# Feedback to Improve the Quality of CPR

J. Yeung, J. Soar, and G.D. Perkins

## Introduction

Ischemic heart disease is a leading cause of death in the world and many people die prematurely from sudden cardiac arrest. It is estimated that 40–46,0000 people in the USA and 700,000 people in Europe experience sudden cardiac arrest each year [1]. Cardiopulmonary resuscitation (CPR) is the attempt to restore spontaneous circulation by performing chest compressions with or without ventilations [2]. Early and effective CPR, prompt defibrillation, early advanced life support, and post-resuscitation care are key components in the 'Chain of Survival' [3]. Standardized resuscitation guidelines and training courses in CPR and advanced life support have been developed in order to improve outcomes from cardiac arrest. These have been implemented through most of Europe, the USA and many other developed countries. Despite this, observational studies report that the quality of CPR in both the out-of-hospital and in-hospital setting is often poor and that survival rates remain low despite significant advances in the science of resuscitation [4–6]. Technological advances mean that it is now possible to measure the quality of CPR during actual resuscitation attempts. Feedback techniques for both individuals and teams are now being developed to improve the quality of CPR during both training and actual resuscitation attempts.

## The Importance of Quality CPR

Studies from the early 1990s were among the first to start to make the link between the quality of CPR and patient outcome. Wik and colleagues observed that the quality of CPR by bystanders was associated with outcome [4]. Good quality CPR was defined in this study as the presence of a palpable pulse upon arrival of the paramedic. The investigators found improved survival to hospital discharge rates among patients who received good quality bystander CPR (23 % survival) as opposed to poor quality CPR (1 % survival) or no CPR (6 % survival) prior to the arrival of the emergency medical service (EMS). Similar findings were also observed at the same time by Gallagher et al. [5] and Van Hoeyweghen et al. [6] in 2071 and 3306 consecutive out-of-hospital cardiac arrests in New York and Belgium, respectively.



### Chest Compressions

Effective chest compressions are essential to promote forward blood flow and maintain heart and brain perfusion. However, even optimal chest compressions only deliver 20–25 % of normal organ blood flow [7]. Chest compression depth, rate, and interruptions in chest compressions have been shown to have a direct influence on patient outcome [7, 8].

Animal studies show a linear relationship between chest compression depth and coronary perfusion pressure and that the 'effectiveness' of CPR is sensitive to small changes in compression depth [9, 10]. These findings were confirmed in humans in the late 1980s by Ornato et al. who demonstrated a linear relationship between compression force delivered by a Thumper™ device and systolic blood pressure and end-tidal $CO_2$ [11]. Based on these data the International Liaison Committee for Resuscitation recommended that chest compression depth should be between 40–50 mm in adults [12]. This corresponds to approximately 20 % of the anteroposterior diameter of an adult chest [13].

Recent studies have shown that chest compression depth does influence patient survival. Using an accelerometer device placed on the chest to measure sternal movement, Edelson et al. [7] found an association between chest compression depth and the probability of shock success in a mixed population of in- and out-of-hospital patients in ventricular fibrillation. A higher mean compression depth during the 30 seconds of CPR preceding a defibrillation attempt was associated with an increased chance of shock success (adjusted odds ratio 1.99 for every 5 mm increase; 95 % confidence interval 1.08–3.66). In this study, all five patients with a mean compression depth of 50 mm had successful defibrillation. Using the same device, Kramer-Johansen et al. [8] showed in a logistic regression analysis of 208 out-of-hospital resuscitation attempts that an increase in compression depth was associated with a better chance of admission to hospital alive (odds ratio 1.05 (95 % CI; 1.01, 1.09) per mm increase in compression depth).

The International Liaison Committee for Resuscitation recommends that chest compressions are performed at a rate of 100 per minute. Animal models of cardiac arrest [14–16] show a constant stroke volume and improved hemodynamics by increasing compression rate up to 130 to 150/min, with the duty cycle maintained at 50 % (time in compression versus decompression). Abella et al. examined chest compressions in 97 in-hospital resuscitation attempts and found a greater return of spontaneous circulation in patients receiving chest compressions at rates above 87 per minute compared to those with a compression rate below 72 per minute (75 % versus 43 %) [17].



