

Ventilation during resuscitation efforts for out-of-hospital primary cardiac arrest

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Current Opinion in Critical Care 2009, 15:228–233

Purpose of review

To discuss recent findings surrounding the role of ventilation during cardiopulmonary resuscitation for individuals with out-of-hospital primary cardiac arrest.

Recent findings

Active assisted ventilation during primary cardiac arrest may not always be beneficial and, in some circumstances, may lead to worse outcomes. By interrupting chest compressions and thereby decreasing vital organ perfusion, rescue breathing may be deleterious. In addition to the time required to administer breaths, the delay due to the insertion of advanced airways, even by well trained individuals, is often extensive. Furthermore, once intubation is completed, excessive hyperventilation occurs frequently, even by recently trained medical providers. Although most experts agree that excessive ventilation is harmful during out-of-hospital cardiac resuscitation, the optimal rate, tidal volume, timing, and technique of ventilation is still unknown. There is increasing evidence that, in patients with witnessed arrests and a shockable rhythm, the optimal form of ventilation is passive oxygen insufflation.

Summary

Assisted ventilation during the initial provision of cardiopulmonary resuscitation is less important than previously believed. It is hypothesized that, by training prehospital medical providers to utilize passive oxygen insufflation for individuals with primary cardiac arrest, critical organ perfusion will increase and, therefore, survival after out-of-hospital cardiac arrest will improve.

Keywords

cardiac arrest, cardiocerebral resuscitation, continuous chest compression CPR, ventilation, ventricular fibrillation

Curr Opin Crit Care 15:228–233
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1070-5295

Introduction

Components of cardiopulmonary resuscitation (CPR) that are believed to affect hemodynamics and survival during out-of-hospital cardiac arrest (OHCA) include chest compression rate, compression depth, allowing complete chest recoil, hands-off time and ventilation rate, and duration [1].

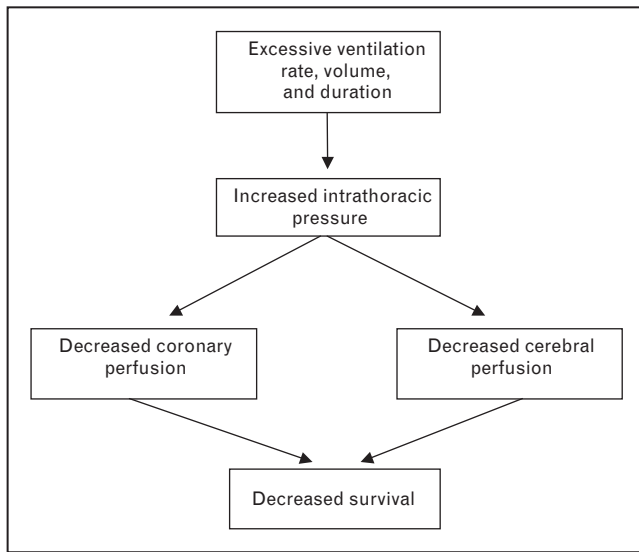
For decades the Advanced Cardiac Life Support Guidelines for cardiac arrest have advocated positive pressure ventilation delivered by early endotracheal intubation. However, this is now being challenged by many experts [2].

Recent prehospital clinical studies suggest that utilizing passive oxygen insufflation during resuscitation efforts for patients with witnessed OHCA and a shockable rhythm can significantly improve outcomes [3,4*,5]. This review focuses on the role of ventilation

during cardiac resuscitation by prehospital medical providers.

Ventilation physiology

There is an inverse relationship between intrathoracic pressure and coronary perfusion pressure and subsequent survival from cardiac arrest [6,7] (Fig. 1). Increased ventilation rates and duration cause increased intrathoracic pressure. Elevated intrathoracic pressure impedes venous return to the heart, thereby decreasing forward blood flow to the myocardium and brain during CPR [6–8]. Conversely, generation of negative intrathoracic pressure during the release phase of chest compressions augments venous return to the heart, significantly improving hemodynamics and outcome [9–12]. This fundamental physiologic concept also applies to states of shock and is applicable to cardiopulmonary interactions during resuscitation efforts, regardless of the cause of the low-flow state [13]. In theory, if chest compressions were not interrupted

Figure 1 Effects of assisted ventilation

Additionally, the focus on airway takes provider focus away from critical chest compressions.

during ventilation and the standard ventilatory volumes were forcefully delivered, the resulting intrathoracic pressures would be higher and the consequent reduction of venous return would be worse.

