhythms + false non-shockable rhythms], 3) positive predictive value = [true shockable rhythms]/[true shockable rhythms + false shockable rhythms], and 4) negative predictive value [true non-shockable rhythms]/[true non-shockable rhythms + false non-shockable rhythms].
Sensitivity or negative predictive value < 100% would result in unnecessary rhythm-related prolongations in chest compression. Specificity or positive predictive value < 100% would result in unnecessary rhythm-related interruptions in chest compression. The incidence of the underlying rhythm will influence predictive values. One important caveat is that a non-shockable rhythm could be a perfusing rhythm.

Background
The international guidelines on cardiopulmonary resuscitation (CPR) of 2005 emphasize that rescuers should push hard enough, push fast enough, allow only a minimum of interruptions of chest compressions, ventilate, and defibrillate as soon as possible. However, chest compressions and ventilations distort the electrocardiogram (ECG). An automatic external defibrillator (AED) needs interruptions to work properly, causing a so-called "hands-off interval", where CPR stops and ECG is artifact free. As a consequence of these interruptions of CPR, myocardial and cerebral blood flow drops, thereby also decreasing the probability for success of defibrillation and increasing the probability of central nervous damage. This forms the rationale for developing methods that would remove CPR artifacts from the ECG during CPR administration enabling continuous ECG monitoring and discrimination between shockable and non-shockable ECG rhythms without having to interrupt chest compression. This should lead to a shorter "hands-off" delay time before defibrillation.
Currently, reliable analyses of ECG tracings can only be achieved during so-called "hands-off" intervals, when both chest compression and ventilation are discontinued for an interval of at least 12 seconds. Additional time is required for charging the defibrillator and the subsequent delivering a shock. (Eftestøl 2002 2270) The rescuer is therefore prompted to "step back, do not touch the patient." With these interruptions, the lifesaving benefits of chest compression are compromised. (Cobb 1999 1182) (Wik 2003 1389) (Yu 2002 368)
Animals studies show that these interruptions of chest compression prompted by AEDs, for rhythm analyses and defibrillator charging reduce the likelihood of successful resuscitation by as much as 50%. (Achleitner 2001 61) (Marenco 2001 1193) (van Alem 2003 17)
Significantly better outcomes have been reported if hands-off intervals are minimized or avoided (Kern 2002 645) (Abella 2007 54)
As the human heart can fibrillate at frequencies overlapping with the chest compression rate, this complicates the process of CPR artifact removal. (Rheinberger 2008 130)

Besides the technical difficulties designing a CPR artifact removal algorithm in order to filter one signal to retain another signal, which may have the same or a similar frequency, there are other problems to consider:
1. In real emergency situations, the rates and amplitudes of chest compressions and ventilations are not constant over time.
2. The CPR ECG artifacts are, in general, not sinusoidal and can contain high frequencies.
3. The shape of the CPR ECG artifacts can change over time.
4. The coupling between chest compressions and the ECG can change over the course of time, leading to a change in amplitude of the CPR–ECG artifacts. Therefore, we suggest that sophisticated adaptive removal algorithms are needed." (Rheinberger 2008 130)
At this moment, there are no studies in humans, neither RCT's, or uncontrolled studies, nor retrospective studies. Presently, the only studies available in this field are studies using ECG recording mixed with CPR artifacts and animal studies, so all presented evidence is per definition LOE 5.

By using a simple adaptive filter, a reduction of 70%–90% of artifacts was found in compression corrupted EGCs, (Tan 2005 111) so shockable ventricular arrhythmias can be differentiated from electrocardiographic rhythms not requiring defibrillation in the presence of chest compression-induced artifact with sensitivity and specificity above 90%. (Tan 2008 S409)
However, some other methods showed in increased sensitivity for the shock/no-shock decision of an automated external defibrillator (AED) after CPR. The sensitivity improved from 56% (95% CI, 47—64%) to 90% (95% CI, 84—94%). However, the specificity decreased from 91% (95% CI, 87—93%) to 80% (95% CI, 76—84%). (Ruiz de Gauna 2008 271)

In addition, the articles reviewed addressed ECG rhythm as a dichotomous variable (shockable *vs* non-shockable rhythms), presenting the "shockable rhythm" as a rhythm that should prompt delivery of an electrical shock. However, delivery of an electrical shock to a "shockable rhythm" could result in the rhythm remaining the same or been converted into a non-shockable, non-perfusing, rhythm such as pulseless electrical activity (PEA) or asystole. Thus, some "shockable rhythms" could behave as "non-shockable rhythms." A clinically more relevant approach would be to identify shockable rhythms with a high probability of returning a perfusing rhythm upon delivery of an electrical shock. Numerous studies indicate that analysis of the amplitude and frequency characteristic of a "shockable rhythm" may help predict the outcome of the electrical shock. However, there were no studies identified in which ECG rhythm analysis incorporated the probability that a "shockable rhythm" would return a perfusing rhythm after delivery of an electrical shock. **Thus a gap in knowledge was identified**. With the current approach, many "shockable rhythms" will behave as "non-shockable rhythms" leading to unnecessary interruptions in chest compression.

