Improving the efficiency of cardiopulmonary resuscitation with an inspiratory impedance threshold valve

Keith Lurie, MD; Todd Zielinski, MS; Scott McKnite, BS; Pamela Sukhum, BA

In an effort to improve the efficiency of cardiopulmonary resuscitation (CPR), a new inspiratory impedance threshold valve has been developed to enhance the return of blood to the thorax during the chest decompression phase. This new device enhances negative intrathoracic pressure during chest wall recoil or the decompression phase, leading to improved vital organ perfusion during both standard CPR and active compression-decompression CPR. With active compression-decompression CPR, addition of the impedance threshold valve results in sustained diastolic pressures of >55 mm Hg in patients in cardiac arrest. The new valve shows promise for patients in asystole or shock refractory ventricular fibrillation, when enhanced return of blood flow to the chest is needed to "prime the pump." The potential long-term benefits of this new valve remain under study. (Crit Care Med 2000; 28[Suppl.]:N207–N209)

KEY WORDS: standard cardiopulmonary resuscitation; active compression-decompression cardiopulmonary resuscitation; cardiopulmonary resuscitation; inspiratory impedance threshold valve; vital organ perfusion; coronary perfusion pressure; intrathoracic pressure; diastolic pressure; asystole; ventricular fibrillation

Several new mechanical devices have been developed in recent years to improve the currently poor outcomes for patients in cardiac arrest (1, 2). One new technique, active compression-decompression (ACD) cardiopulmonary resuscitation (CPR), uses a suction device to compress and decompress the chest (1–5). ACD CPR enhances blood return to the thorax by decreasing intrathoracic pressure during the decompression phase of CPR. Studies evaluating intrathoracic pressures during ACD CPR led to the recognition that occlusion of the airway during the chest wall decompression phase resulted in an additional decrease in negative intrathoracic pressure and more blood return to the chest (6). Based on this mechanism, a small inspiratory impedance valve (Fig. 1) was developed to occlude the airway selectively during the decompression phase of CPR, without resistance to exhalation or active ventilation (1, 2, 7–9). The impedance threshold valve (ITV) is inserted into any standard respiratory circuit and can be used with standard CPR, ACD CPR, and other methods of CPR including the following: vest CPR, interposed abdominal counterpulsation CPR, and phased thoracic-abdominal compression-decompression CPR. The ITV has been shown to significantly increase vital organ blood flow when used with either standard CPR or ACD CPR in a porcine model of ventricular fibrillation (7–9) and to decrease defibrillation energy thresholds when used together with ACD CPR (7). In patients undergoing ACD CPR, use of the inspiratory valve group significantly increased end-tidal CO_2, systolic, diastolic, and coronary perfusion pressures compared with patients treated with ACD CPR alone (9).

Mechanisms of Action

Decreases in negative intrathoracic pressure during the decompression phase of CPR enhance both ventilation and return of venous and arterial blood into the thorax. This important mechanism has been studied rigorously (1–10). During CPR the chest functions like a bellows. The recoil of the chest during the decompression phase of standard CPR is the principal driving force behind the return of blood to the thorax. With standard CPR, the decrease in negative intrathoracic pressure generated by chest wall recoil provides for only marginal levels of blood return. As a result, over time forward blood flow out of the chest decreases secondary to decreasing venous return of blood to the chest.

The effects of inspiration while maintaining a closed glottis in patients who are awake is called the Mueller maneuver (11). With this maneuver, inspiratory effort results in a marked decrease in intrathoracic pressure and there is an increase in venous blood return to the chest. During cardiac arrest, chest wall recoil during CPR decreases intrathoracic pressure. By occluding the airway selectively during the chest wall decompression phase with the ITV, intrathoracic pressures decrease further, as in the Mueller maneuver, and more blood flows back into the thorax. With the next chest compression phase, stroke volume is increased. Consequently, the ITV harnesses the kinetic energy associated with the chest wall recoil, thereby increasing the overall efficiency of CPR.

Description of the ITV

The ITV was designed to prevent inspiratory gas exchange only when intrathoracic pressures are less than atmospheric pressure. As soon as the chest wall recoils after a chest compression, the silicone diaphragm occludes the lumen within the valve (ResQ-Valve; CPRx LLC,

From the Cardiac Arrhythmia Center, Cardiovascular Division, University of Minnesota (Mr. Zielinski and McKnite and Ms. Sukhum), and CPRx LLC (Dr. Lurie), Minneapolis, MN.