## Interruptions in Chest Compressions

Interruptions in chest compressions (also referred to as no-flow time or hands-off time) are common during resuscitation [18, 19]. Whilst some interruptions are necessary such as during defibrillation or pulse/rhythm checks, many of the interruptions observed in practice are avoidable. Two specific contributors to no-flow time are the period between cessation of chest compression prior to a defibrillation shock (known as the pre-shock pause) and the time following the shock to resumption of chest compression (post-shock pause) [8]. Prolonged pre- and post-shock pauses are associated with a reduced chance of successful defibrillation.

Yu et al. were one of first groups to demonstrate the adverse effects of prolonged pre-shock pauses [20]. Using a porcine model of prolonged (7 min) ventricular fibrillation the effect of increasing pre-shock pauses on return of spontaneous circulation rates and post resuscitation hemodynamic function was evaluated. The durations of pre-shock pauses were modeled on the time taken for commercially available automated external defibrillators to analyze the rhythm, charge the capacitor, and deliver a shock (range 10 to 19.5 seconds). The study showed that return of spontaneous circulation rates were significantly higher in animals treated with minimal (3 second) pre-shock pause as opposed to those treated with a 15 or 20 second pre-shock pause (100 % survival versus 20 % and 0 % respectively). Prolonged pre-shock pauses were associated with more marked myocardial dysfunction in the 24 hours after return of spontaneous circulation.

Two physiological explanations have been suggested for how interruptions in chest compressions reduce shock success. The traditional explanation is that interruptions in chest compressions reduce coronary perfusion pressure [20], which decreases the probability of return of spontaneous circulation after attempted defibrillation [21]. Alternatively, Chamberlain et al. suggest that chest compressions empty the right ventricle and thus reduce ventricular interaction in the arrested heart. Reducing ventricular interaction will increase left ventricular volume and hence myocyte stretch. Therefore, when defibrillation takes place and coordinated electrical activity is restored, the heart is able to generate an effective contraction [22].

The findings by Yu et al. [20] were subsequently confirmed in observational studies in humans which showed that an increase in the duration of the pre-shock pause was associated with a reduction in the likelihood of shock success. Eftestol et al. used ventricular fibrillation waveform prediction models on electrocardiogram (EKG) outputs from humans in cardiac arrest to show that increasing pre-shock pauses (as brief as 5 seconds) were associated with a 50 % relative reduction in the calculated probability of return of spontaneous circulation [23]. Edelson et al. demonstrated that first shock success (defined as removal of ventricular fibrillation for at least 5 seconds following defibrillation) was associated with shorter pre-shock pauses (adjusted odds ratio of 1.86 for every 5 second decrease in pre-shock pause) [7]. Berg and colleagues used a pig model of prolonged ventricular fibrillation to show that a delay in resuming chest compressions after defibrillation was associated with reduced return of spontaneous circulation and neurologically intact survival at 48 hours [24]. These data provide a clear rationale for reducing the duration of pre-shock and post-shock pauses.

### Ventilation Rate and Hyperventilation

Resuscitation guidelines in 2005 recommended a ventilation rate of 8–10 breaths per minute during CPR [2]. In practice, most rescuers ventilate at much higher rates leading to hyperventilation and hypocarbia [25]. Ventilations can interrupt chest compression and reduce vital organ perfusion. Positive pressure ventilation increases intrathoracic pressure and decreases venous return to the heart, rendering CPR less effective. Aufderheide et al. [26] reproduced ventilation rates seen in an observational study during actual resuscitation attempts in a pig model of ventricular fibrillation cardiac arrest. The study showed that an excessive ventilation rate (30/min) increased intrathoracic pressure, reduced coronary perfusion pressure and lowered survival compared to a slower ventilation rate (12/min). The addition of supplemental $CO_2$ to the inspired gas in the hyperventilation group to correct for hypocarbia failed to correct these harmful effects. This implies that raised intrathoracic pressure is the predominant harmful mechanism when high ventilation rates are used during CPR.