Evidence Reviewed
The current clinical approach is to analyze the ECG rhythm during pauses in chest compression. However, pauses are considered detrimental for successful resuscitation in part because blood flow is interrupted. However, the complete mechanism by which pauses compromise resuscitation are is not fully established. Moreover, the available data apply mostly to manual CPR. The effects of pauses using hemodynamically more effective CPR techniques are not known. Nevertheless, it is highly desirable to develop methods that could enable ECG rhythm analysis without pauses; i.e., during chest compression. Hence, this worksheet evaluated the impact of methods capable of removing CPR artifact from the ECG enabling a decision making process during ongoing CPR without the need to interrupt chest compression for ECG rhythm analysis.
The articles reviewed included methods to analyze ECG signals corrupted by artifacts generated by chest compression. Various approaches were reported. Some approaches used external references to identify the compression artifact (i.e., blood pressure or compression force) others used only information contained in the surface ECG. Change in accuracy was often evaluated by feeding the raw signal and the treated signal to a commercially available AED.

Findings
Twenty-one (21) articles were retrieved. All included an algorithm development; however, only 10 had an additional testing phase and only these where included for the evidence review. All 10 studies represented LOE 5 (Aramendi 2007 115) (Eilevstjønn 2004 131) (Irusta 2008 925) (Irusta 2009 1229) (Li 2007 131) (Li 2008 198) (Ruiz de Gauna 2008 271) (Tan 2008 S409) (Werther 2009 1301), analyzing ECG rhythms obtained during human resuscitation, and one that studied an animal (swine) model (Berger 2007 145). In 9 of these 10 studies, effects on sensitivity (ability to detect a shockable rhythm) and specificity (ability to detect the absence of a shockable rhythm) were assessed. The remaining study included only sensitivity. In the 9 human studies, human datasets were used; which comprised of ECG recordings during human CPR or recording of human rhythms without CPR mixed with artifacts from swine or human asystolic CPR. In 1 study, the analysis was performed real-time during swine CPR. A summary of the findings of 7 of these studies is included in the Table below:

	Irusta, U	Ruiz de Gauna, S	Li,Y	Li,Y	Aramendi, E	Eilevstjon, J	Berger, RD
	2009	2008	2007	2008	2007	2004	2007
	Human						Swine
Sensitivity	95.6	90.1	91.0	93.3	98.1	96.7	97.5
PPV		63.4	75.7	91.3		71.8	99.0
Specificity	85.6	80.4	84.0	88.5		79.9	95.2
NPP		95.5	94.5	91.0		97.9	88.2

Sensitivity: The evidence reviewed indicates that the sensitivity for identifying a shockable rhythm after removing compression artifacts ranged from 90.1% to 98.1% in the human studies signaling a robust capability for correctly identifying a shockable rhythm during chest compression. Failure to attain 100% sensitivity indicates the presence of false non-shockable rhythms, which would result in the continuation of chest compression despite the presence of a shockable rhythm. However, there is no information at the present time on the clinical relevance of extending chest compression in the presence of shockable rhythms. Current 2005 Guidelines recommendations emphasize minimally interrupted chest compression and the delivery of interrupted chest compressions for periods of approximately 2 minutes without rhythm check. The importance of shock delivery is the return of a perfusing rhythm. Analysis of uncorrupted VF waveforms indicates that not all electrical shocks result in a perfusing rhythm and that such can be predicted based on the VF amplitude and frequency characteristics. Accordingly, guiding the timing of shock delivery by the likelihood that an electrical shock will result in a perfusing rhythm may obviate the current approach guided to deliver a shock when a "shockable" rhythm is recognized. The effect of this approach on sensitivity is unknown based on the reviewed studies.

Specificity: The evidence reviewed indicates that the specificity after removing compression artifacts was lower than the sensitivity and ranged from 79.9% to 88.5% in the human studies. Failure to attain 100% specificity indicates the presence of false shockable rhythms, which would result in the interruptions in chest compression despite the presence of a non-shockable rhythm. Such occurrence may not be desirable given the importance of continued blood flow generation during CPR.

