Emergency Ventilatory Management in Hemorrhagic States: Elemental or Detrimental?

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Background: A study was performed to demonstrate that slower respiratory rates (RRs) of positive-pressure ventilation can preserve adequate oxygenation and acid-base status in hemorrhagic states, whereas “normal” or higher RRs worsen hemodynamics.

Methods: Eight swine (ventilated with 12 mL/kg tidal volume, 0.28 Fio2; RR of 12 breaths/min) were hemorrhaged to < 65 mm Hg systolic arterial blood pressure (SABP). RRs were then sequentially changed every 10 minutes to 6, 20, 30, and 6 breaths/min.

Results: With RRs at 6 breaths/min, the animals maintained pH > 7.25/Sao2 > 99%, but increased mean SABP (from 65 to 84 mm Hg; p < 0.05), time-averaged coronary perfusion pressure (CPP) (from 50 ± 2 to 60 ± 4 mm Hg; p < 0.05), and cardiac output (Qt) (from 2.4 to 2.8 L/min; p < 0.05). With RRs of 20 and 30 breaths/min, SABP (73 and 66 mm Hg), CPP (47 ± 3 and 42 ± 4 mm Hg), and Qt (2.5 and 2.4 L/min) decreased, as did PaO2 and Paco2 (< 30 mm Hg), with p < 0.05 for each comparison, respectively. When RR returned to 6 breaths/min, SABP (95 mm Hg), CPP (71 ± 6 mm Hg), and Qt (3.0 L/min) improved significantly (p < 0.05).

Conclusion: After even moderate levels of hemorrhage in animals, positive-pressure ventilation with “normal” or higher RRs can impair hemodynamics. Hemodynamics can be improved with lower RRs while still maintaining adequate oxygenation and ventilation.

Key Words: Hemorrhage, Shock, Hypovolemia, Hemorrhagic shock, Ventilation, Positive-pressure ventilation, Hemodynamics, Mechanical ventilation, Auto-positive end-expiratory pressure, Preload, Venous return, Coronary perfusion pressure, Respiratory support, Resuscitation, Cardiac arrest.

The potential detrimental effects of positive-pressure ventilation (PPV) on hemodynamics have been well known ever since the seminal description by Cournand et al. more than a half century ago. In contrast to spontaneous ventilation, which decreases intrathoracic pressure and enhances venous return into the right atrium (cardiac preload), PPV increases intrathoracic pressure, thus diminishing venous return. In addition to diminished preload, PPV may also increase pulmonary vascular resistance to some degree and may also have a direct external compression on the heart. Nevertheless, the major mechanism of cardiac output impairment is diminished preload, and the effects are most pronounced in hypovolemic states.

Most clinicians are quite familiar with this concept in terms of the application of positive end-expiratory pressure (PEEP) or in terms of the auto-PEEP phenomenon that can occur during mechanical ventilation with PPV. In both of these conditions, and particularly when using ventilatory techniques that exclude spontaneous breaths, intrathoracic pressures can remain high throughout the respiratory cycle and can severely impair cardiac output. Although low levels of PEEP (5–10 cm H2O) have no clinically apparent effects in normovolemic patients, even these low levels of PEEP can be detrimental when there is preexisting diminished preload caused by hypovolemia.

Similarly, intermittent PPV can be detrimental to cardiac output. The diminished cardiac output effects of PPV with PEEP last throughout the respiratory cycle and thus, generally, can be much more pronounced. However, the negative hemodynamic effects of intermittent PPV can also be quite significant in the face of hypovolemia, and such exacerbating effects of PPV can be difficult to distinguish when severe circulatory compromise already exists. Particularly in the early phases of resuscitation when more sophisticated hemodynamic monitoring is not as available or even feasible, the possible detrimental effects of respiratory techniques on hemodynamic compromise may elude even the most discerning clinician.

Fortunately, in most cases of major trauma, there is no need for active ventilatory assistance in the prehospital setting, either with endotracheal tubes or bag-valve-mask devices. However, many of the patients who do receive prehospital intubation and intermittent PPV are those most likely to be at risk for hemodynamic compromise, such as the exsanguinating patient or those with tense pericardial tam-
ponade or severe tension pneumothorax.\textsuperscript{16–20} Such patients with underlying severe circulatory compromise may be moribund or, at best, in severe shock states.\textsuperscript{19,20}

Traditionally, paramedics have been taught to provide endotracheal intubation and PPV (on-scene or en route) for such patients for “airway protection,” to “pump in more oxygen” (or some other colloquial training phrase), and to provide compensatory hyperventilation for the evolving state of systemic lactate acidosis secondary to “anaerobic metabolism.”\textsuperscript{18,21,22} Likewise, many patients with severe head injury traditionally have received intubation and PPV for airway protection, enhanced oxygenation, and “therapeutic hyperventilation.”\textsuperscript{17,23,24}

Even with recent precautions against overzealous hyperventilation for head injury (relevant to the concept of modifying intracranial pressures), most paramedic protocols still call for delivery of an accelerated respiratory rate (RR), usually more than 10 to 12 breaths/min.\textsuperscript{25–29} Similar directives are also provided for patients in extremis after traumatic circulatory arrest, despite the fact that ventilatory needs (i.e., the need to remove carbon dioxide [CO\textsubscript{2}]) are generally quite low in such moribund states.\textsuperscript{13,29–32} Although the need for intermittent PPV to provide adequate lung inflation for oxygenation purposes is still quite relevant in such patients, CO\textsubscript{2} production and delivery from the tissues to the lungs is quite limited in such low-flow states.\textsuperscript{31} Therefore, although adequate lung inflation is indicated under such conditions, there is little demand to clear CO\textsubscript{2}. Even a normal resting RR (e.g., 10–12 breaths/min) may be unnecessarily high and, under the circumstances of severe circulatory compromise, intermittent PPV at such “normal” rates will very likely impair cardiac output to some degree.

Traditionally, the extremely low rate of survival associated with circulatory arrest after trauma has been attributed to the severity of the underlying injury and delays in reaching definitive therapy and blood supplies, and not necessarily the type of prehospital care techniques rendered (unless they result in longer scene times). Likewise, the typical univariate correlation between endotracheal intubation and worse outcomes also has been explained in terms of the intubation being a marker for a more severely injured patient.\textsuperscript{33} Such patients may be easier to intubate or more apt to be seen as a candidate for intubation. However, some investigators now have begun to question these classic assumptions.\textsuperscript{33} Specifically, they have challenged the notion that severity of injury is the lone factor leading to worse outcomes and, in turn, have raised the issue that overzealous ventilation may also be a contributory factor.\textsuperscript{33–37}

Unfortunately, to date, published clinical data are lacking that explicitly demonstrate the potential exacerbating effects of PPV with rapid (or even normal) RRs on compromised hemodynamics, particularly in those critically injured patients at most risk. However, some inferential clinical data do support this concept. For example, contrary to the more common experiences of worse outcomes associated with endotracheal intubation (and PPV) after posttraumatic circulatory arrest, some Emergency Medical Services systems that have used PPV with lower than normal RRs for such circumstances have (paradoxically) correlated placement of an endotracheal tube with improved survival rates.\textsuperscript{19,20} Nevertheless, formal controlled trials have never been implemented to validate this concept.

Therefore, the purpose of this study was to create an experimental model that could explicitly demonstrate the detrimental hemodynamic effects of PPV after even moderate levels of hemorrhage and also to demonstrate that lower than normal resting RRs can improve hemodynamics and still preserve adequate oxygenation, ventilation (removal of CO\textsubscript{2}), and acid-base status under such conditions.

**MATERIALS AND METHODS**

**Institutional Review Board**

The study was conducted in compliance with the University of Minnesota Institutional Review Board and its policies for animal use and protections. Logs of subject use and disposition and documentation of anesthesia and analgesia were maintained.

**Subjects and Preparation**

Eight female farm pigs with average weights of approximately 35.0 kg (range, 32–36 kg) were anesthetized with 7 mL (100 mg/mL) of intramuscular ketamine HCl (Ketaset, Fort Dodge Animal Health, Fort Dodge, IA) for initial sedation. Intravenous access with an 18-gauge angiocatheter (Jelco Ethicon, Inc., Arlington, TX) was obtained through a lateral ear vein. Propofol anesthesia (PropoFlo, Abbott Laboratories, North Chicago, IL) was delivered as an initial intravenous bolus of 2.3 mg/kg. While the animals were spontaneously breathing but heavily sedated, they were intubated with a 7.0-Fr endotracheal tube (Medline Industries, Inc., Mundelein, IL). The animals were then given an additional propofol dose of 30 mg intravenously and anesthesia was maintained with a propofol infusion of 160 µg/kg/min throughout the protocol.

Animals were positioned supine and bilateral femoral artery and right jugular venous cannulations were performed under aseptic conditions. Aortic, left ventricular, and right atrial pressures were recorded continuously during the preparatory phase and during the experimental protocol, using micromanometer-tipped catheters (Mikro-Tip Transducer, Millar Instruments, Inc., Houston, TX). A pulmonary artery catheter (with thermodilution cardiac output measuring devices) was placed through a sheath in the right internal jugular vein. During the preparatory phase, the animals were ventilated with room air using a volume-cycled positive-pressure ventilator (Harvard Apparatus Co., model 607, Dover, MA) set to an average rate of 12 breaths/min and a tidal volume ($V_T$) of 12 mL/kg. Analysis of arterial blood gases (IL Synthesis, model 20, Instrumentation Laboratory, Lexington, MA) was performed using blood withdrawn from the
femoral artery catheter. Electrocardiographic monitoring was recorded with a lead II electrocardiogram. Intrathoracic airway pressure (ITP) was continuously measured with a micromanometer-tipped catheter positioned 2 cm below the tip of the endotracheal tube. A COSMOS Novametrix monitor was used to assess end-tidal CO₂ (ETCO₂).