## The Quality of CPR is often Sub-optimal during Clinical Resuscitation Attempts

A number of prospective observational studies have demonstrated that the quality of CPR during in-hospital and out-of--hospital resuscitation attempts is frequently sub-optimal. Abella et al. [18] studied 67 patients who suffered in hospital cardiac arrests and analyzed parameters of CPR quality. Chest compression rates were too slow (< 90/min) 28.1 % of the time and 37.4 % of chest compressions were of inadequate depth (< 38 mm). Ventilation rates were excessive nearly two thirds of the time. Chest compressions were only performed for 76 % of the resuscitation attempts [18]. The findings were similar in the study by Wik et al. of 176 out-of-hospital resuscitation attempts [19]. In this study, chest compressions were not given during 48 % (95 % CI, 45–51 %) of the resuscitation attempts. Chest compression depth averaged 34 mm (95 % CI, 33–35 mm) with 72 % of compressions below 38 mm [19]. Poor quality CPR is not limited to clinical resuscitation attempts. In an observational study of clinicians under direct supervision during advanced resuscitation simulation training, we found that chest compressions were almost always too shallow (97 %) and no compressions were performed for 37 % of the resuscitation attempts [27].

Losert et al. reported that it is possible to perform high quality CPR with a motivated and experienced team [28]. Data from 80 patients with non-traumatic cardiac arrest admitted to the emergency department showed that the highly trained emergency department staff performed good quality chest compressions (rate 96/min) with only 7 % of chest compressions being too shallow and that no-flow durations (without chest compressions) were similarly low (12.7 %). However, there was scope for improvement as 32 % of patients were hyperventilated.

Technologies introduced to facilitate early defibrillation such as the automated external defibrillator (AED or shock advisory defibrillator) may not be achieving their full potential due to the delays imposed by the device between cessation of chest compression and shock delivery. Pauses ranging from 5.2 to 28.4 seconds [29] have been reported during which the defibrillators analyzed the underlying heart rhythm and charged the capacitor in preparation for shock delivery. A direct comparison between AEDs and manual defibrillation showed that the pre- and post-shock pauses were longer in patients receiving shocks from AEDs than from manual defibrillators (22 vs 15 s and 20 vs 9 s, respectively). However, 26 % of shocks given via the manual defibrillator were given inappropriately (when the adjudication panel defined the rhythm as non-shockable) compared to only 6 % in the AED group [30].



## Strategies for Improving the Quality of CPR

### Real-time Feedback during CPR Training and Actual Resuscitation

Subjective evaluation of resuscitation performance by CPR instructors is limited by the difficulty of assessing the adequacy of performance by observation alone, particularly the adequacy of ventilation and chest compression [31]. Audio (e.g., metronome for compression rate or audible click when adequate compression depth is achieved) and visual feedback (e.g., lights illuminating when adequate compression depth is achieved) have been incorporated into resuscitation training manikins for a number of years. The use of these devices during training has a positive effect on both initial skill acquisition and retention of skills several weeks after initial training [32].

More sophisticated devices have been developed recently that convert objective measures of CPR performance (e.g., compression depth) into spoken instructions on how performance can be improved (e.g., shallow chest compressions prompt the instruction “press a little harder”). The audible instructions can be combined with visual displays to further enhance performance. Wik et al. showed that the use of one of these devices during basic life support training improved the proportion of correctly performed compressions from a mean of 33 to 77 % and correct inflations from a mean of 9 to 58 % [33]. The improved performance was maintained both 6 and 12 months after initial training [34, 35]. Sutton et al. also found similar improvements in skill acquisition in providers of pediatric basic life support using this technology compared to one-on-one instructor led training. In addition to better CPR parameters, volunteers also had lower error rates in chest compressions and ventilations, resulting in higher pass rates in skills testing [36].