Acknowledgements:

Citation List

Aase, S. O., T. Eftestøl, J. H. Husøy, et al. (2000). "CPR artifact removal from human ECG using optimal multichannel filtering." IEEE transactions on bio-medical engineering **47**(11): 1440.

Reviewer Comment: Article limited to the development of a method for removing chest compression artifact. Testing to assess accuracy was not included. Article excluded from the evidence evaluation. Describes the workings of a technique that filters a weighted artifact signal from a noise-free ECG signal. As artifact signals ECGs recorded from animals in asystole during precordial compressions at rates 60, 90, and 120 compressions/min were used.

Abella, B. S., D. P. Edelson, S. Kim, et al. (2007). "CPR quality improvement during in-hospital cardiac arrest using a real-time audiovisual feedback system." Resuscitation **73**(1): 54.

Achleitner, U., K. Rheinberger, B. Furtner, et al. (2001). "Waveform analysis of biphasic external defibrillators." Resuscitation **50**(1): 61.

Amann, A., U. Achleitner, H. Antretter, et al. (2001). "Analysing ventricular fibrillation ECG-signals and predicting defibrillation success during cardiopulmonary resuscitation employing N(alpha)-histograms." Resuscitation **50**(1): 77.

Reviewer Comment: Article limited to the development of a method and testing in swine the ability to separate resuscitated from non-resuscitated animals immediately before delivery of electrical shocks. The analysis was made with chest compression; however, there was no comparison relative to analysis without artifact. Article excluded from the evidence evaluation.

Aramendi, E., S. R. de Gauna, U. Irusta, et al. (2007). "Detection of ventricular fibrillation in the presence of cardiopulmonary resuscitation artefacts." Resuscitation **72**(1): 115.

LOE 5 Good. Supporting. Another filtering method to clean the surface ECG that commercial AEDs capture through standard patches. Mean sensitivities of 97.83%, 98.27%, 98.32% and 98.02% were achieved, producing sensitivity increases of 28.44%, 49.75%, 59.10% and 64.25%, respectively, sufficient for ECG analysis during CPR.

Berger, R. D., J. Palazzolo and H. Halperin (2007). "Rhythm discrimination during uninterrupted CPR using motion artifact reduction system." Resuscitation **75**(1): 145.

LOE 5 Good. Supporting. Porcine study of chest compression filtering during CPR. During CPR, VF was correctly classified in 35 of 222 attempts using the raw ECG, and in 310 of 318 cases using the MARS-filtered ECG ($p < 0.001$); sensitivity of 97.5%, specificity of 95.2%, PPV of 99%, NPV of 88.2% reflecting overall accuracy of 97.1%.

Cobb, L. A., C. E. Fahrenbruch, T. R. Walsh, et al. (1999). "Influence of cardiopulmonary resuscitation prior to defibrillation in patients with out-of-hospital ventricular fibrillation." JAMA **281**(13): 1182.

Eftestøl, T., K. Sunde and P. A. Steen (2002). "Effects of interrupting precordial compressions on the calculated probability of defibrillation success during out-of-hospital cardiac arrest." Circulation **105**(19): 2270.

Reviewer Comment: Article deals with effect of interruptions during chest compression on defibrillation success. Article excluded from the evidence evaluation.

Eilevstjønn, J., T. Eftestøl, S. O. Aase, et al. (2004). "Feasibility of shock advice analysis during CPR through removal of CPR artefacts from the human ECG." Resuscitation **61**(2): 131.

LOE 5 Good. Supporting. Yet another adaptive artifact filtering technique. From a test set consisting of 92 shockable and 174 non-shockable episodes a sensitivity of 96.7% and specificity of 79.9% was achieved, an increase of approximately 15 and 13%, respectively, compared to no filtering.

Husøy, J. H., J. Eilevstjønn, T. Eftestøl, et al. (2002). "Removal of cardiopulmonary resuscitation artifacts from human ECG using an efficient matching pursuit-like algorithm." IEEE transactions on bio-medical engineering **49**(11): 1287.

Reviewer Comment: Excellent article but limited to the development of an algorithm. Testing to assess accuracy was not included. Article excluded from the evidence evaluation. In this study, using both pigs and recorded ECG's, a compression rate of 120/min was used as the earlier study by Aase et al. showed that artifact removal becomes increasingly more difficult when the compression rate goes from 60 to 90, and to 120/min, which is the highest rate that should be of clinical interest. This is due to a higher degree of overlap between the artifact and VF signal in the frequency domain. Using a more realistic scenario in this study, using 2 pigs and 200 recorded ECG's of human VF and 71 of human VT, the multichannel adaptive filter was successfully used for removal of CPR artifacts in ECG signals.