Elevated intrathoracic pressure due to positive pressure ventilation is transferred primarily via the nonvalvular spinal cord veins and cerebrospinal fluid, increasing intracranial pressure and decreasing cerebral perfusion pressure and cerebral blood flow [14–16].

Aufderheide *et al.* [6] found that survival in swine ventilated at 12 breaths per minute (with 100% O₂) was six of seven (86%), compared with a survival rate of one of seven (17%) in two groups of pigs at a rate of 30 breaths per minute (one group with 100% O₂, another with 95% O₂ and 5% CO₂) ($P < 0.001$). Swine with higher intrathoracic pressure caused by excessive ventilation rate and duration had significantly lower coronary perfusion pressure and survival rates [6]. These findings were not confirmed by Milander *et al.* [17]. Perhaps this is due to the different methods of compressions and ventilation (Milander—manual; Aufderheide—mechanical) [6]. Nevertheless, Aufderheide's editorial 'Death by Hyperventilation' has spawned widespread discussion and investigational work related to the interplay between ventilation, coronary perfusion pressure, cerebral perfusion pressure, and survival [7].

Although there is no question that some ventilation occurs by chest compressions alone, the exact tidal

volume and significance of air movement without active ventilation continues to be debated [18,19].

Gasping

We have recently reported the frequency and significance of gasping in patients with OHCA using two methodologies [20]. The first was a retrospective analysis of 113 consecutive OHCA cases from the Phoenix Fire Department Regional Dispatch Center to determine the presence of gasping soon after collapse. The second was a retrospective analysis of 1218 patients with OHCA in Arizona documented by EMS first care reports to determine the incidence of gasping after arrest in relation to the EMS response intervals. The primary outcome measure was survival to hospital discharge. An analysis of witnessed and unwitnessed OHCA with attempted resuscitation found that 44/113 (39%) of all arrested patients had gasping. A high incidence of gasping in victims of OHCA (55%) has also been reported by Clark *et al.* [21].

Our analysis of 1218 witnessed OHCA demonstrated that the presence or absence of gasping correlated with EMS response interval. Gasping was present in 33% of patients (39/119) who arrested after EMS arrival, in 20% (73/363) when response interval was less than 7 min, in 14% (50/360) when response interval was 7–9 min and in only 7% (25/338) when EMS response interval was more than 9 min. Survival to hospital discharge occurred in 28% (54/191) of patients who gasped compared with only 8% (80/1027) among those who did not (adjusted OR 3.4, 95% CI 2.2–5.2) [20].

We also found that, among the 481 patients who received bystander CPR, survival occurred in 39% (30/77) of patients who gasped compared with only 9% (38/404) among those who did not (adjusted OR 5.1, 95% CI 2.7–9.4) [20]. Thus, gasping is common following OHCA but decreases rapidly with time. Gasping likely represents marginal cerebral blood flow that is subnormal, but is still enough to be associated with increased survival. These results suggest that the recognition of gasping should be taught to: bystanders (so that CPR is initiated in patients with some, but inadequate, cerebral blood flow); Emergency Medical Dispatchers (so as not to dissuade them from initiating prompt resuscitation instructions when appropriate); and EMS and hospital personnel (as an indication that their resuscitation efforts are being at least partially effective and should be continued).