Technological advances have allowed the integration of performance feedback into portable devices which can be used during actual resuscitation attempts. **Figure 1** shows an example of two such devices where feedback from an accelerometer placed on the victim’s chest (to measure compression parameters) and transthoracic impedance measurements (to detect ventilation) are used to provide audio and visual feedback on performance during actual resuscitation attempts.

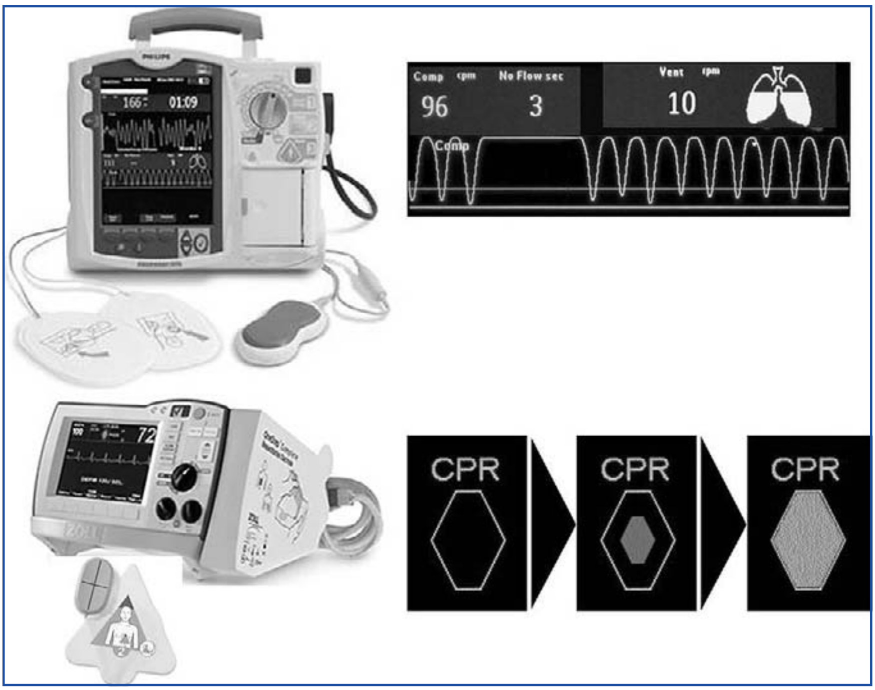


**Fig. 1.** Examples of commercially available cardiopulmonary resuscitation (CPR) feedback devices. The small rectangular box (accelerometer) is placed on the patient’s sternum and used to measure sternal movement and compression rate. Changes in transthoracic impedance or end-tidal $CO_2$ are used to monitor ventilation rates. Displays on the defibrillator monitor provide visual feedback on compression +/- ventilation performance. The visual feedback may be supplemented by audible prompts such as “compress the chest deeper”.

The impact of introducing this technology into clinical practice has been evaluated in three prospective before-after cohort studies. Kramer-Johansen et al. [8] reported improved CPR quality with real time automated feedback in pre-hospital cardiac arrests when the technology was introduced across three European ambulance services. Resuscitation attempts after introduction of the device had significantly greater compression depth (38 versus 34 mm), percentage of correct compression depth (53 versus 24 %) and compression rate (109 versus 121/min). The importance of introducing the technology in a coordinated and structured manner with supporting education and training was highlighted when the same team introduced it into a fourth ambulance service [37]. On this occasion the feedback technology failed to lead to any improvement in CPR quality. This was ascribed to a lack of supporting infrastructure and training for those using the device. A similarly disappointing result was found when the device was introduced into a hospital based resuscitation system. Despite showing less variation in CPR quality measures between resuscitation attempts in the feedback group there were no significant differences in the quality of CPR after the introduction of the feedback technology [38].