Presented, in part, at the Wolf Creek V Conference, September 1999, Rancho Mirage, CA.

Address requests for reprints to: Keith G. Lurie, MD, CPRx LLC, 4330 Upton Avenue South, Minneapolis, MN 55410. E-mail: lurie@newcpr.com

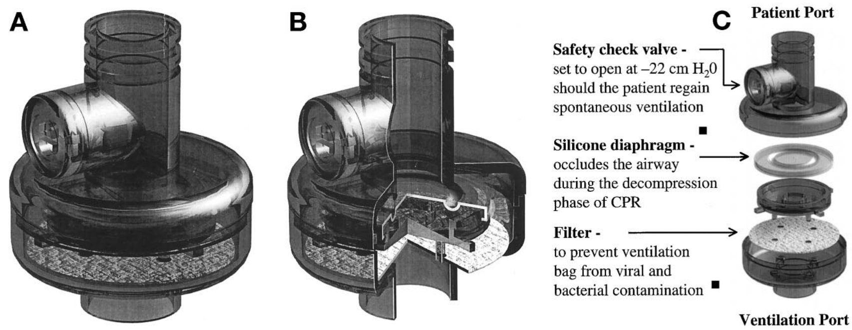

Figure 1. The inspiratory impedance threshold valve (ResQ-Valve, CPRx LLC, Minneapolis, MN) functions by occluding the airway during the decompression phase of cardiopulmonary resuscitation (*CPR*). The small valve is easily inserted into any standard respiratory circuit between the ventilation bag and endotracheal tube, face mask, Combitube, or laryngeal mask airway. The valve (*A*) and cut-away views (*B* and *C*) are shown.

Use of the impedance threshold valve during cardiopulmonary resuscitation optimizes the bellows-like action ofthe chest.

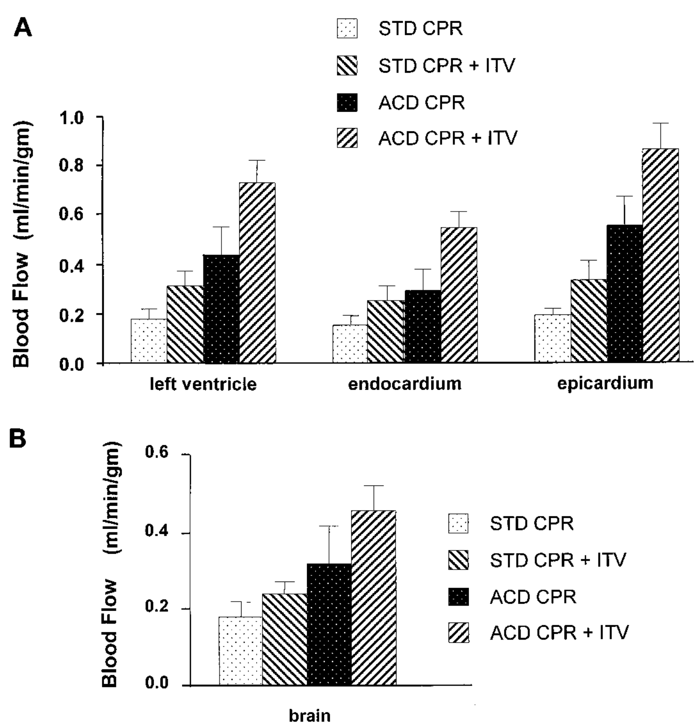

Figure 2. Blood flow during performance of cardiopulmonary resuscitation (*CPR*) in a porcine model of ventricular fibrillation is illustrated. Both left ventricular, epicardial, endocardial blood flow (*A*) and brain blood flow (*B*), measured using radiolabeled microspheres, increased with the addition of the impedance threshold valve (*ITV*) with standard CPR (*STD*) and when the ITV was used during active compression-decompression (*ACD*) CPR (2, 7, 8).