Data were digitized by a digital recording system (Superscope II v1.295, GW Instruments, Somerville, MA) and a Power Macintosh G3 computer (Apple Computer, Inc., Cupertino, CA). Temperature was recorded with a rectal thermometer and maintained between 37.5°C and 39.5°C. Either a fan and a cooling blanket or a Bair Hugger, Temperature Management System (Augustine Medical, model 505, Eden Prairie, MN) was used, as needed. Hove pinching and canthal reflex were frequently checked to ensure adequate sedation throughout the study.

After the preparatory phase, the animals initially received mechanical ventilation using 0.28 FIO₂, VT of 12 mL/kg, and RR of 12 breaths/min. The animals were continuously monitored with recorded tracings for electrocardiography, expired VT, ETCO₂, RRs, ITP, and systolic systemic arterial blood pressure (SABP) in addition to aortic and right atrial diastolic pressures. Measurements of aortic and right atrial pressures were made at end-expiration. Coronary perfusion pressure (CPP) was also measured as the aortic diastolic pressure minus the right atrial pressure. However, accounting for RR-dependent, breath-by-breath fluctuations in coronary perfusion, an “average” CPP was calculated electronically from continuous tracings that averaged the CPP uniformly over 10-minute intervals during the protocol.

**Protocol**

The animals, serving as their own controls, had blood removed through peripheral catheters over 15 minutes until their SABP fell below 65 mm Hg using the same ventilatory settings: PPV at 12 mL/kg VT; no PEEP; RR of 12 breaths/min. After 5 minutes (steady state), RR was reduced to 6 breaths/min and then, every 10 minutes, RRs were progressively changed to 20 breaths/min, and 30 breaths/min, and then returned to 6 breaths/min. All measurements were made just before changing the RR, including SABP, cardiac output (Qt), mean ITP, ETCO₂, and aortic and right atrial pressures. Concurrently, blood was sampled from the arterial catheter for pH, SaO₂, PaO₂, PaCO₂, and hemoglobin level.

### Statistical Analysis

Hemodynamic and perfusion parameters were analyzed using analysis of variance, with a value of \( p < 0.05 \) considered statistically significant. Sample size was calculated on the basis of expected differences in systolic blood pressure between groups. All data are expressed as mean ± SEM.

### RESULTS

Immediately after anesthesia and before blood withdrawal, the time-calculated averaged CPP was measured at 84 ± 7 mm Hg, Qt at 3.4 L/min, and pH 7.48 ± 0.01. After blood withdrawal, the mean SABP was 65 ± 2 mm Hg and mean Qt was 2.4 L/min. The main results of the subsequent interventions are displayed in Table 1. After lowering the RR (from 12 to 6 breaths/min) while maintaining the same VT and FIO₂, mean ITP fell from an average of 15 ± 2 mm Hg and all animals had pronounced elevations in SABP (mean, 65 ± 2 to 84 ± 4 mm Hg; \( p < 0.05 \)). Similar elevations in the time-averaged CPP (50 ± 2 to 60 ± 4 mm Hg; \( p < 0.05 \)) and Qt (2.4 to 2.8 L/min; \( p < 0.05 \)) also were observed. Meanwhile, all animals maintained a pH greater than 7.25 (mean, 7.28 ± 0.02) and SaO₂ > 99%.

With RRs at 20 and 30 breaths/min, respectively, mean ITP increased to 16 ± 2 and 19 ± 2 mm Hg and SABP (73 and 66 mm Hg, respectively), Qt (2.5 and 2.4 L/min), and CPP (47 ± 3 and 42 ± 4 mm Hg) incrementally fell (\( p < 0.05 \) for all comparisons). Whereas arterial oxygen saturations were maintained, the mean PaO₂ decreased below 30 mm Hg and the pH became alkalotic (mean pH, 7.51 ± 0.01

### Table 1 Mean Values (n = 8) for Cardiopulmonary Variables Using Various Rates of PPV in a Swine Model of Moderate, Controlled Hemorrhage

<table>
<thead>
<tr>
<th>RR (breaths/min)</th>
<th>12</th>
<th>6</th>
<th>20</th>
<th>30</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA (mm Hg)*</td>
<td>1 ± 1</td>
<td>0 ± 1</td>
<td>4 ± 1</td>
<td>5 ± 1</td>
<td>0 ± 1</td>
</tr>
<tr>
<td>ITP (mm Hg)</td>
<td>15 ± 2</td>
<td>12 ± 2</td>
<td>16 ± 2</td>
<td>19 ± 2</td>
<td>11 ± 2</td>
</tr>
<tr>
<td>Ao Syst (mm Hg)*</td>
<td>65 ± 2</td>
<td>84 ± 4</td>
<td>73 ± 4</td>
<td>66 ± 5</td>
<td>95 ± 6</td>
</tr>
<tr>
<td>Ao Diast (mm Hg)</td>
<td>51 ± 2</td>
<td>71 ± 5</td>
<td>59 ± 4</td>
<td>52 ± 5</td>
<td>81 ± 6</td>
</tr>
<tr>
<td>PaO₂ (mm Hg)</td>
<td>68 ± 4</td>
<td>138 ± 13</td>
<td>113 ± 6</td>
<td>115 ± 3</td>
<td>174 ± 20</td>
</tr>
<tr>
<td>PaCO₂ (mm Hg)</td>
<td>35 ± 1</td>
<td>62 ± 2</td>
<td>28 ± 1</td>
<td>19 ± 1</td>
<td>58 ± 2</td>
</tr>
<tr>
<td>pH (arterial)</td>
<td>7.46 ± 0.02</td>
<td>7.28 ± 0.02</td>
<td>7.51 ± 0.01</td>
<td>7.62 ± 0.02</td>
<td>7.28 ± 0.01</td>
</tr>
<tr>
<td>CPP (mm Hg)</td>
<td>50 ± 2</td>
<td>60 ± 4</td>
<td>47 ± 3</td>
<td>42 ± 4</td>
<td>71 ± 6</td>
</tr>
<tr>
<td>Qt (L/min)</td>
<td>2.4</td>
<td>2.8</td>
<td>2.5</td>
<td>2.4</td>
<td>3.0</td>
</tr>
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</table>

* Measured at end-expiration.
and 7.62 ± 0.02, respectively). When the RR was returned to 6 breaths/min, mean ITP fell again to 11 ± 2 mm Hg and Qt rose (3.0 L/min; p < 0.05), as did SABP (95 mm Hg; p < 0.05) and CPP (71 ± 6 mm Hg; p < 0.05). The effect of intermittent PPV on blood pressures and CPP is displayed in Figures 1 and 2.

DISCUSSION

This simple animal model demonstrates the detrimental effects of intermittent PPV on hemodynamics in hypovolemic states, even at “normal” resting RRs, and even under the circumstance of moderate hemorrhage. It also demonstrates the major mechanism of cardiac output impairment (elevated mean ITP) and the relative “safety” of using very slow RRs in terms of maintaining adequate respiratory support, even before inducing severe decreases in total body oxygen delivery and CO₂ production. Although the specific model has several limitations in terms of the specific protocol used and the fact that it did not examine animals in severe shock (explained more fully in the following discussion), it clearly demonstrates a potential iatrogenic physiologic concern that should be addressed in future laboratory and clinical investigations.

The main mechanism of hemodynamic compromise from frequent PPV is the resultant increase in ITP. More frequent elevations in ITP diminish venous return and subsequent cardiac output, particularly in hypovolemic conditions. In this study, the shifts in mean ITP did not appear to be as pronounced as the accompanying marked changes in hemodynamics. However, this observation may simply reflect the methodology used. Instead of the traditional cm H₂O units of measure, we used mm Hg, making the values look...
smaller. Also, we measured intrathoracic pressure within the relatively noncompliant large airways (at the carina). An esophageal pressure monitor or other device for measuring transmitted intrathoracic pressures may be a preferable technique to our methodology. Nevertheless, the marked increases in right atrial pressures at the higher ventilatory rates help to serve as another surrogate indicator for the higher intrathoracic pressures and the concomitant inhibition of venous return.

The relatively small incremental changes in airway pressure in the face of significant changes in hemodynamics also may indicate the sensitivity of the cardiovascular system to changes in ITP under conditions of intravascular volume depletion. On a day-to-day basis in the clinical setting, ventilated patients tolerate intermittent PPV without any perceptible effect on hemodynamics, even with very fast RRs and low levels of PEEP. However, under the circumstances of significant hypovolemia, elevations in ITP can impair
cardiac output and CPP markedly (as evidenced in this current animal model of only moderate hemorrhage).

In fact, the experimental model used here was (purposefully) not a “near-fatal” model, only a model of moderate and controlled hemorrhage. Most of the animals did not even manifest significant metabolic acidosis or other signs of severe shock. Had the animals been bled more or had they been allowed to progress to a moribund state or even a state of circulatory arrest, undoubtedly this effect would have been even more pronounced. In our pilot studies to establish the best model for the experiment, animals experiencing more severe hemorrhage exhibited indicators of significant shock (e.g., metabolic acidosis). However, these animals did not tolerate the faster RRs in most circumstances (i.e., they developed circulatory arrest) and had to be quickly removed from the ventilator or resuscitated, thus resulting in incomplete data collection. Although lethal circulatory impairment from faster RRs could be considered a reasonable study endpoint, our intent in this initial study was to demonstrate the mechanism and reversibility of the effects. Therefore, because the animals were being used as their own controls in this inaugural study, we wanted to choose a model that would not cause intraexperimental death so that we could obtain a full set of data points in all animals.