The use of these devices is not without potential limitations. The accuracy of the devices for measuring chest compression depth may be influenced by the surface the victim is positioned on. If the victim is situated on a compressible surface such as a bed and mattress then most devices are unable to take account of the degree of compression of the underlying mattress. Thus compressions registering on the device as being of adequate depth may in fact still be too shallow due to a failure to compensate for additional compression of the mattress [39]. We investigated this phenomenon using a commercially available accelerometer device and found that CPR guided by the feedback device led to significant under compression of the chest as 35–40 % of the total compression depth measured was attributable to compression of the underlying mattress [40]. Using a backboard to increase the stiffness of the bed/mattress had little effect on improving compression depth in this model. Other potential limitations to feedback devices include increased mechanical work required to perform chest compressions [41] and the potential for injury to rescuers associated with moving parts in certain devices [42]. To date, no randomized controlled clinical trials have been conducted to investigate the clinical benefits or otherwise of these devices, so the clinical impact of introducing these technologies remains to be determined.



## Post-event Debriefing

The use of post event debriefing in simulator based training has been shown to significantly improve team performance [43] and is widely used by the military and in aviation for improving future performance particularly in the context of rare or stressful events. Participation as a member of a cardiac arrest team can be a stressful and challenging experience. Junior doctors have reported feeling un-prepared and concerned about managing cardiac arrest and have called for more feedback on their performance [44]. In addition to potentially being able to improve the quality of CPR, post-event debriefing may have a part to play in reducing stress amongst members of the resuscitation team.

Dine et al. investigated a strategy of post-event debriefing among nurses during advanced resuscitation training [45]. Following a simulated cardiac arrest, participants received a 5-min structured program of post-arrest debriefing in which the participants were shown the actual transcript of their own CPR efforts and briefly counseled on how to improve their CPR to comply with consensus resuscitation guidelines. Post-event debriefing in this format led to significant improvements in the quality of CPR. These improvements were further augmented when real-time audiovisual feedback was available during the resuscitation attempt. The combination of feedback and debriefing improved compression rate compliance from 45 to 84 % ($p = 0.001$) and doubled the number of compressions of adequate rate and depth (29 versus 64 %, $p = 0.005$).

Post-event debriefing of medical residents after in-hospital resuscitation attempts was studied in a before-after cohort study by investigators from the University of Chicago [46]. A unique debriefing program (Resuscitation with Actual Performance Integrated Debriefing, RAPID) was introduced to allow discussion of cases during a 45 minute session each week. Cardiac arrest data transcripts detailing the quality of CPR, EKG traces, and problems with specific resuscitation attempts were converted into presentation slides. These were used to provide feedback on performance and to reinforce the scientific evidence behind resuscitation techniques. Compared to the historical control group (who received real time audiovisual feedback on CPR performance only) the RAPID cohort delivered improved ventilation rates (13 vs 18/min, $p < 0.001$) and increased compression depth (50 vs 44 mm, $p = 0.001$) compared with the control group. Knowledge about resuscitation among the members of the cardiac arrest team also improved significantly. There were also improved patient outcomes (increase in return of spontaneous circulation rate from 44.6 to 59.4 %, $p = 0.03$). This is the best real patient study to date supporting the use of debriefings for resuscitation teams. The study used a historical control group and spanned the change in resuscitation guidelines in 2005. This is a potential confounding factor as the new guidelines emphasized the importance of CPR quality and of minimizing interruptions in chest compression.

## Future Developments in Technology

Remote guidance and feedback to lay rescuers who witness a collapse may be possible with new mobile cellular phone technology in the future. In a manikin study, untrained individuals given audiovisual prompts sent by an ambulance dispatch center to a cellular phone were more likely to deliver chest compressions than those who received telephone instructions alone [47]. The use of new video phones to guide and provide feedback during a resuscitation attempt is also being studied.