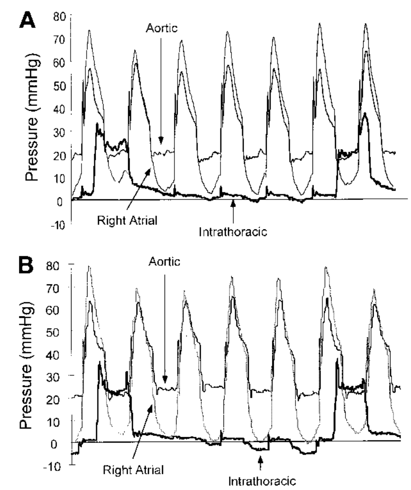

Figure 3. *A*, a representative series of pressure tracings demonstrating simultaneous measurement of intrathoracic, right atrial, and left ventricular pressures after 6 mins of ventricular fibrillation and 12 mins of standard cardiopulmonary resuscitation (CPR) in a pig model of cardiac arrest are shown. *B*, standard CPR alone (*A*) was compared with standard CPR with the impedance threshold valve (ITV) (*B*). The progressive decrease in intrathoracic pressure, measured in the trachea, can be observed after each ventilation when the ITV is used.

Minneapolis, MN), thereby preventing all inspiratory gas exchange. During rescuer ventilation, the lumen within the ITV remains open and there is no resistance to ventilation. Similarly, during the chest compression phase, there is no resistance to expiratory gas exchange. The ITV is equipped with a safety check valve that will open at a set cracking pressure should the patient regain spontaneous respiration. The valve also contains a bacteria-static filter to prevent transmission of disease. The impedance valve is designed to fit between a standard ventilation bag and an endotracheal tube, a face mask, a laryngeal mask airway, Combitube, or other airway assist device. When it is used in combination with a face mask, the ITV functions well and the seal is adequate.

Animal Studies

The first investigation on the concept of inspiratory impedance during ACD CPR was performed in a porcine model of ventricular fibrillation. The addition of an inspiratory impedance valve resulted in a marked enhancement of vital organ perfusion (Fig. 2) and a decrease in the total energy required for effective defibrillation (7). In studies with standard CPR, the benefit was similar (8). Figure 3 demonstrates the changes in intrathoracic (measurements obtained in the trachea), right atrial, and aortic pressures in a pig model of cardiac arrest. Intrathoracic pressures were lower and the coronary perfusion pressures (diastolic aortic minus right atrial pressures) were higher with the ITV.

Clinical Studies

The ITV was studied in patients in cardiac arrest during ACD CPR (9). In a

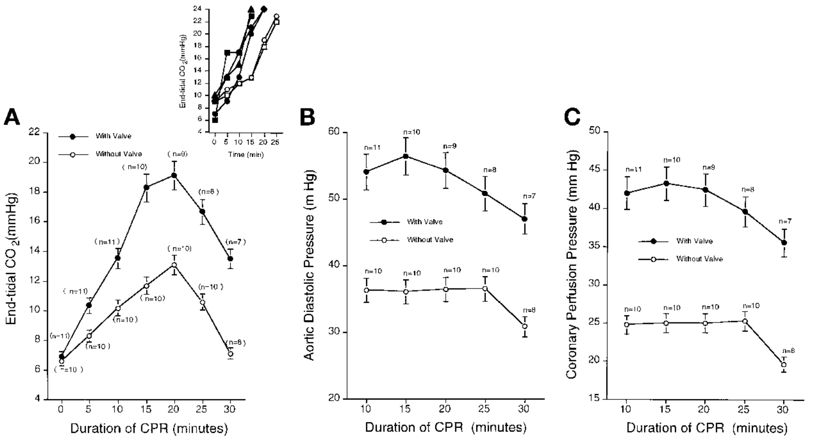

Figure 4. *A*, end-tidal CO_2 ($ETCO_2$) levels for patients receiving active compression-decompression (ACD) cardiopulmonary resuscitation (*CPR*) plus impedance threshold valve (ITV) vs. ACD CPR alone (*open circles*) are compared. Within minutes after intubation (T = 0), there was a significantly greater increase and more rapid rise in peak $ETCO_2$ levels in the ACD CPR plus valve group when compared to ACD CPR alone ($p < .001$ for peak values). *Numbers* in *parentheses* reflect the number of patients still in cardiac arrest at each time point. *Inset graph* shows data from each individual patient who survived in each group (*filled symbols* represent ACD + valve; *open symbols* represent ACD alone) (9). *B*, diastolic blood pressures in patients with out-of-hospital cardiac arrest receiving ACD CPR alone vs. ACD CPR plus the valve (ITV) are illustrated. Patients underwent endotracheal intubation at T = 0 mins. The differences between diastolic pressures were highly statistically significant ($p < .01$) between groups (9). *C*, coronary perfusion pressures (diastolic aortic minus right atrial) are shown in the same patient population.