Unfortunately, this nonlethal model sometimes can lead to confusing results, especially in swine. It is been the longstanding observation of many investigators that swine (with only moderate levels of controlled hemorrhage) can develop interesting physiologic compensatory mechanisms. These compensatory mechanisms will routinely improve the animals’ hemodynamics during the course of a typical experimental period (particularly when using a controlled bleed). Therefore, as expected, during the course of the overall study protocol for each animal, each of them gradually improved their hemodynamics. Thus, at first glance, by the time their RR was eventually placed at 20 and 30 breaths/min, the animals’ hemodynamic numbers (blood pressures and total body cardiac output) appear to be similar to (or even better than) the baseline numbers (at RR of 12 breaths/min). However, while there were gradual spontaneous hemodynamic improvements during the experimental periods, we were able to demonstrate in this study (using the animals as their own controls) that each of the individual side-by-side comparisons of contiguous experimental steps (i.e., each of the incremental changes in respiratory rates such as 12 to 6 breaths/min and 30 to 6 breaths/min) still led to striking (and statistically significant) differences. Also, the hemodynamic improvements between the first RR of 6 breaths/min compared with the second reading at 6 breaths/min supports the hypothetical notion that the lower RR may have augmented the animals’ own spontaneous improvement. One could also interpret that the initial step to lower the RR to 6 breaths/min may have improved the overall clinical state of the animals after the hemorrhage and thus may have even enhanced their tolerance of the higher RRs. More importantly, the key observation here was the effect of increased RRs on coronary perfusion pressure. Despite improvements in other hemodynamic numbers as time progressed, this key indicator was still lower at the higher RRs when compared with the much earlier baseline reading (at RR of 12 breaths/min). Likewise, the CPP measurements at the final step (RR of 6 breaths/min) were not only immediately and dramatically improved (within seconds) from the previous step of 30 breaths/min, but it almost was normalized in these animals that had experienced significant hemorrhage. Therefore, despite the confounding variable of spontaneous hemodynamic improvements commonly observed with this specific model of moderate and controlled hemorrhage in swine, we still feel very comfortable with the overall conclusion that we were able to demonstrate the effect (and mechanism) of hemodynamic compromise induced by positive-pressure breathing at “normal” or increased respiratory rates in the face of relative hypovolemia. Nevertheless, we recognize the limitations of this inaugural study design and therefore strongly recommend further study of this concept in different models that will transcend this initial experiment.

One potential concern with this model is the issue of hypoventilation. In this particular model, when the RR was lowered to 6 breaths/min, PaCO₂ rose to hypoventilatory levels. However, in all individual cases, the pH always remained above 7.25. If the situation had been worse (i.e., more severe hemorrhage), CO₂ production and/or CO₂ return to the heart and lungs eventually would have fallen off and, in all likelihood (on the basis of our pilot work and other clinical observations), hypoverilation would not have been observed.31 As is seen in most cardiac arrest or near-arrest cases (traumatic or nontraumatic), there is little need to ventilate (clear CO₂), only the need to provide intermittent lung inflation to avoid significant intrapulmonary shunting and diminished arterial oxygenation.13,17,32 Even in this nonfatal model of moderate hemorrhage in which the hemodynamic insult was much less severe, pH remained in an acceptable zone and it simply reflected higher PaCO₂ levels. In fact, many would argue that a slightly acidic environment may be the best circumstance for facilitation of tissue oxygen uptake under the stress of relative hypoperfusion, and certainly the alkaloysis observed at the faster RRs is much less preferable and probably detrimental in terms of oxyhemoglobin dissociation at the tissues.

Therefore, a ventilatory rate of 6 breaths/min would have, quite likely, been more than adequate for more severe (near-lethal) cases of hemorrhage and circulatory compromise when CO₂ delivery to the lungs is severely limited. However, even in this current model of only moderate hemorrhage, the “permissive” hypercapnia clearly was worth the tradeoff in terms of the resulting dramatic improvements in systemic oxygen transport (maintenance of oxygen saturation with improved Qt and CPP).

Because coronary perfusion pressure immediately (and transiently) diminishes with breath-to-breath fluctuations (Fig. 1), a measurement must be made over time. It is intu-
itive that with more frequent fluctuations (at the higher RRs), there will be less “area under the curve” (i.e., CPP is suppressed more often). A CPP calculation over time is one methodology for better understanding the summary effect of higher PPV rates on coronary perfusion, rather than a snapshot measurement. In this study, the effects on CPP observed on a breath-to-breath basis were perhaps even more dramatic than the cardiac output changes (Fig. 1). Thus, the clear impairment of CPP in this nonfatal model of only moderate hemorrhage underscores the risk for patients with even more unstable hemodynamics who are most likely to receive prehospital (or preoperative) intubation and PPV. More importantly, this effect on CPP clearly would not be observed or appreciated in the clinical setting, particularly in prehospital circumstances, where it is even difficult to accurately measure SABP levels below 80 mm Hg.

With the growing use of prehospital and emergency department capnography, clinicians in those settings are now beginning to recognize the concept of diminished ventilatory demand in severe circulatory compromise and particularly in cardiac arrest cases.31,32 They are also beginning to appreciate, with more frequency, the concept of the auto-PEEP effect and the fact that overzealous ventilation can be a possible cause of pulseless electrical activity and electromechanical dissociation in nontraumatic cardiac arrest,11,27,34 and that it correlates with increased mortality and worse outcomes in trauma patients.35–37 While it has been presumed traditionally that severe hyperventilation (defined as very low PaCO2) can have detrimental effects if it leads to excessive cerebral vasoostriction or if it causes oxyhemoglobin dissociative impairment or cardiovascular suppression from alkalosis, the low PaCO2 may also represent a surrogate marker for the adverse hemodynamic effects of PPV when it is provided at unnecessarily high RRs. Either way,11,27,34 it is not clear why many standard protocols for trauma resuscitation (when provided) still have called for normal or supernormal respiratory rates. In addition, the specific issues of delineating appropriate choices of VT and RR are not addressed in many Emergency Medical Services/trauma systems, leaving the ventilatory techniques up to the paramedic’s training or just traditional behavior. In that respect, most nationally accepted training manuals and published paramedic protocols still call for rapid respiratory rates (e.g., 15–20 breaths/min) regardless of the clinical condition and regardless of the severity of the hemodynamic compromise.26–29 Anecdotally, one usually hears the stated rationale for these approaches as a being a way “to pump in more Os (oxygen)” or to “hyperventilate” the patient (meaning faster RRs) to compensate for the presumed evolving anaerobic metabolism from the severe “shock state.”

Although such statements are well-intended and sound rational, they are not necessarily consistent with the physiology of severe shock states, and particularly the physiology of the moribund or near-moribund trauma patient for whom endotracheal intubation and PPV is most likely to be given.31,33 Nevertheless, in the absence of any other directives, most paramedics will still be likely to use faster RRs during critical trauma resuscitations because they will rely on both published guidelines and most traditional training. Therefore, in our opinion, these traditional training standards and protocols should be revisited and reconsidered.

The concept of detrimental effects of intermittent PPV should also be considered as a potential confounding variable in studies of critically injured patients. This will be especially important to recognize in any proposed clinical trials of interventions for severe posttraumatic hemorrhage.38 Specifically, this concept becomes extremely critical if one considers the concept that an inappropriate ventilatory strategy has the ability to mask a beneficial effect of a study intervention, particularly if that ventilatory technique leads to the patient’s inadvertent and unrecognized iatrogenic demise.

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**DISCUSSION**

Dr. Karen J. Brasel (Milwaukee, Wisconsin): The authors have examined the known interaction between ventilatory management and hemodynamics that we’re all used to treating in the intensive care unit and in an animal model analogous to the prehospital setting. Focusing on the B of the ABCs, they have demonstrated in a model of fixed hemorrhage the effect of low and high respiratory rates on various hemodynamic parameters.

I have the following questions for the authors. Only the coronary perfusion pressure or your minute coronary perfusion pressure is worse with respiratory rates of 20 and 30. All of your other hemodynamic parameters are better at respiratory rates of 20 and 30 than at your baseline respiratory rates of 12. Can you comment as to why this might be? Do you have any information on end-organ perfusion such as was mentioned in the discussion of the last article—base deficit, lactate, oxygen delivery?

Is this truly worse to provide respiratory rates of 20 and 30 rather than respiratory rates of 6? The animals with the respiratory rate of 6 did have a slight respiratory acidosis. Is 10 minutes of this model enough? Might this effect be exacerbated with either a longer time or a more severe model?

Finally, although delayed resuscitation may be appropriate for penetrating trauma patients in an urban setting, for blunt trauma patients we are certainly still volume resuscitating. Can you comment on the effect that volume resuscitation might have had on the parameters that you measured? I’d like to thank the Program Committee for the opportunity to discuss this article.

Dr. Robert W. Hopkins (Providence, Rhode Island): Before we go to rewriting the Emergency Medical Technician manuals, we ought to at least know what the ICPs are. Most of the patients that are out on the streets are going to be motor vehicle crashes, not gunshot wounds to the aorta.
Dr. Gregory Beilman (Minneapolis, Minnesota): How do you control for the variable of time? My experience with fixed-volume hemorrhage models is that you bring their systolic blood pressure down to 65 and 20 minutes later it is 90 again.

Basically, with your model, you’re not mixing up the variables. You’re going at a rate of 6, a rate of 20, a rate of 30, and back to a rate of 6.