Strategies to reduce the pre-shock pause imposed by AEDs are also being investigated. These may include reducing the number of voice prompts, pre-charging the capacitor during CPR, and new diagnostic algorithms to reduce the time taken for rhythm analysis. Filtering technology to remove the artefacts created by CPR has also now been developed. This would allow rhythm analysis to take place during ongoing CPR. This approach was investigated using a databank of EKG traces from 229 patients in cardiac arrest [48]. The algorithm was able to identify a shockable rhythm with a sensitivity of 93 % and a specificity of 89 %, yielding a positive predictive value of 91 %. A non-shockable rhythm was identified with a sensitivity of 89 %, a specificity of 93 %, and a positive predictive value of 91 % during uninterrupted chest compression.

Utilization of signals frequently collected by defibrillators, such as transthoracic impedance and EKG signals, may also play a role in providing feedback on the quality of CPR. Transthoracic impedance measurements through defibrillator pads are already used in some defibrillators to monitor ventilation rate. In an experimental study in humans, investigators found that monitoring transthoracic impedance could also reliably detect esophageal intubation [49]. Analysis of the EKG signal, particularly the characteristics of the ventricular fibrillation waveform is able to predict the likelihood of shock success. Using this technology Li et al. were able to differentiate between good and poor quality CPR in a pig model of cardiac arrest [50]. The development of these and related technologies is likely to play an increasing role in providing feedback to aid the delivery of optimal CPR to patients in the future.

## Conclusion

Good quality CPR improves survival from cardiac arrest. Numerous studies show that the quality of CPR is poor during training and real resuscitation attempts. Feedback devices that measure CPR quality during actual skill performance and provide prompts to correct any deficiencies can improve skill performance. Feedback devices may reduce rescuer fatigue and improve willingness to perform CPR in lay people. Real time audio feedback during CPR has been called 'The Guardian Angel of CPR' [51]. It has also been suggested that audio feedback on AEDs will enable 'the untrained layperson to become the next critical care practitioner' [52]. There is good evidence to support the regular use of feedback devices during training and whenever available in cardiac arrest situations. The use of feedback devices during actual CPR followed by a post-event briefing may further improve skill performance during subsequent resuscitation attempts.

### References

1. International Liaison Committee for Resuscitation (2005) International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. Part 1: introduction. Resuscitation 67: 181–186
2. Jacobs I, Nadkarni V, Bahr J, et al (2004) Cardiac arrest and cardiopulmonary resuscitation outcome reports: update and simplification of the Utstein templates for resuscitation registries. A statement for healthcare professionals from a task force of the international liaison committee on resuscitation. Resuscitation 63: 233–249
3. Perkins GD, Soar J (2005) In hospital cardiac arrest: missing links in the chain of survival. Resuscitation 66: 253–255
4. Wik L, Steen PA, Bircher NG (1994) Quality of bystander cardiopulmonary resuscitation influences outcome after prehospital cardiac arrest. Resuscitation 28: 195–203
5. Gallagher EJ, Lombardi G, Gennis P (1995) Effectiveness of bystander cardiopulmonary resuscitation and survival following out-of-hospital cardiac arrest. JAMA 274: 1922–1925
6. Van Hoeyweghen RJ, Bossaert LL, Mullie A, et al (1993) Quality and efficiency of bystander CPR. Belgian Cerebral Resuscitation Study Group. Resuscitation 26: 47–52
7. Edelson DP, Abella BS, Kramer-Johansen J, et al (2006) Effects of compression depth and preshock pauses predict defibrillation failure during cardiac arrest. Resuscitation 71: 137–145
8. Kramer-Johansen J, Myklebust H, Wik L, et al (2006) Quality of out-of-hospital cardiopulmonary resuscitation with real time automated feedback: a prospective interventional study. Resuscitation 71: 283–292
9. Babbs CF, Voorhees WD, Fitzgerald KR, Holmes HR, Geddes LA (1983) Relationship of blood pressure and flow during CPR to chest compression amplitude: evidence for an effective compression threshold. Ann Emerg Med 12: 527–532
10. Bellamy RF, DeGuzman LR, Pedersen DC (1984) Coronary blood flow during cardiopulmonary resuscitation in swine. Circulation 69: 174–180