'Real life' cardiopulmonary resuscitation

The quality of CPR delivered by trained medical professionals has a significant impact on survival [22]. Due to many factors, the quality of CPR provided by medical

professionals is inconsistent [23]. In addition, inadvertent hyperventilation may be contributing to the generally dismal survival rates from OHCA. Aufderheide *et al.* [7,11] demonstrated this in a two-part clinical observational study aimed at determining: the incidence of hyperventilation during out-of-hospital CPR with the objective of quantifying the degree of excessive ventilation in humans; and whether comparable excessive ventilation rates during CPR in animals significantly decreased coronary perfusion pressure and survival. They found that ventilation rates in OHCA victims averaged 37 breaths per minute (range, 19–49) – twice what the 2000 AHA Guidelines recommended at the time of the study. Interestingly, the same ventilation rate (37 per minute) was observed by Milander *et al.* [17] for in-hospital cardiac resuscitation. In Aufderheide's study, even after focused retraining, medical providers ventilated at 22 breaths per minute (range, 15–31) [6]. These studies identify that even additional, focused training to avoid hyperventilation may not be effective and other strategies may be necessary. There appears to be a significant difference between CPR performance by medical providers in the classroom and performance during an actual cardiac arrest.

When CPR is provided by a single rescuer, interrupting chest compressions may be even more problematic if assisted ventilation is provided. With each cessation of chest compressions, coronary and cerebral perfusion pressures decrease, requiring additional time to restore blood flow [24].

Rationale for assisted ventilation

Due to the eventual development of hypoxemia, hypercarbia, and acidosis, some form of assisted ventilation is required in prolonged cardiac arrest. The precise timing of when assisted ventilation is required is unknown.

Lurie and associates have suggested that assisted ventilation, with an impedance threshold device (ITD), would provide better hemodynamics and may improve outcome [25,26]. The ITD is a small, 35-ml device that can be attached to any airway [e.g. facemask, Combitube (Tyco-Kendall, Mansfield, Massachusetts, USA), King LT (King Systems Corporation, Noblesville, Indiana, USA) or endotracheal tube]. Each time the chest recoils during CPR there is a decrease in intrathoracic pressure. The ITD transiently blocks air from entering the lungs during recoil and enhances this pressure decrease. This not only facilitates venous return to the chest but also decreases intracranial pressure. Thus, blood flow to both the heart and brain is increased on each subsequent chest compression. Although the ITD appears to improve hemodynamics in the laboratory, it requires additional costs and training to EMS providers and adds complexity

to a resuscitation effort. Therefore, other solutions have been developed. One of these solutions will be described in detail below and entails removing assisted ventilation completely during the first several minutes of 'Cardiocerebral' Resuscitation.

The role of assisted ventilation in the treatment of OHCA patients is complex and many questions remain in the literature. The key question is whether ventilation, when added to chest compressions, improves survival. For layperson CPR, we do not believe the evidence justifies the addition of ventilation for adult OHCA [27]. For treatment by EMS providers, the current state of the human clinical literature does not support any strong recommendation. However, we believe that assisted ventilation should be provided for victims of OHCA with prolonged downtime as well as arrests caused by drowning, drug overdose, asthma, or similar conditions that are respiratory in origin [2]. We believe that EMS providers can be trained to discriminate respiratory arrests from cardiac arrests and gauge the need for assisted ventilation.

Rationale for passive oxygen insufflation

Animal data indicate that chest compressions without assisted ventilation are at least as effective as chest compressions plus assisted ventilation for the initial treatment of ventricular fibrillation [18,28]. Animal studies have established that interruption of chest compressions is lethal in models of prolonged ventricular fibrillation [24,29].

The physiological penalty of assisted ventilation with its frequently incorrect rate and duration is a persistently positive intrathoracic pressure throughout the decompression phase of CPR. This decreases cardiac preload, cardiac output, and hinders right ventricular function [30–32].

In addition, there is debate whether ventilation early in OHCA is of any benefit at all, even if done 'correctly.' In adults with primary cardiac arrest, arterial blood oxygenation is almost always normal at the time of the arrest and the lungs have a reservoir of oxygen available for the blood that flows through the pulmonary circulation during CPR [24,33]. Thus, any interruption or decrease of blood flow is overwhelmingly negative compared with any potential benefit of additional oxygen availability in the lungs.