Dr. Matthew J. Wall (Houston, Texas): I enjoyed your presentation. When I was an Emergency Medical Technician, there wasn’t much supportive monitoring available, and now, end-tidal CO₂ is available on ambulances, and some are using it as a surrogate for cardiac output. Have you considered that as a screen to identify those with a low cardiac output so you are particularly careful about not elevating the intrathoracic pressure in those groups of patients?

Dr. David J. Dries (St. Paul, Minnesota): I think you’re really comparing an old standard. In Advanced Cardiac Life Support protocols now, they already speak about low tidal volume ventilation, not the large tidal volumes that you are using. I’d be interested to know whether you have data that look at the same respiratory rates with small tidal volumes, so you can tell us whether it’s a tidal volume effect or whether it’s a rate effect that you’re seeing.

Dr. Paul E. Pepe (closing): Thank you very much. I appreciate the comments. The first question that was asked was why the only parameter that was worse at 20 and 30 breaths/min was the minute coronary perfusion pressure. What happens, we think, is that over the experimental period, there is actually “spontaneous” compensatory improvement in basic hemodynamic function in such controlled hemorrhage models after moderate degrees of hemorrhage.

Still, we observed a progressive decrease at rates of 20 and 30 breaths/min compared with 6 breaths/min, especially in terms of the main endpoint examined, coronary perfusion pressure. Then, of course, it improved dramatically, going back to the respiratory rate of 6 again. Despite the typical observations of overall compensatory self-improvements in hemodynamics in such models, there are still pronounced, step-by-step effects, whether you’re looking at aortic pressure or coronary perfusion pressures or any of the other parameters.

In terms of measurements of end-organ perfusion, there wasn’t really much of an effect observed. We only induced a moderate hemorrhage here and saw no significant metabolic acidosis. There was a decrease in mixed venous content, but not enough apparently to cause a metabolic acidosis in this model.

We have performed some pilot studies in which we hemorrhaged animals to more severe levels of blood loss and they were getting into trouble with metabolic acidosis. In these cases, we couldn’t complete the experiment. Either we had to take the animals immediately off the ventilator, because they weren’t tolerating it (very low blood pressures), or they would go into circulatory arrest and had to be resuscitated.

That would have been an interesting endpoint in itself to show that you can cause death in the animals with this protocol. However, in this study we were mostly interested in demonstrating, in an animal model, what the hemodynamic effects would be, even in a moderate hemorrhage situation. So we already know that—and I guess that should be the next series of studies we do—the effect is fairly dramatic and much more pronounced in terms of what happens when the animals are more severely hemorrhaged.

In terms of the carbon dioxide levels being at higher levels for 10 minutes, again, this primarily resulted in a relative respiratory acidosis. I don’t think that a pH of 7.28 in this moderate hemorrhage situation would be a problem except perhaps for what could be happening cerebrally with high PaCO₂ levels if this involved a head injury model.

However, with a hemorrhage as the principal insult, I’d rather have that pH of 7.28 than one of 7.6. Also, if this had been an animal with a more severe hemorrhage, that would have been a situation in which there would have been less CO₂ production and therefore we would like to see arterial hyperventilation and central hypocarbia, even with “normal” respiratory rates.

This would have led to overventilating, even at a respiratory rate of maybe 6 or 8, let alone at 12 or more. Also, the concern over hypercarbia leading to cerebral vasodilation and increased intracranial pressure may not be a core issue with which to be concerned in that this physiologic mechanism may be thwarted with diminished oxygen transport. Therefore, the improved oxygen transport seems to be the target of choice.

Then, in terms of the volume resuscitation issues, I agree. If you’re going to resuscitate and you restore volume and get a better or normal perfusion, the animals will need more ventilation. Especially in the human situation when the patients are also thrashing around and there is a lot more energy being consumed (and there’s more metabolism). Then you’re going to need more ventilation under those circumstances. So, one of the problems, of course, is that you have a model here that’s basically sedate, and it behaves a little differently.

However, again, let’s stay on track and remember that we were trying to get close enough to a model imitating severe circulatory compromise without actually killing the animals. Also, if it’s a circulatory arrest after blunt trauma, survival usually is negligible because of the mechanism. Most of our posttraumatic arrest patients who survive are victims of penetrating injury with severe hemorrhage or pericardial tamponade, and although this may initially indicate fluid infusions, these infusions may eventually be limited before definitive hemostasis.

Dr. Hopkins, that’s true, I think that it would be good to know about intracranial pressures as well, but some of the patients for whom I have had a specific interest have been those patients with circulatory arrest, because most clinicians
are extremely pessimistic about them. I think some of them can be very resuscitatable given optimal treatment, and perhaps, with proper ventilatory techniques, others would achieve resuscitation and thus those clinicians would become less pessimistic themselves.

In blunt trauma, it’s often a different situation because of the mechanisms of inducing a fatality, but with penetrating injuries, we have been able to bring some of these folks with circulatory arrest back in many venues. I think that every therapeutic consideration has its place depending on circumstances. Again, you’re doing the right thing by stratifying blunt injuries (particularly those with head injuries) from those with a probable primary vascular injury after a gunshot or stab wound.

Dr. Beilman, yes, one of the limitations of the study is the way we chose to perform the protocol. I think that next time, as I have in other studies I’ve done, I may randomize those various interventions in different sequences. However, anticipating this problem of “self-improvement” in blood pressure, we chose to do it this way to look at the immediate effects from one step to another. I agree with you. Spontaneous improvements in hemodynamics are a problem with these models, nevertheless the step-by-step comparisons were still very pronounced here in terms of the immediate differences that we observed when we moved from, say, 6 to 20 or 30 back to 6 again. I think we still made out fairly well despite this confounding, common phenomenon seen by many others such as yourself. Next time, we may also use a more severe insult or an uncontrolled bleed.

Dr. Wall, you are absolutely right on target about monitoring end-tidal CO₂. I think that’s why there is now more attention being paid to this concern, because a lot of our colleagues in emergency medicine and in Emergency Medical Services are now getting used to understanding some of the physiologic sequelae of diminished flow that we often see in the intensive care unit or in the operating room.

Again, I think that absolutely you’re on target in terms of that suggestion, and this may help us to delineate appropriate candidates for reduced ventilatory rates and thus address many of the concerns cited by the other reviewers. We need to study it more.

Dr. Dries, I serve on the committees for the American Heart Association that called for lower tidal volumes. We did recommend lower tidal volumes, but only in the situation involving unprotected airways because of the risk of gastric insufflation. Also, this recommendation was only valid when supplemental oxygen was available. We also emphasized that without supplemental oxygen, or once endotracheal intubation was performed, we would adjust the tidal volumes upward again.

Another situation in which we would use lower tidal volumes, of course, is based on our data with acute respiratory distress syndrome patients who have a diffuse, heterogeneous lung disease and are on levels of PEEP > 10 cm H₂O. In such circumstances, larger lung expansion with 10 to 15 mL/kg tidal volume basically is going to be a problem because of “stretch over stretch.”

However, in this current experimental situation, in which you have lungs that are relatively normal and no PEEP, the animals do get underinflated just as many humans do with PPV at levels < 8 mL/kg (vs. spontaneous respirations, which usually provide better gas distribution in dependent lung zones). Again, the same need for these higher tidal volumes is probably true in the case of humans when there is no PEEP and no diffuse heterogeneous lung injury.

In future studies, we can look at it both ways. However, in this particular model, we did initially experiment with different and lower tidal volumes and found them to be inadequate. In summary, 12 mL/kg was probably the most appropriate tidal volume. Thanks for raising this issue so we could help to clarify and emphasize these important considerations.
PREHOSPITAL FLUID RESUSCITATION OF THE PATIENT WITH MAJOR TRAUMA

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ABSTRACT

The most appropriateprehospitalapproach to resuscitative fluid interventions for trauma patients involves: determining the mechanism of injury (i.e., blunt versus penetrating versus thermal injury); identifying anatomic involvement (i.e., truncal versus isolated head injury versus isolated extremity injury); and staging the condition (i.e., hemodynamic stability versus instability versus moribund state). Based on available data, the liberal use of fluid infusions for presumed uncontrolled internal hemorrhage, such as that usually occurring after penetrating abdominal and thoracic injuries, is no longer advised. Although some infusions might be appropriate in patients with extremely severe hemorrhage (i.e., no palpable blood pressure, unconscious), the priority in such patients is rapid evacuation to definitive surgical intervention, with airway control and intravenous access provided en route. The data are less clear for patients with blunt injuries, particularly those with closed head injury. Most researchers would still recommend that patients with isolated extremity and head injuries, either blunt or penetrating, are candidates for immediate support of blood pressure through fluid infusions. However, the addition of potential intra-abdominal, intra-pelvic, or intrathoracic injuries with uncontrolled hemorrhage confounds the decision-making process. Although conventional wisdom has been to provide aggressive blood pressure support under these circumstances through judicious use of isotonic, or perhaps hypertonic, fluid resuscitation, recent experimental data challenge even this philosophy. Use of new blood substitutes might help to resolve some of these issues by providing oxygen delivery with limited volume in the face of uncontrolled hemorrhage. Key words: blood substitute; blunt injury; head injury; hemoglobin-based oxygen carrier; hemorrhage; injury; intravenous fluid; penetrating injury; resuscitation; shock; trauma.