11. Ornato JP, Levine RL, Young DS, Racht EM, Garnett AR, Gonzalez ER (1989) The effect of applied chest compression force on systemic arterial pressure and end-tidal carbon dioxide concentration during CPR in human beings. Ann Emerg Med 18: 732–737
12. International Liaison Committee for Resuscitation (2005) International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. Part 2: Adult basic life support. Resuscitation 67: 187–201
13. Pickard A, Darby M, Soar J (2006) Radiological assessment of the adult chest: implications for chest compressions. Resuscitation 71: 387–390
14. Maier GW, Tyson GS Jr, Olsen CO, et al (1984) The physiology of external cardiac massage: high-impulse cardiopulmonary resuscitation. Circulation 70: 86–101
15. Halperin HR, Tsitlik JE, Guerci AD, et al (1986) Determinants of blood flow to vital organs during cardiopulmonary resuscitation in dogs. Circulation 73: 539–550
16. Feneley MP, Maier GW, Kern KB, et al (1988) Influence of compression rate on initial success of resuscitation and 24 hour survival after prolonged manual cardiopulmonary resuscitation in dogs. Circulation 77: 240–250
17. Abella BS, Sandbo N, Vassilatos P, et al (2005) Chest compression rates during cardiopulmonary resuscitation are suboptimal: a prospective study during in-hospital cardiac arrest. Circulation 111: 428–434
18. Abella BS, Alvarado JP, Myklebust H, et al (2005) Quality of cardiopulmonary resuscitation during in-hospital cardiac arrest. JAMA 293: 305–310
19. Wik L, Kramer-Johansen J, Myklebust H, et al (2005) Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. JAMA 293: 299–304
20. Yu T, Weil MH, Tang W, et al (2002) Adverse outcomes of interrupted precordial compression during automated defibrillation. Circulation 106: 368–372
21. Paradis NA, Martin GB, Rivers EP, et al (1990) Coronary perfusion pressure and the return of spontaneous circulation in human cardiopulmonary resuscitation. JAMA 263: 1106–1113
22. Chamberlain D, Frenneaux M, Steen S, Smith A (2008) Why do chest compressions aid delayed defibrillation? Resuscitation 77: 10–15
23. Eftestol T, Sunde K, Steen PA (2002) Effects of interrupting precordial compressions on the calculated probability of defibrillation success during out-of-hospital cardiac arrest. Circulation 105: 2270–2273
24. Berg RA, Hilwig RW, Berg MD, et al (2008) Immediate post-shock chest compressions improve outcome from prolonged ventricular fibrillation. Resuscitation 78: 71–76
25. O'Neill JF, Deakin CD (2007) Do we hyperventilate cardiac arrest patients? Resuscitation 73: 82–85
26. Aufderheide TP, Sigurdsson G, Pirrallo RG, et al (2004) Hyperventilation-induced hypotension during cardiopulmonary resuscitation. Circulation 109: 1960–1965
27. Perkins GD, Boyle W, Bridgestock H, et al (2008) Quality of CPR during advanced resuscitation training. Resuscitation 77: 69–74
28. Losert H, Sterz F, Kohler K, et al (2006) Quality of cardiopulmonary resuscitation among highly trained staff in an emergency department setting. Arch Intern Med 166: 2375–2380
29. Snyder D, Morgan C (2004) Wide variation in cardiopulmonary resuscitation interruption intervals among commercially available automated external defibrillators may affect survival despite high defibrillation efficacy. Crit Care Med 32:S421–424
30. Kramer-Johansen J, Edelson DP, Abella BS, et al (2007) Pauses in chest compression and inappropriate shocks: A comparison of manual and semi-automatic defibrillation attempts. Resuscitation 73: 212–220
31. Lynch B, Einspruch EL, Nichol G, Aufderheide TP (2008) Assessment of BLS skills: Optimizing use of instructor and manikin measures. Resuscitation 76: 233–243
32. Spooner BB, Fallaha JF, Kocierz L, et al (2007) An evaluation of objective feedback in basic life support (BLS) training. Resuscitation 73: 417–424
33. Wik L, Thowsen J, Steen PA (2001) An automated voice advisory manikin system for training in basic life support without an instructor. A novel approach to CPR training. Resuscitation 50: 167–172
34. Wik L, Myklebust H, Auestad BH, Steen PA (2002) Retention of basic life support skills 6 months after training with an automated voice advisory manikin system without instructor involvement. Resuscitation 52: 273–279