Cardiocerebral resuscitation

With a focus on minimizing interruptions to chest compressions and avoiding hyperventilation, prehospital providers in Arizona and Wisconsin implemented a

resuscitation protocol termed ‘Cardiocerebral Resuscitation’ (CCR) in 2004. This protocol was developed and named to stress the specific goal of resuscitating the heart and brain [24,34]. The CCR approach to ventilation was based, in part, on observations by Steen *et al.* [35]. They demonstrated that passive oxygen insufflation via an endotracheal tube during a swine model of ventricular fibrillation arrest provided adequate oxygenation. Another goal of CCR is to minimize the chest compression interruptions and pulmonary overinflation that reliably accompany prehospital endotracheal intubation.

The CCR protocol initially introduced to EMS systems in Arizona included emergency medical dispatch-directed instructions for continuous chest compressions without rescue breathing by bystanders. EMS providers who did not witness the event were trained to: initiate resuscitation with 200 immediate, uninterrupted, deep chest compressions (1 1/2" - 2" depth) at a rate of 100 compressions per minute; analyze the cardiac rhythm and deliver a single defibrillator shock when indicated; perform 200 immediate postshock chest compressions before any pulse check or rhythm reanalysis; administer epinephrine (1 mg) via intravenous or intraosseous route as soon as possible (without interrupting chest compressions) and repeat with each cycle of chest compressions and rhythm reanalysis; delay endotracheal intubation until after three cycles of chest compressions and rhythm reanalyses were completed [36•] (Fig. 2).

Early and excessive ventilation was discouraged by advocating for passive oxygen insufflation. This was accomplished by placement of an oropharyngeal airway and a nonrebreather facemask with high flow oxygen. However, because of EMS providers’ resistance to excluding assisted ventilation in Arizona, bag-mask ventilation was

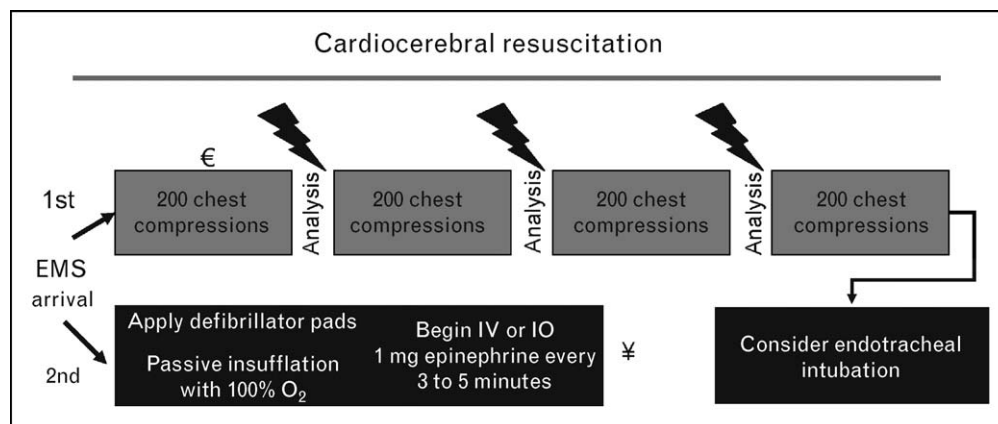
permitted as an alternative to passive oxygen insufflation, with a recommended ventilation rate of eight per minute and a tidal volume of 500 ml per breath. The method of ventilation was thus left to the discretion of each EMS provider [36•].

In a before-and-after analysis of 886 patients in two large metropolitan cities in Arizona, survival to hospital discharge increased from 1.8% (4/218) before CCR training to 5.4% (36/668) after CCR training [odds ratio (OR), 3.0; 95% confidence interval (CI), 1.1–8.9]. In the subgroup of 174 patients with witnessed ventricular fibrillation, survival increased from 4.7% (2/43) before CCR training to 17.6% (23/131) after CCR training (OR, 8.6; 95% CI, 1.8–42.0) [36•].