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For more than three decades, the traditional approach to prehospital treatment of trauma patients with low blood pressure resulting from obvious or presumed hemorrhage has been to attempt to restore normal systemic arterial blood pressure.1–7 The rationale for this approach has been to ensure and maintain vital organ perfusion while awaiting definitive surgical intervention and hemostasis.1–3 The two modalities most often used to achieve this goal are: 1) rapid intravenous infusions of isotonic crystalloid or colloid solutions (normal saline, lactated Ringer’s solution, albumin, or hetastarch); and 2) use of the pneumatic antishock garment (PASG), also known as military antishock trousers (MAST).1–7

The basis for this approach was largely established by the results of several elegant animal studies performed in the 1950s and 1960s.8–10 Researchers found that animals receiving both blood and intravenous isotonic fluid as resuscitative measures had a greater likelihood of survival after severe hemorrhage when compared with animals receiving blood alone. The animals left untreated usually died or sustained irreversible organ damage. In addition, restoring blood pressure to normal or close to normal was associated with an improved outcome. The results of these studies immediately affected the standard treatment of wounded soldiers in Vietnam by battlefield medics, which contrasted with previous battlefield approaches.11 In turn, the infusions of intravenous fluids to normalize blood pressure eventually was transferred to the streets of the United States and other western societies by the 1970s with the development of modern paramedic services.

The PASG was developed as a modification of the jet aviator’s G-suit.4,12–18 It was designed to help normalize blood pressure in the face of post-traumatic hypotension4,13,19 through its ability to increase peripheral vascular resistance. The PASG also had the theoretic advantage of providing a potential tamponade effect for underlying injuries with active internal bleeding.20 By the 1980s, the PASG and aggressive intravenous fluid resuscitation had become the standard of care for all trauma patients with potential signs or symptoms of presumed hemorrhagic shock.1–4,6,7

Despite these longstanding traditional management approaches, recent experimental and clinical data have indicated a modification to this universal approach to the trauma patient.11,21–31 Although raising blood pressure and restoring...
perfusion to vital organs are clearly believed to be beneficial after hemorrhage is controlled, growing evidence indicates that raising blood pressure before achieving adequate hemostasis may be detrimental.\textsuperscript{21–33} While the original animal studies that laid the groundwork for fluid resuscitation more or less involved controlled hemorrhage models with fixed amounts of blood loss,\textsuperscript{8–10} more current studies have begun to examine the effects of raising blood pressure during uncontrolled hemorrhage.\textsuperscript{21–31} These studies and their potential implications for clinical epidemiology, research, and management are discussed in detail.\textsuperscript{34}

\textbf{EVIDENCE AGAINST PREOPERATIVE BLOOD PRESSURE ELEVATION}

Several animal studies performed in the 1980s and 1990s found that treatment with intravenous fluids before hemorrhage is controlled increases the mortality rate, especially if blood pressure is elevated.\textsuperscript{21–27} Possible mechanisms responsible for worse outcomes include hydraulic acceleration of ongoing hemorrhage as a result of the elevated systemic blood pressure, mechanical dislodgment of active soft clot formation, and dilution of existing clotting factors from administration of large volumes of intravenous fluids.\textsuperscript{21,33}

Research in humans, although limited, has supported this concept. A large, prospective, controlled clinical trial comparing immediate prehospital and emergency department intravenous fluid resuscitation with fluid resuscitation delayed until arrival in the operating room was conducted in Houston, Texas, in the 1980s and early 1990s.\textsuperscript{33} In this study, hypotensive (systemic blood pressure $<90$ mm Hg) patients with penetrating torso injuries received either aggressive isotonic fluid resuscitation preoperatively (immediate group) or were given fluids only on arrival in the operating room (delayed group). Patients in the immediate resuscitation group had a higher mortality rate and a higher rate of postoperative complications compared with patients in the delayed resuscitation group. The authors of this study concluded that rapid administration of intravenous fluids before hemorrhage is controllable results in worse outcomes in this subpopulation of hypotensive patients with penetrating truncal injuries.

Despite some negative reaction to this initial clinical effort to resolve the question of when to provide fluid resuscitation,\textsuperscript{35} the study remains the strongest available evidence to date regarding the issue. Also, counterarguments to the initial critiques of the study have noted that, at the very least, there is no demonstrable advantage to administering fluids in this subpopulation of trauma patients.\textsuperscript{36} In addition, experimental studies in multiple animal models have all supported the concept of the detrimental effect of fluid resuscitation in uncontrolled hemorrhage.\textsuperscript{21–31} Furthermore, this effect is found regardless of the solution used (i.e., blood, lactated Ringer’s solution, hypertonic saline\textsuperscript{22,26,29}). More importantly, in other prehospital studies, fluid resuscitation has yet to be correlated scientifically with improved survival in the clinical setting, particularly in moribund patients who intuitively would benefit the most.\textsuperscript{37,38} The key factors in the survival of moribund patients appear to be limited to rapid transport to an appropriate trauma facility and aggressive airway control.\textsuperscript{34,37,38}

Therefore, the working hypothesis at this time is that intravenous fluid resuscitation should probably be delayed until hemostasis is achieved. Following this line of thinking, if the anatomic site of bleeding is a large vessel within the thoracic or abdominal cavity, bleeding control will usually require surgical hemostasis. Although large intravenous fluid infusions may be necessary as soon as bleeding is controlled, aggressive fluid resuscitation in the prehospital or emergency department settings might still be detrimental in such patients.\textsuperscript{28,33} In contrast, a hypotensive trauma patient with isolated severe hemorrhage from an extremity probably would benefit from immediate prehospital fluid resuscitation because the bleeding can be controlled outside of the operating room setting.

The consideration that hemostasis must be achieved before blood pressure is raised might also explain why antishock garments have not provided the anticipated benefit, particularly in patients with penetrating abdominal injuries.\textsuperscript{39–44} In prospective trials, one difference between PAG patients and control patients has been a marked elevation in systolic blood pressure among the patients who had prehospital PAG application.\textsuperscript{39} This elevation in systolic blood pressure is consistent with findings of retrospective studies and the initial anecdotal reports that originally espoused the widespread use of the PAG device. Based on traditional wisdom, most clinicians might anticipate that elevating blood pressure in the face of presumed hemorrhagic shock (post-traumatic hypotension) would be beneficial and improve patient outcome.\textsuperscript{4,12,13,17} In these clinical trials, however, patients with major vascular injuries, both arterial and venous, were found to trend toward decreased survival.\textsuperscript{39} Survival rates were approximately 90% for patients with solid organ, abdominal wall, or bowel injuries, with or without PAG application. When the subset of patients with large-vessel involvement (e.g., inferior vena cava, renal vein, hepatic artery) was examined, survival rates were 49% for the PAG group and 65% for the control group.\textsuperscript{39} Again, this observation is
compatible with the evolving paradigm that blood pressure elevation before hemostasis may be detrimental. It must be kept in mind, however, that through peripheral vascular compression, the PASG lowers total body cardiac output and that other mechanisms may also explain the disadvantages of this device.

**Blunt versus Penetrating Trauma**

Although both experimental and clinical studies supporting delay of fluid resuscitation are somewhat compelling, the clinical studies generally involved patients with penetrating injuries. The role of fluid resuscitation in patients with blunt trauma is less clear. For example, after motor vehicle collisions, patients with multisystem injuries traditionally have been provided blood pressure support for major fractures and closed head injury. However, a patient trapped in a vehicle who has altered mental status, left upper quadrant pain, a closed femur fracture, and hypotension presents a challenging dilemma for clinicians. Although aggressive preoperative fluid resuscitation theoretically could accelerate hemorrhage from a major splenic rupture or avulsion (a potential here), blood pressure support for brain injury is also considered to be a key therapeutic intervention. Also, a femur fracture can result in massive blood loss and fluid sequestration leading to profound shock conditions.

Nevertheless, recent experimental models of head injury have refuted the traditional universal use of aggressive blood pressure support in patients with head injury. Although better outcomes have been correlated with increased systemic blood pressure in patients with severe head injury, a higher blood pressure might simply be a marker for less severe head and systemic injury. Conversely, hypotension might be a marker for other factors that lead to a bad outcome and in itself is not necessarily detrimental.

Therefore, further clinical and experimental studies are necessary to better delineate the role of fluid resuscitation in these complicated patients. The type of injuries, their anatomic location, and their severity must be kept in mind when such research efforts are designed. Specifically, stratification of patients with and without head injuries must be made clear, as should stratification of those in extremis conditions.

**Fluid Resuscitation in the Moribund Patient**

Although experimental evidence has demonstrated the potential detrimental effects of aggressive fluid resuscitation in uncontrolled hemorrhage, many animal studies have suggested that blood or fluid administration may be of value in patients with “severe circulatory compromise” (i.e., mean systemic arterial blood pressure <40 mm Hg). However, patients with such a degree of hypotension typically present without a measurable blood pressure and are usually unconscious.

One retrospective study found that patients with such severe circulatory compromise might benefit from application of the PASG. However, that conclusion may have been limited by the study design (selective retrospective analysis, accuracy of prehospital blood pressure measurements <70 mm Hg, and statistical power). In the prospective clinical trial of immediate versus delayed intravenous fluid resuscitation for penetrating torso injury, patients who had a systemic arterial blood pressure of <70 mm Hg were generally pulseless and clinically moribund. These patients’ chance of survival was very low regardless of their prehospital treatment. At the same time, a retrospective subanalysis of all patients with injury severity scores >26 showed that patients had worse outcomes with early fluid resuscitation.

Despite the animal data, statistically significant evidence from prospective clinical trials is still lacking regarding the value of fluid resuscitation for the most severely injured patients. Nevertheless, considering the animal data and grim outlook for these patients, rapid fluid infusions still might be empirically reasonable in the absence of pulse and consciousness.