35. Wik L, Myklebust H, Auestad BH, Steen PA (2005) Twelve-month retention of CPR skills with automatic correcting verbal feedback. Resuscitation 66: 27–30
36. Sutton RM, Donoghue A, Myklebust H, et al (2007) The voice advisory manikin (VAM): an innovative approach to pediatric lay provider basic life support skill education. Resuscitation 75: 161–168
37. Olasveengen TM, Tomlinson AE, Wik L, et al (2007) A failed attempt to improve quality of out-of-hospital CPR through performance evaluation. Prehosp Emerg Care 11: 427–433
38. Abella BS, Edelson DP, Kim S, et al (2007) CPR quality improvement during in-hospital cardiac arrest using a real-time audiovisual feedback system. Resuscitation 73: 54–61
39. Perkins GD, Smith CM, Augre C, et al (2006) Effects of a backboard, bed height, and operator position on compression depth during simulated resuscitation. Intensive Care Med 32: 1632–1635
40. Perkins GD, Kocierz L, Smith SCL, McCulloch R, Davies RP (2009) Compression feedback devices over estimate chest compression depth when performed on a bed. Resuscitation 80: 79–82
41. van Berkom PF, Noordergraaf GJ, Scheffer GJ, Noordergraaf A (2008) Does use of the CPREzy involve more work than CPR without feedback? Resuscitation 78: 66–70
42. Perkins GD, Augre C, Rogers H, Allan M, Thickett DR (2005) CPREzy: an evaluation during simulated cardiac arrest on a hospital bed. Resuscitation 64: 103–108
43. Townsend RN, Clark R, Ramenofsky ML, Diamond DL (1993) ATLS-based videotape trauma resuscitation review: education and outcome. J Trauma 34: 133–138
44. Hayes CW, Rhee A, Detsky ME, Leblanc VR, Wax RS (2007) Residents feel unprepared and unsupervised as leaders of cardiac arrest teams in teaching hospitals: a survey of internal medicine residents. Crit Care Med 35: 1668–1672
45. Dine CJ, Gersh RE, Leary M, et al (2008) Improving cardiopulmonary resuscitation quality and resuscitation training by combining audiovisual feedback and debriefing. Crit Care Med 36: 2817–2822
46. Edelson DP, Litzinger B, Arora V, et al (2008) Resuscitation with actual performance integrated debriefing (RAPID) improves CPR quality and initial patient survival. Resuscitation Science Symposium A61:29 (abst)
47. Choa M, Park I, Chung HS, et al (2008) The effectiveness of cardiopulmonary resuscitation instruction: animation versus dispatcher through a cellular phone. Resuscitation 77: 87–94
48. Li Y, Bisera J, Geheb F, Tang W, Weil MH (2008) Identifying potentially shockable rhythms without interrupting cardiopulmonary resuscitation. Crit Care Med 36: 198–203
49. Kohler KW, Losert H, Myklebust H, et al (2008) Detection of malintubation via defibrillator pads. Resuscitation 77: 339–344
50. Li Y, Ristagno G, Bisera J, et al (2008) Electrocardiogram waveforms for monitoring effectiveness of chest compression during cardiopulmonary resuscitation. Crit Care Med 36: 211–215
51. Heightman AJ (2005) The guardian angel of CPR. JEMS 30:4
52. Pepe PE, Wigginton JG (2006) Key advances in critical care in the out-of-hospital setting: the evolving role of laypersons and technology. Crit Care 10:119