In an analysis of CCR protocol compliance involving 2460 patients with OHCA from Arizona, survival was significantly better among patients who received CCR 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] [36•].

In 2004, CCR was initiated in Rock and Walworth counties, Wisconsin, as an alternative to the 2000 Guidelines. This was specifically for the treatment of OHCA with a witnessed collapse and an initial rhythm of ventricular fibrillation. Patients with a nonshockable rhythm received an advanced airway and assisted ventilation [3]. Using historic controls during 2001–2003 when patients were receiving 2000 AHA Guidelines for reference, Kellum reported 92 witnessed arrests with an initially shockable rhythm. Eighteen patients survived (20%) and 14 (15%) were neurologically intact. During the 3 years after implementation of CCR, there were 89 such

Figure 2 Cardiocerebral resuscitation



€, If adequate bystander chest compressions are provided; perform immediate rhythm analysis and shock if indicated; ¥, Once these tasks are done, relieve 1st EMS and perform chest compressions; ⚡, single shock if indicated followed immediately chest compressions at 100/min without pulse check nor rhythm analysis.

patients: 42 (47%) survived and 35 (39%) were neurologically intact [4*].

Outcome for passive oxygen insufflation

In Arizona, the subgroup analysis of CCR-treated, neurologically intact survivors receiving passive oxygen insufflation is very similar to that found by Kellum *et al.* in Wisconsin [5] (Bobrow BJ, in preparation). Patients with a nonshockable rhythm, however, may be less likely to survive with passive oxygen insufflation than assisted ventilation [5] (Bobrow BJ, in preparation).

Is assisted ventilation needed for patients with nonwitnessed ventricular fibrillation or a nonshockable presenting rhythm? Although still unproven by randomized controlled trials, there is some evidence that the answer is yes. However, there is concern that creating additional complexity for providers may decrease the benefit for the subgroup of patients with a witnessed collapse and a shockable rhythm, and perhaps for all subgroups. This question revolves, in part, around the key issue of efficacy vs. effectiveness. Medical therapies that are 'efficacious' when studied in a controlled environment are often less 'effective' when applied in general practice (the 'real world') [37,38]. Also, cardiac arrests are relatively rare events; so optimal resuscitation is probably more likely when the approach to resuscitation is simple. Adding complexity to an already stressful, challenging, and relatively uncommon clinical scenario may be detrimental to overall patient survival. Statewide survival from OHCA in Arizona has improved remarkably since the institution of CCR [36*,39]. Despite this significant improvement, recent findings raise the question whether creating an additional decision point to treat patients with a shockable rhythm with passive oxygen insufflation and those with a nonshockable rhythm with assisted ventilation may increase overall survival. Further study in multiple systems is required before this question will be answered with a high degree of confidence.

Conclusion

Prehospital studies of ventilation for out-of hospital primary cardiac arrest suggest that assisted ventilation is not essential in the initial phase of witnessed ventricular fibrillation resuscitation and may be detrimental. This is especially true for individuals gasping before or after the initiation of chest compressions. Furthermore, in nonrandomized clinical trials, the survival rates for adults with witnessed ventricular fibrillation who receive passive oxygen insufflation are higher than historic and concurrent controls who received assisted ventilation. However, survival among patients with nonshockable rhythms, although very low, may be better when some assisted ventilation is provided. How to best integrate

these concepts into clinical practice to optimize overall survival rates is a challenge that requires future investigation.

Acknowledgements

The authors would like to thank P.R.B., MA, Arizona Department of Health Services Bureau of Emergency Medical Services and Trauma System, for her assistance in the preparation of this manuscript.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 270).