One consideration that might help guide such therapy for severely compromised patients is the use of end-tidal carbon dioxide (ETCO₂) measurements to detect critical perfusion levels in which total body oxygen consumption and CO₂ production begin to fall significantly. End-tidal carbon dioxide levels are affected primarily by the level of pulmonary blood flow. Thus in severely injured patients whose cardiac output is very low, little CO₂ is delivered from tissues to the pulmonary circuit and the exhalation of CO₂ is minimal. Measurements of ETCO₂ therefore reflect total body cardiac output and can be used as one noninvasive means of monitoring directional changes in blood flow during cardiopulmonary resuscitation and fluid resuscitation (Figs. 1 and 2). As shown in Figure 2, ETCO₂ can increase in response to aggressive fluid resuscitation in a patient with severe trauma. However, the suggestion to begin fluid resuscitation according to ETCO₂ measurement in severe trauma is still only empiric and unstudied, particularly in those patients with uncontrolled hemorrhage. It is still not known whether ETCO₂ levels should constitute trigger points for fluid infusions or how much or how fast the fluids should be infused. Studies examining these issues are strongly encouraged.
One confounding factor to be considered in these and any other studies of severe circulatory compromise is the detrimental effects of positive-pressure ventilation, particularly in patients with presumed hemorrhagic shock and severely depressed preload. This additional controversy demonstrates how stratification of the severity (staging) of injuries is important in future research endeavors. Confounding the situation further is the recent experimental evidence that bolus infusions might be more detrimental than slow infusions in near-fatal hemorrhage. In addition, such investigations have also used hypertonic solutions. Therefore, the choice of fluid may also have to be considered when analyzing the results of these studies.

**Resuscitation with Noncrystalloid Fluids**

The type of fluid that should be administered to trauma patients, even those with controlled hemorrhage, has been the subject of considerable debate. In North America, crystalloids are typically given to replace blood loss, but several studies have examined the use of fluid substitutes, such as colloids and hypertonic saline, for prehospital use. Although isotonic crystalloids (e.g., normal saline or lactated Ringer’s solution) remain the principal choice today in the United States, various types of colloids (all very different in themselves) are often the fluid of choice in other countries, such as Australia and European nations. Obviously, this further complicates the interpretation of meta-analysis and cross-study comparisons.

Proponents of the use of colloids, such as albumin, argue that fluids given to replace blood loss from the intravascular space should be designed to remain in that space. The traditional teaching concerning crystalloid infusions has been the “3:1 rule,” whereby 1 liter of crystalloid remains in the vascular space for every 3 liters infused. This approach requires that large volumes of balanced salt solutions be administered to replace blood loss. It could be further argued that such infusions carry inherent risks. For example, infusions of such large volumes of crystalloid might decrease intravascular colloid osmotic pressure, potentially increasing the risk of developing or exacerbating pulmonary or cerebral edema. Nevertheless, most analyses have not yet proven definitively the advantage of albumin over crystalloids.

The main alternative solutions studied for trauma resuscitation in the United States are hypertonic saline and nonprotein plasma expanders, such as dextran and hetastarch. These fluids are less antigenic and less expensive than albumin but still may induce allergic reactions, coagulopathies, and seizures. Limiting the volumes infused may avoid some of these problems.

Some clinical trials have specifically examined the efficacy of hypertonic saline. Experimentsally, hypertonic saline increases myocardial contractility, induces vasodilation to precapillary resistance vessels, and improves redistribution of fluid from the extravascular to the vascular compartments. In addition, because considerably smaller volumes are needed to restore intravascular volume, hypertonic saline solutions have been advocated as a resuscitative agent for field use, particularly for hypotensive patients with severe head injury.

A prospective, multicenter trial from 1991 compared the outcomes of hypotensive trauma patients treated with normal saline or hypertonic saline in dextran (e.g., 7.5% NaCl in 6% dextran 70). The two groups received equal volumes of fluid in the prehospital phase, followed by standard isotonic infusions in the emergency department. Although the patients in the hypertonic saline in dextran group had higher systemic blood pressures on arrival at the hospital, no significant difference in overall mortality was seen between the two groups at 24 hours. There were no clinically significant complications of hypernatremia or dextran-related allergic reactions among the patients who received hypertonic saline in dextran. The authors concluded that despite theoretic concerns, hypertonic saline in dextran was safe and further study was warranted.

However, one of the problems with this study was that relatively
small volumes of fluid were administered in the prehospital setting to a group of patients with predominantly penetrating injuries. Both groups of patients received only 250 mL of either fluid, and the two groups were then given standard isotonic fluid infusions in similar fashions, confounding the results.

Future research could repeat this protocol with a third study arm that includes a group receiving no fluid in the field, or even a fourth group of patients who receive the single dose of 250 mL of hypertonic saline in dextran alone. This would help to address the question of whether any prehospital administration of fluids is warranted. Another consideration would be a comparison of preoperative versus postoperative infusion of hypertonic saline in dextran. Finally, use of hypertonic saline in dextran in patients with or without concomitant head injury (without any additional isotonic fluid infusions) should be examined more closely. Although other data seem to support its efficacy,64–66 the general consensus is that definitive clinical trials are lacking.

In the meantime, most experts in the United States generally hold that limited crystalloid infusions are preferable to most other colloid infusions in the prehospital setting and in the early resuscitative phases of trauma care.5 The rationale is that crystalloid is inexpensive, readily available, and nonantigenic and that administration of any isotonic infusions might be followed by plasma expanders or blood products in the emergency department or operating room. Also, no firm data support the use of the more expensive colloid solutions.67 Nevertheless, the potential anti-inflammatory properties of some colloids also create some appeal for researchers and further study.68

The hetastarches, which are commonly used in Europe, and artificial hemoglobins are not as well studied as crystalloids and other intravascular infusions.59,63,69–78 Although further research into these types of resuscitative agents can be anticipated, many of these agents have been demonstrated to have a potential for raising blood pressure, a factor to consider in patients with uncontrolled hemorrhage.79 For example, many of the hemoglobin-based oxygen-carrier products are thought to have nitric-oxide scavenging effects that lead to smooth-muscle constriction and subsequent blood pressure elevation.79 However, it is hoped that the oxygen-carrying properties will outweigh the risk of secondary hemorrhage.70,71

One trial of the artificial hemoglobin diaspirin cross-linked hemoglobin (DCLHb) for trauma patients was terminated prematurely because of an increased number of deaths in the experimental group.69 However, study bias and other factors may have led to this unexpected observation with this particular product.69

The recent introduction of another compound, HBOC-201, a purified form of bovine hemoglobin, has sparked renewed interest in artificial hemoglobin. HBOC-201 has been shown to have some promise in the laboratory.70,71 In a swine model of trauma, Manning et al.70 demonstrated the successful resuscitation and survival of asanguinous animals with uncontrolled hemorrhage that were given HBOC-201 compared with the high mortality found in the control group given standard crystalloid infusions.

In addition to improved oxygen-carrying capacity, HBOC-201 is relatively temperature stable75 and could be stored in ambulances or in military far-forward positions, thus making it attractive to researchers. In terms of human data, HBOC-201 has been used successfully as a short-term blood substitute in hundreds of surgical patients72–78 but has not yet been tested in any of the various subpopulations of trauma patients. Nevertheless, the concept of providing improved oxygen transport in the face of uncontrollable hemorrhage is appealing, and future clinical trials of this new compound would be worthwhile.

**Complications of Preoperative Fluid Resuscitation**

Blood pressure alone is a poor predictor of shock (defined as inadequate perfusion of tissues). Despite
the recently evolving paradigm that limiting preoperative fluid is preferable in most patients with internal hemorrhage to prevent secondary bleeding or acceleration of ongoing hemorrhage, concern still exists over the potential for other sequelae of shock. The duration and degree of systemic hypotension that a patient can withstand are the issue.

The clinical study comparing immediate with delayed fluid resuscitation showed a higher incidence of postoperative complications in the immediate resuscitation group (i.e., patients who received aggressive fluid administration in the prehospital and emergency department settings). The incidence of acute respiratory distress syndrome, sepsis, coagulopathies, and renal failure was greater in the immediate resuscitation group compared with the delayed resuscitation group.

Several possible explanations have been offered for this observation, including decreased oxygen-carrying capacity from accelerated hemorrage. The statistically lower hemoglobin levels on arrival in the emergency department for patients who received prehospital fluid resuscitation was more pronounced than those predicted by simple hemodilution alone.

Again, these findings suggest that prehospital fluid might be harmful in patients with penetrating injuries to the torso and presumed internal bleeding in an urban emergency medical services (EMS) system with rapid transport intervals. Concern over more prolonged periods of hypovolemia without fluid resuscitation still exists, however, particularly in patients with blunt injury. More importantly, the definition of “prolonged” must be clarified. Above all, the dilemma of maintaining perfusion to the brain and other vital organs in patients with closed head injury remains a significant worry. Further study is required in venues in which there are prolonged transport times and potentially long delays until definitive surgical hemostasis. Also, many investigators consider blunt trauma a disease of massive soft-tissue injury and systemic inflammation, making it much different from the more focused penetrating injury that primarily leads to more localized injury and bleeding.

**CONCLUSION**

The liberal use of fluid infusions for patients with presumed uncontrollable internal hemorrhage, such as that usually occurring after penetrating abdominal and thoracic injuries, is no longer advised. In fact, this recommendation is not new but actually long established, if one considers the observations made during past wars. Although some infusion may be appropriate in patients with extremely severe internal hemorrhage, the priority in such patients is rapid transport to definitive surgical hemostasis.

The use of fluid infusions in patients with blunt trauma is not always clear. For patients with isolated extremity and head injuries (blunt or penetrating), immediate support of blood pressure through fluid infusions is considered beneficial when the bleeding is controllable. However, potential intra-abdominal, intrapelvic, or intrathoracic injuries and bleeding complicate the picture. Although blood pressure support through judicious use of isotonic or hypertonic fluid resuscitation generally has seemed reasonable, some recent experimental data even challenge this approach.