blinded, randomized, prospective study, a total of 21 patients in out-of-hospital cardiac arrest were studied. Ten patients received ACD CPR during advanced life support with a sham ITV (the silicone diaphragm was removed), and 11 patients received ACD CPR plus the ITV. All had asystole when the mobile intensive care unit arrived at the scene and the study was performed. The end-tidal CO_2 values were similar at the time of intubation (T = 0). With ACD CPR plus the ITV, end-tidal CO_2 rose more rapidly and to a higher value than those patients who received ACD CPR alone (Fig. 4*A*). Four of 11 patients in the valve group had a spontaneous return of circulation after a mean time of 19.8 ± 2.8 mins vs. two of ten patients in the ACD group alone (with a mean time of 26.5 ± 0.7 mins of CPR ($p < .05$) for time from initiation of advanced life support CPR to return of spontaneous circulation (Fig. 4A, *insert*). The mean peak systolic blood pressure in patients who received ACD CPR plus an active valve was 108 ± 3.1 mm Hg vs. 90 ± 6.4 mm Hg in the ACD CPR alone group ($p < .05$). More striking, however, were the differences in diastolic blood pressure, mean arterial pressure, and coronary perfusion pressure. Diastolic blood pressures in patients who received ACD CPR plus the ITV were >55 mm Hg, and coronary perfusion pressures in that same group were >35 mm of Hg ($p < .05$) (Fig. 4, *B* and *C*). Diastolic blood pressures and coronary perfusion pressures of this magnitude have not previously been reported in patients in cardiac arrest (9).

CONCLUSIONS

These new observations support the hypothesis that use of the ITV during CPR optimizes the bellows-like action of the chest. The hemodynamic benefits of the ITV during ACD CPR are striking in animals and in patients. At present, we still lack data in patients regarding the potential benefits of the ITV with standard CPR alone. Additional studies are under way to evaluate the potential long-term benefit of the ITV with both standard and ACD CPR.

REFERENCES

1. Lurie KL, Sukhum P, Voelckel W, et al: Recent advances in mechanical CPR devices. *Curr Opin Crit Care* 1999; 5:184–192
2. Lurie KG, Lindner KH: Recent advances in cardiopulmonary resuscitation. *J Cardiovasc Electrophysiol* 1997; 8:584–600
3. Cohen TJ, Tucker KL, Lurie KG, et al: Active compression-decompression: A new method of cardiopulmonary resuscitation. *JAMA* 1992; 267:2916–2923
4. Lurie KG: Active compression-decompression CPR: A progress report. *Resuscitation* 1994; 28:115–122
5. Plaisance P, Adnet F, Vicaut E, et al: Benefit of active compression-decompression cardiopulmonary resuscitation as a prehospital advanced cardiac life support: A randomized multicenter study. *Circulation* 1997; 95: 955–961
6. Shultz JJ, Coffeen P, Sweeney M, et al: Evaluation of standard and active compression-decompression CPR in an acute human model of ventricular fibrillation. *Circulation* 1994; 89:684–693
7. Lurie KG, Coffeen PR, Shultz JJ, et al: Improving active compression-decompression cardiopulmonary resuscitation with an inspiratory impedance valve. *Circulation* 1995; 91:1629–1632
8. Lurie KG, Mulligan K, McKnite S, et al: Optimizing standard cardiopulmonary resuscitation with an inspiratory threshold valve. *Chest* 1998; 113:1084–1090
9. Plaisance P, Lurie K, Payen D: Inspiratory impedance during active compression decompression cardiopulmonary resuscitation: A randomized evaluation in patients in cardiac arrest. *Circulation* 2000; 101:989–994
10. Lindner K, Pfenninger E, Lurie KG, et al: Effects of active compression-decompression resuscitation on myocardial and cerebral blood flow in pigs. *Circulation* 1993; 88: 1254–1263
11. Berne RM, Levy MN: *Cardiovascular Physiology.* Second Edition. St. Louis, CV Mosby, 1997, p 216