- 1 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation* 2005; 112:IV1-203.
- 2 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care: Part 7.1: Adjuncts for Airway Control and Ventilation. *Circulation* 2005; 112:IV-51-IV-7.
- 3 Kellum MJ, Kennedy KW, Ewy GA. Cardiocerebral resuscitation improves survival of patients with out-of-hospital cardiac arrest. *Am J Med* 2006; 119:335-340.
- 4 Kellum MJ, Kennedy KW, Barney R, *et al.* Cardiocerebral resuscitation improves neurologically intact survival of patients with out-of-hospital cardiac arrest. *Ann Emerg Med* 2008; 52:244-252.
- Demonstrated three-fold improvement for OHCA victims with witnessed ventricular fibrillation treated with passive oxygen insufflation.
- 5 Vadeboncoeur TF, Bobrow BJ, Clark L, *et al.* Abstract 3: The survival rate from out-of-hospital cardiac arrest is superior with passive oxygen insufflation compared to active assisted ventilation. *Circulation* 2007; 116 (16_Meeting-Abstracts):II_923-b.
- 6 Aufderheide TP, Sigurdsson G, Pirralo RG, *et al.* Hyperventilation-induced hypotension during cardiopulmonary resuscitation. *Circulation* 2004; 109:1960-1965.
- 7 Aufderheide TP, Lurie KG. Death by hyperventilation: a common and life-threatening problem during cardiopulmonary resuscitation. *Crit Care Med* 2004; 32 (9 Suppl):S345-S351.
- 8 Heidenreich JW, Higdon TA, Kern KB, *et al.* Single-rescuer cardiopulmonary resuscitation: 'two quick breaths'—an oxymoron. *Resuscitation* 2004; 62:283-289.
- 9 Yannopoulos D, Tang W, Roussos C, *et al.* Reducing ventilation frequency during cardiopulmonary resuscitation in a porcine model of cardiac arrest. *Respir Care* 2005; 50:628-635.
- 10 Lurie KG, Zielinski T, McKnite S, *et al.* Use of an inspiratory impedance valve improves neurologically intact survival in a porcine model of ventricular fibrillation. *Circulation* 2002; 105:124-129.
- 11 Aufderheide TP, Pirralo RG, Provo TA, Lurie KG. Clinical evaluation of an inspiratory impedance threshold device during standard cardiopulmonary resuscitation in patients with out-of-hospital cardiac arrest. *Crit Care Med* 2005; 33:734-740.
- 12 Pirralo RG, Aufderheide TP, Provo TA, Lurie KG. Effect of an inspiratory impedance threshold device on hemodynamics during conventional manual cardiopulmonary resuscitation. *Resuscitation* 2005; 66:13-20.
- 13 Pepe PE, Raedler C, Lurie KG, Wigginton JG. Emergency ventilatory management in hemorrhagic states: elemental or detrimental? *J Trauma* 2003; 54:1048-1055; discussion 55-57.
- 14 Guerci AD, Shi AY, Levin H, *et al.* Transmission of intrathoracic pressure to the intracranial space during cardiopulmonary resuscitation in dogs. *Circ Res* 1985; 56:20-30.
- 15 Ludwig HC, Klingler M, Timmermann A, *et al.* The influence of airway pressure changes on intracranial pressure (ICP) and the blood flow velocity in the middle cerebral artery (VMCA). *Anesthesiol Intensivmed Notfallmed Schmerzther* 2000; 35:141-145.
- 16 Colomina MJ, Godet C, Pellise F, *et al.* Transcranial Doppler monitoring during laparoscopic anterior lumbar interbody fusion. *Anesth Analg* 2003; 97:1675-1679.