As implied in the preceding discussion, the traditional management of trauma in the prehospital setting paradoxically has been complicated by well-intentioned attempts to simplify it. Most EMS systems worldwide have developed treatment algorithms that often do not delineate between the different mechanisms of injury or anatomic location of wounds. The result has been mistreatment or misunderstanding of conflicting study data. In that respect, the classic debate of “scoop and run” versus scene stabilization has by definition oversimplified prehospital care strategies. Confounding the discussion further, only a few prospective controlled clinical trials have been conducted to validate or refute the prehospital interventions currently used for major trauma patients. Future discussions of the epidemiology, research, and ultimately management of trauma should include discrimination of the mechanism of injury (i.e., blunt versus penetrating versus thermal injury), anatomic involvement (i.e., truncal versus extremity versus isolated head injury), and staging of the condition (i.e., hemodynamic stability versus instability versus moribund state). In particular, the controversial issue of prehospital care for trauma patients with potential internal hemorrhage, with or without head injury, needs to be examined more closely. Finally, the various types of colloid and crystalloid fluids also need to be examined more closely, as does the development of oxygen-carrying media. In all of these cases, the confounding factor of current ventilatory techniques for severely injured patients must be considered as well.

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**Consensus Presentation**

The consensus group agreed that both animal and human trials indicate that patients respond differently to the various types of major trauma. Trauma patients are not a homogeneous group, and they vary in their physiologic reactions to the injury according to type and severity of the injuries they sustain. Some patients deteriorate into circulatory arrest, others develop severe shock states, and some remain in a hemodynamically stable condition. The mechanism of trauma and its anatomic involvement can significantly affect these responses and, in turn, influence the appropriate approach to fluid resuscitation. In addition, age and comorbidities can be significant factors. Children may have different fluid replacement requirements than do adults. Even among adults, the fluid replacement requirements of a younger person, both in terms of rates and absolute amounts, may differ from those of an elderly person, who might have several comorbid conditions. Thus no single recommendation can be made for prehospital fluid resuscitation of trauma patients.

In addition to patient variables, the resources and characteristics of the EMS system influence prehospital fluid resuscitation decisions. For example, the time it takes to transport the patient from the scene to the operating room may be a critical factor in determining appropriate fluid volumes and rates. Therefore, the consensus participants suggested that EMS providers collaborate with local and regional trauma services to develop a coordinated approach to fluid management in the trauma patient.

**Controller Hemorrhage**

The consensus group noted that a truly controlled hemorrhage is rare in the prehospital setting. A better term might be controllable hemorrhage, which reflects the likelihood that if bleeding were to occur, EMS providers would probably be able to control it. This generally applies to extremity injuries or superficial soft-tissue wounds of the trunk.

In the trauma patient with controllable hemorrhage, the consensus group recommended resuscitation with intravenous fluids if the patient shows clinical signs of shock, such as altered mental status or poor peripheral perfusion. Use of capnography, if available, was recommended as a potential means of evaluating perfusion.

Adequate volume should be infused to reverse clinical signs of shock while ensuring continued hemostasis. Fluid could be administered as intravenous boluses, the volume based on factors such as the patient’s hemodynamic status, age, and comorbidities and the amount of the hemorrhage. After each bolus, patients should be reassessed and given additional boluses as indicated. Reassessment should include examination of lung sounds and respiratory status for evidence of pulmonary edema.

**Uncontrollable Hemorrhage**

Based on the best available data, the appropriate approach to fluid resuscitation of a trauma patient with presumably uncontrollable hemorrhage largely depends on the mechanism of injury, be it penetrating or blunt, the anatomic involvement, and the severity of the physiologic compromise.

**Penetrating Trauma**

For the patient with penetrating trauma and presumed uncontrollable hemorrhage, the goal is to keep the out-of-hospital time as short as possible. Along with rapid evacuation, maintaining an open airway and ensuring adequate ventilation and oxygenation are the first priorities. Intravenous access, preferably with large-bore catheters, should be established en route to the hospital.

Although the available data are not definitive, for patients with presumed uncontrollable hemorrhage who show some signs of shock but are not near imminent circulatory arrest (e.g., responsive to verbal stimuli, palpable pulse), the amount of fluid administered should be limited. Intravenous access with two large-bore catheters should still be established en route to the hospital, but fluids should be limited to “keep vein open” (KVO). Small titrated boluses may be considered in some patients with severe tachycardia and those who show signs of further hemodynamic deterioration. However, there is insufficient clinical research to define the role of fluid administration more precisely in these patients.

Moribund patients with near-fatal injuries are reasonable candidates for more immediate fluid resuscitation. These patients typically have signs of extreme fluid resuscitation. These patients typically have signs of extreme shock (e.g., unresponsive to verbal stimuli, no palpable peripheral pulse). As fluid is being administered, the patient’s status should be continuously assessed. Once signs of improvement are noted, such as return of pulses or improved mental status, the rate of fluid administration can be tempered. The overall goal is not to return patients to a state of normal perfusion but rather to achieve perfusion adequate enough to maintain viability of vital organs until the time of definitive intervention.

**Blunt Trauma**

Although many trauma life support courses recommend that 2 liters of fluid be given to all
TABLE 1. Prehospital Fluid Resuscitation of Trauma Patients: Summary of Consensus Group Recommendations

- Discriminate between blunt, penetrating, and thermal injury or combinations thereof (e.g., blast injury).
- If there are concerns about potential internal or other uncontrollable hemorrhage, rapidly evacuate and transport the patient to definitive surgical facilities where hemostasis can be achieved.
- Manage the airway as indicated. Maintain airway patency, adequate oxygenation, and adequate ventilation. Avoid hyperventilation with positive-pressure breaths (either high respiratory rates or excessively large tidal volumes (>15 mL/kg)) because they can compromise cardiac output (due to decreased venous return) and cerebral perfusion (due to cerebral vasoconstriction). Respiratory rates of 8 to 10 breaths/min are generally adequate for patients with shock and even fewer (6 to 8 breaths/min) for those with circulatory or near-circulatory arrest.
- Establish intravenous access with large-bore catheters.
- If bleeding can be controlled (e.g., an isolated extremity injury), provide rapid intravenous fluid infusions for patients with blunt or penetrating trauma who show signs or symptoms of compromised circulation.
- In patients with penetrating trauma, infuse isotonic intravenous fluids if the patient is moribund (unconscious, no palpable pulses); otherwise, restrict fluid infusions, particularly in patients with penetrating torso injuries.
- In patients with blunt trauma, especially those with severe head injury, provide enough intravenous fluid infusion to maintain perfusion using clinical judgment but avoid excessive fluid administration (because of the theoretical risks of cerebral and pulmonary edema and secondary hemorrhage). Recognize that proper endpoints for determining adequacy of fluid resuscitation are still unknown.
- Consider end-tidal carbon dioxide (ETCO₂) monitoring as an adjunct to identify patients with severe circulatory compromise.
- Establish a coordinatedprehospital treatment protocol with local and regional trauma services.

Although the consensus was that intravenous fluid administration be based more on the patient’s clinical condition. Although underresuscitation must be avoided, providers should recognize that overresuscitation can also be harmful. The group agreed that the cookbook approach of at least 2 liters of fluid to all trauma patients and the approach that volume can be administered copiously without consequence should be discouraged.

Although the consensus was that fluid administration generally should be more liberal in patients with blunt trauma, particularly those with signs of shock, the consensus group recommended that intravenous fluid administration be based more on the patient’s clinical condition. Although underresuscitation must be avoided, providers should recognize that overresuscitation can also be harmful. The group agreed that the cookbook approach of at least 2 liters of fluid to all trauma patients and the approach that volume can be administered copiously without consequence should be discouraged.

Although the consensus was that fluid administration generally should be more liberal in patients with blunt injury than in those with penetrating injury, most patients with blunt trauma still should receive just enough prehospital fluid to maintain perfusion. Volume overload should be avoided to prevent complications such as pulmonary edema and the potential for worsening hemorrhage. The difficulty remains in terms of understanding how much and how fast to infuse, if at all.

Patients with closed head injury present a particular challenge. Intravascular volume support may be necessary to maintain cerebral perfusion and prevent secondary cerebral injury, but excess volume can increase cerebral edema and intracranial pressure. Pending further research to determine best clinical practices, EMS providers should consider these concerns when assessing and treating individual patients.

Again, the principal difficulty faced by the consensus group in discussing fluid resuscitation in blunt trauma is that the proper volume and rate for initial resuscitation in such patients, using current techniques, are unknown. More importantly, just as elusive are the proper endpoints to be measured that would guide such therapy. Overall, the group generally would err on the side of beginning to give fluids en route to hypotensive patients with blunt trauma, especially those with severe head trauma and those with any clear clinical signs of shock.

prehospital factors

The consensus group considered how EMS providers can determine the patient’s perfusion and metabolic status using available techniques. Checking pulses and blood pressure can be difficult in the trauma patient, and these measurements are crude estimates of actual perfusion. Assessment of mental status as a sign of shock can be confounded by the presence of head injury, drugs, or alcohol. The participants agreed that ETCO₂ can be a useful adjunct, particularly in patients who have already been intubated, to assess perfusion in low-flow states. End-tidal carbon dioxide measurements provide an indication of changes in cardiac output and tissue perfusion. If a patient is in severe shock, ETCO₂ levels will be very low. Ventilation generally should be kept constant when using capnometry to assess perfusion. However, positive-pressure breaths can be detrimental in patients with severely compromised circulation, serving to confound the shock state even further. Therefore, in trauma patients with presumed hypovolemia and severe circulatory compromise, infrequent breaths, using 10 to 15 mL/kg tidal volume, are recommended as the constant. In EMS systems that have capnometry available, EMS providers should receive specific training in its use.