Irusta, U. and J. Ruiz (2009). "An algorithm to discriminate supraventricular from ventricular tachycardia in automated external defibrillators valid for adult and paediatric patients." Resuscitation **80**(11): 1229.

LOE 5. Good Supporting. Study with a limited amount of ECG recordings of SVT and VT yielding a good discriminination with both a sensitivity and specificty of about 98%

Irusta, U., J. Ruiz, S. R. de Gauna, et al. (2009). "A least mean-square filter for the estimation of the cardiopulmonary resuscitation artifact based on the frequency of the compressions." IEEE transactions on bio-medical engineering **56**(4): 1052.

LOE 5 Good. Supporting. Filtering technique tested on 89 shockable and 292 nonshockable ECG samples from real out-of-hospital sudden cardiac arrest episodes, using the shock advice algorithm of a commercial AED. Compression artifacts were removed using a least mean-square filter in which the CPR artifact was estimated based only on the frequency of compression. Practical approach that could be incorporated to existing AEDs with minimal additional modifications. Sensitivity and specificity for the validation set were 95.6 (84.4 - 99.6; 95% CI) and 85.6 (78.9 - 90.5; 95% CI), respectively.

Irusta, U., J. Ruiz, S. Ruiz de Gauna, et al. (2008). "An Algorithm to Discriminate SVT from VT in Pediatric AED Based on Spectral Parameters." Computers in Cardiology **35**: 925.

Kern, K. B., R. W. Hilwig, R. A. Berg, et al. (2002). "Importance of continuous chest compressions during cardiopulmonary resuscitation: improved outcome during a simulated single lay-rescuer scenario." Circulation **105**(5): 645.

Klotz, A., A. Amann and H. G. Feichtinger (2004). "REMOVAL OF CPR ARTIFACTS IN VENTRICULAR FIBRILLATION ECG BY LOCAL COHERENT LINE REMOVAL." Signal processing conference, Vienna, Austria: 2203.

Reviewer comment: Paper from a conference, therefore most probably not peer-reviewed. Outline of algorithm of filtering technique to demonstrate the effect of this method on a VF-dataset from an animal model.

Langhelle, A., T. Eftestøl, H. Myklebust, et al. (2001). "Reducing CPR artefacts in ventricular fibrillation in vitro." Resuscitation **48**(3): 279.

Reviewer Comment: Article limited to the development of a method using and adaptive filter technique. Testing to assess accuracy was not included. Article excluded from the evidence evaluation. Fixed coefficient filters used in animals cannot solve the problem of CPR artifact reduction in humans, due to overlapping frequency spectra for artifacts and VF signals, so an adaptive filter was used in this animal study with 9 pigs. Separating CPR artefacts from the myocardial ECG signal during VF in man is more difficult than the corresponding problem in pigs where it has been successfully achieved by applying digital filters with fixed coefficients by Strohmenger. The results with the adaptive filter clearly outperformed the fixed coefficient filter for all signal-to-noise ratio's (SNR) levels. At an original SNR of 0 dB, the restored SNRs were 9.0 ± 0.7 dB versus 0.9 ± 0.7 dB respectively (P<0.0001).

Li, Y., J. Bisera, F. Geheb, et al. (2008). "Identifying potentially shockable rhythms without interrupting cardiopulmonary resuscitation." Critical Care Medicine **36**(1): 198.

LOE 5 Fair. Supporting. Paper on waveletbased transformation and shape-based morphology detection for rhythm classification. To design the algorithm, 29 recordings on 29 patients from a ventricular tachyarrhythmia database were used. For validation, the algorithm was tested on an independent population of 229 victims, including recordings of both ECG and depth of chest compressions obtained during suspected out-of-hospital sudden death. The recordings included 111 instances in which the ECG was corrupted during chest compressions. A shockable rhythm was identified with a sensitivity of 93% and a specificity of 89%, yielding a positive predictive value of 91%. A nonshockable rhythm was identified with a sensitivity of 89%, a specificity of 93%, and a positive predictive value of 91% during uninterrupted chest compression.

Li, Y., J. Bisera, W. Tang, et al. (2007). "Automated detection of ventricular fibrillation to guide cardiopulmonary resuscitation." Critical pathways in cardiology **6**(3): 131.

LOE 5 Fair. Supporting. The Fourier-transform-based amplitude spectrum analysis algorithm was validated on 33,095 ECG segments, including 8840 segments corrupted by compression artifacts from 232 patients after out-of-hospital cardiac arrest. 9187 of 10,042 VF segments and

20,884 of 23,053 non-VF segments were correctly classified, with a sensitivity of 91.5% and a specificity of 90.6%. Although the proposed algorithm has a lesser predictive value for VF detection than the uncorrupted ECG's in clinical settings, it has the major potential for automated rhythm identification to guide defibrillation without repetitive interruptions of CPR.