- 17** Milander MM, Hiscok PS, Sanders AB, *et al.* Chest compression and ventilation rates during cardiopulmonary resuscitation: the effects of audible tone guidance. *Acad Emerg Med* 1995; 2:708–713.
- 18** Idris AH, Becker LB, Fuerst RS, *et al.* Effect of ventilation on resuscitation in an animal model of cardiac arrest. *Circulation* 1994; 90:3063–3069.
- 19** Deakin CD, O'Neill JF, Tabor T. Does compression-only cardiopulmonary resuscitation generate adequate passive ventilation during cardiac arrest? *Resuscitation* 2007; 75:53–59.
- 20** Bobrow BJ, Zuercher M, Ewy GA, *et al.* Gasping during cardiac arrest in humans is frequent and associated with improved survival. *Circulation* 2008; 118:2550–2554.
- 21** Clark JJ, Larsen MP, Culley LL, *et al.* Incidence of agonal respirations in sudden cardiac arrest. *Ann Emerg Med* 1992; 21:1464–1467.
- 22** Rea TD, Helbock M, Perry S, *et al.* Increasing use of cardiopulmonary resuscitation during out-of-hospital ventricular fibrillation arrest: survival implications of guideline changes. *Circulation* 2006; 114:2760–2765.
- 23** Wik L, Kramer-Johansen J, Myklebust H, *et al.* Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. *JAMA* 2005; 293:299–304.
- 24** Ewy GA. Cardiocerebral resuscitation: the new cardiopulmonary resuscitation. *Circulation* 2005; 111:2134–2142.
- 25** Lurie KG, Voelckel WG, Zielinski T, *et al.* Improving standard cardiopulmonary resuscitation with an inspiratory impedance threshold valve in a porcine model of cardiac arrest. *Anesth Analg* 2001; 93:649–655.
- 26** Langhelle A, Stromme T, Sunde K, *et al.* Inspiratory impedance threshold valve during CPR. *Resuscitation* 2002; 52:39–48.
- 27** Cardiopulmonary resuscitation by bystanders with chest compression only (SOS-KANTO): an observational study. *Lancet* 2007; 369:920–926.
- 28** Berg RA, Sanders AB, Kern KB, *et al.* Adverse hemodynamic effects of interrupting chest compressions for rescue breathing during cardiopulmonary resuscitation for ventricular fibrillation cardiac arrest. *Circulation* 2001; 104:2465–2470.
- 29** Yu T, Weil MH, Tang W, *et al.* Adverse outcomes of interrupted precordial compression during automated defibrillation. *Circulation* 2002; 106:368–372.
- 30** Cournand A, Motley HL, *et al.* Physiological studies of the effects of intermittent positive pressure breathing on cardiac output in man. *Am J Physiol* 1948; 152:162–174.
- 31** Cheifetz IM, Craig DM, Quick G, *et al.* Increasing tidal volumes and pulmonary overdistention adversely affect pulmonary vascular mechanics and cardiac output in a pediatric swine model. *Crit Care Med* 1998; 26:710–716.
- 32** Theres H, Binkau J, Laule M, *et al.* Phase-related changes in right ventricular cardiac output under volume-controlled mechanical ventilation with positive end-expiratory pressure. *Crit Care Med* 1999; 27:953–958.
- 33** Meursing BT, Wulterkens DW, van Kesteren RG. The ABC of resuscitation and the Dutch (re) treat. *Resuscitation* 2005; 64:279–286.
- 34** Kern KB, Valenzuela TD, Clark LL, *et al.* An alternative approach to advancing resuscitation science. *Resuscitation* 2005; 64:261–268.
- 35** Steen S, Liao Q, Pierre L, *et al.* Continuous intratracheal insufflation of oxygen improves the efficacy of mechanical chest compression-active decompression CPR. *Resuscitation* 2004; 62:219–227.
- 36** Bobrow BJ, Clark LL, Ewy GA, *et al.* Minimally interrupted cardiac resuscitation by emergency medical services for out-of-hospital cardiac arrest. *JAMA* 2008; 299:1158–1165.
- Showed significant system-wide improvement in OHCA survival with training emergency medical services providers to minimize interruptions to chest compressions for ventilations.
- 37** Westfall JM, Mold J, Fagnan L. Practice-based research—'Blue Highways' on the NIH roadmap. *JAMA* 2007; 297:403–406.
- 38** Brooks SC, Morrison LJ. Implementation of therapeutic hypothermia guidelines for postcardiac arrest syndrome at a glacial pace: seeking guidance from the knowledge translation literature. *Resuscitation* 2008; 77:286–292.
- 39** Bobrow BJ, Vadeboncoeur TF, Clark L, Chikani V. Establishing Arizona's statewide cardiac arrest reporting and educational network. *Prehosp Emerg Care* 2008; 12:381–387.