Marenco, J. P., P. J. Wang, M. S. Link, et al. (2001). "Improving survival from sudden cardiac arrest: the role of the automated external defibrillator." JAMA **285**(9): 1193.

Neurauter, A., T. Eftestøl, J. Kramer-Johansen, et al. (2008). "Improving countershock success prediction during cardiopulmonary resuscitation using ventricular fibrillation features from higher ECG frequency bands." Resuscitation **79**(3): 453.

Reviewer Comment: Excellent article but limited to the development of an approach to assess countershock prediction in VF rhythms with compression artifacts by using higher ECG frequency bands (12-24 Hz) without removal or CPR artifacts. Testing to assess accuracy was not included. Article excluded from the evidence evaluation.

Rheinberger, K., T. Steinberger, K. Unterkofler, et al. (2008). "Removal of CPR artifacts from the ventricular fibrillation ECG by adaptive regression on lagged reference signals." IEEE transactions on bio-medical engineering **55**(1): 130.

Reviewer Comment: Excellent article but limited to the development of an algorithm. Testing to assess accuracy was not included. Method is not real-time. Article excluded from the evidence evaluation. Filter technique using adaptive regression on lagged copies of a reference (CPR) signal, using a Kalman method. Similar method as study from same author of 2006.

Ruiz de Gauna, S., J. Ruiz, U. Irusta, et al. (2008). "A method to remove CPR artefacts from human ECG using only the recorded ECG." Resuscitation **76**(2): 271.

LOE 5 Good. Supporting. The shock/no-shock decision of an automated external defibrillator (AED) was evaluated using recorded ECG's before and after CPR suppression for 131 shockable and 347 non-shockable samples. The sensitivity improved from 56% (95% CI, 47—64%) to 90% (95% CI, 84—94%). However, the specificity decreased from 91% (95% CI, 87—93%) to 80% (95% CI, 76—84%).

Ruiz de Gauna, S., J. Ruiz, U. Irusta, et al. (2005). "CPR Artefact Removal from VF Signals by Means of an Adaptive Kalman Filter Using the Chest Compression Frequency as Reference Signal." Computers in Cardiology **32**: 175.

Reviewer Comment: Description of technique.

Tan, Q., G. A. Freeman, F. Geheb, et al. (2008). "Electrocardiographic analysis during uninterrupted cardiopulmonary resuscitation." Critical Care Medicine **36**(Suppl): S409.

LOE 5 Good. Supporting. Filter technique, recognizing shockable and non non-shockable rhythms with a sensitivity of 92.1% and a specificity pf 90.5% with an average attenuation of compression-induced artifact of more than 35 dB.

Tan, Q., G. A. Freeman, F. J. Geheb, et al. (2005). "ECG RHYTHM ADVISORY METHOD - Patent Review JP20050139203 20050512." http://www.wikipatents.com/jp/2005339533.html: 30.

Tan, Q., F. Geheb and J. E. Brewer (2005). "A SIMPLE ADAPTIVE FILTER ALGORITHM TO REMOVE CPR ARTIFACTS FROM ECG SIGNALS." Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors **9**(1): 111.

van Alem, A. P., F. W. Chapman, P. Lank, 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.

Werther, T., A. Klotz, M. Granegger, et al. (2009). "Strong corruption of electrocardiograms caused by cardiopulmonary resuscitation reduces efficiency of two-channel methods for removing motion artefacts in non-shockable rhythms." Resuscitation **80**(11): 1301.

LOE 5. Good. Supporting. Model made with recorded ECG's and CPR artefacts, showing an increased sensitivity for recognizing shockable rhythms while the specificity remained unchanged at about 90%.

Werther, T., A. Klotz, G. Kracher, et al. (2009). "CPR artifact removal in ventricular fibrillation ECG signals using Gabor multipliers." IEEE transactions on bio-medical engineering **56**(2): 320.

Reviewer Comment: Good article but limited to the development of an algorithm. Testing to assess accuracy was not included. Article excluded from the evidence evaluation.

Wik, L., T. B. Hansen, F. Fylling, et al. (2003). "Delaying defibrillation to give basic cardiopulmonary resuscitation to patients with out-of-hospital ventricular fibrillation: a randomized trial." JAMA **289**(11): 1389.

Yu, T., M. H. Weil, W. Tang, et al. (2002). "Adverse outcomes of interrupted precordial compression during automated defibrillation." Circulation **106**(3): 368.