In some EMS systems, transport to the hospital may be prolonged, particularly if air medic units are unavailable or the system is located in a rural setting. This extended prehospital phase places an even greater burden on EMS personnel.
The risks to the patient become greater, and prehospital providers must be more rigorous and careful in their assessment and management. Because patients may be in severe shock for an extended period, the possibility of underresuscitation with fluids may be greater. Paradoxically, these patients are at higher risk for overresuscitation with fluids as well. Therefore, the recommendation for those experiencing extended prehospital phases of care is to limit intravenous fluids to the amount needed to reverse severe shock and to prevent the possible risk of excess fluid. Rescuers should also keep in mind that patients with crush syndrome may have a greater need for fluids than those without crush syndrome.

CONCLUSION

Because trauma patients are not a homogeneous group, fluid resuscitation in the field must be individualized according to the mechanism, anatomic involvement, and severity of the injury, as well as certain patient characteristics and estimated transport time to definitive surgical intervention. The consensus group agreed on certain points for prehospital fluid resuscitation, as summarized in Table 1. However, they also agreed that many questions remain unanswered regarding optimal prehospital fluid management. For example, proper clinical endpoints for the optimal type, amount, and rate of fluid to be administered are unknown. Clinical markers of adequate perfusion also are suboptimal. Consequently, no firm recommendations can be made as to what markers EMS providers should use to determine the appropriate use of fluid resuscitation.

References


ABSTRACT

Background  Automated external defibrillators save lives when they are used by designated personnel in certain public settings. We performed a two-year prospective study at three Chicago airports to assess whether random bystanders witnessing out-of-hospital cardiac arrests would retrieve and successfully use automated external defibrillators.

Methods  Defibrillators were installed a brisk 60-to-90-second walk apart throughout passenger terminals at O’Hare, Midway, and Meigs Field airports, which together serve more than 100 million passengers per year. The use of defibrillators was promoted by public-service videos in waiting areas, pamphlets, and reports in the media. We assessed the time from notification of the dispatchers to defibrillation, survival rate at 72 hours and at one year among persons with cardiac arrest, and the device correctly indicated that the problem was not due to ventricular fibrillation. The rescuers of 6 of the 11 successfully resuscitated patients had no training or experience in the use of automated defibrillators, although 3 had medical degrees. Ten of the 18 patients with ventricular fibrillation were alive and neurologically intact at one year.

Conclusions  Automated external defibrillators deployed in readily accessible, well-marked public areas in Chicago airports were used effectively to assist patients with cardiac arrest. In the cases of survivors, most of the users had no duty to act and no prior training in the use of these devices. (N Engl J Med 2002; 347:1242-7.)

CARDIOVASCULAR disease remains the most common cause of death in the United States and most other Western nations. Among these deaths, sudden, out-of-hospital cardiac arrest claims approximately 1000 lives each day in the United States alone. Most of these cardiac arrests are due to ventricular fibrillation. Though highly reversible with the rapid application of a defibrillator, ventricular fibrillation is otherwise fatal within minutes, even when cardiopulmonary resuscitation is provided immediately. The overall survival rate in the United States is estimated to be less than 5 percent.

Recent developments in automated-external-defibrillator technology have provided a means of increasing the rate of prompt defibrillation after out-of-hospital cardiac arrest. After minimal training, nonmedical personnel (e.g., flight attendants and casino workers) are able to use defibrillators in the workplace, with life-saving effects. Nonetheless, such programs have involved designated personnel whose job description includes assisting persons who have had sudden cardiac arrest. Data are still lacking on the success of programs in which automated external defibrillators have been installed in public places to be used by persons who have no specific training or duty to act.

Beginning in June 1999, the City of Chicago placed highly visible, readily accessible automated external defibrillators for public use at its municipal airports under the auspices of the Chicago HeartSave Program. We evaluated the success of the program.

METHODS

Study Design  This two-year, prospective, observational study evaluated how often bystanders used automated defibrillators placed in high-traffic locations — airports — and determined the resulting survival rates. The study sites were the three Chicago airports: O’Hare (1,735,561 ft² of terminal space [161,240 m²] and 80 million passengers annually), Midway (259,408 ft² [24,100 m²] and 20 million passengers annually), and Meigs Field (7000 ft [650 m²] and 77,000 passengers annually). The percentage of people with training in cardiopulmonary resuscitation who pass through these airports is not known. Since 1999, basic training in cardiopulmonary resuscitation is provided immediately.
ciscation and the use of automated external defibrillators has been provided to a total of 450 airport police, security personnel, and public-safety dispatchers. Similar training has been made available, on a voluntary basis, to other airport-based employees (i.e., personnel without a specific duty to act in a medical emergency) from both the public sector (e.g., customs and immigration agents and members of the airport commissioner’s staff) and the private sector (e.g., restaurant vendors and custodial workers). During the study, approximately 3000 of 44,000 airport workers were trained. Other potential users of the defibrillators are flight attendants, who have been trained in the in-flight use of defibrillators.17,20

Defibrillators

On June 1, 1999, 33 publicly accessible automated defibrillators were installed throughout the O’Hare terminals. By February 1, 2001, 9 more had been placed in public areas and 17 had been placed in areas that were not accessible to the public (e.g., maintenance and secured baggage areas). Initially, 7 defibrillators were installed at Midway (10 as of March 13, 2001) and 1 at Meigs. Defibrillators were housed in glass-faced cabinets a brisk 60-to-90-second walk apart (Fig. 1). Indicator signs similar to those for toilets and telephones were placed in highly visible positions, usually above concourse walkways, adjacent to the defibrillators. Warning signs cautioned against tampering with or inappropriate use of defibrillators. Cabinets were equipped with audible alarms, strobe lights, and dispatcher alerts (to indicate the site) that were activated when the cabinet door was unsealed. Police, security personnel, and emergency-medical-services personnel were then dispatched to the indicated location unless follow-up callers provided more exact information.

Three-minute public-service announcements were played every half hour on television monitors in waiting areas, indicating the availability of the automated defibrillators, explaining their purpose, and encouraging their use. Printed materials were made available to the public and distributed to the airlines in bulk. Three public training sessions on the use of automated external defibrillators and cardiopulmonary resuscitation were held at various locations in Chicago, and numerous local and national media reports promoted the program.

The Chicago HeartSave Program was approved by the Chicago municipal government as an adjunct to its emergency-medical-services system. The study was considered part of a routine evaluation of the initiative. Participation by the bystanders was entirely voluntary, and informed consent was neither sought nor obtained. The State of Illinois has good-Samaritan laws that protect those who voluntarily provide cardiopulmonary resuscitation to others against litigation.

The defibrillator used (Model E, ForeRunner, Heartstream) delivers a biphasic, truncated exponential defibrillatory wave form and about 150 joules with each shock.22 A single-channel, liquid-crystal electrocardiographic tracing is displayed across the surface of the defibrillator.

Collection of Data

When activated, digital data cards within the defibrillator record electrocardiographic data, rescuers’ voices, machine prompts, thoracic-impedance values, the amount of energy delivered, and the time of all events; data from the cards are downloaded for analysis. Security officers also complete incident reports, which include contact information for the patients and those who assisted them, information on whether bystanders performed cardiopulmonary resuscitation, and information obtained from interviews with the...
persons who provided assistance. We abstracted data from the paramedics’ records on patients’ condition at the time of the arrival and departure of emergency-medical-services personnel and at the time they arrived at the hospital.

Although the actual time of the collapse could not be determined definitively, the time from the notification of dispatchers (e.g., as a result of opening the defibrillator-cabinet door or a telephone call) to the delivery of the first shock was documented with the use of automated clocks at dispatch centers and data cards from the defibrillators. Dispatch and data-card–computer clocks were synchronized prospectively and checked regularly to ensure accuracy.

A patient’s neurologic status, assessed at the scene and at the hospital and reassessed one year later over the telephone by one of the investigators, was defined as good if the patient had a cerebral performance category score of 1 (normal) or 2 (minimal disability).23,24 The time from the delivery of the first shock to the patient’s initial return to consciousness, defined by a purposeful response to spoken commands, was documented, as was the number of shocks required for initial conversion or restoration of spontaneous pulses.

Complications were defined as defibrillator tampering, inappropriate delivery of shocks by the automated defibrillator, failure of the defibrillator to deliver a shock in response to ventricular fibrillation, malfunction of the audible and visual alarms or prompts of the defibrillator, inappropriate use of the defibrillator by rescuers, or injury of rescuers or other bystanders as a result of use of the defibrillator.

RESULTS

Characteristics of the Patients

Between June 1, 1999, and May 31, 2001, an automated defibrillator installed as part of the HeartSave Program was used for 21 persons at O’Hare, 5 at Midway, and none at Meigs. Among these 26 patients, 4 did not have cardiac arrest: 2 persons had seizures, 1 had shortness of breath (the defibrillator was used as a diagnostic tool by an off-duty paramedic), and 1 person, in the custody of immigration officials, feigned a syncopal episode. The defibrillators functioned appropriately — no shock was administered — in the cases of all four patients. Four additional persons with ventricular fibrillation were defibrillated with equipment that was not supplied by the HeartSave Program: three collapsed near gate areas and were defibrillated by nearby flight attendants using defibrillators from airplanes, and a fourth initially underwent defibrillation by paramedics with their own equipment.

Of the 22 patients with cardiac arrest for whom an airport-terminal defibrillator was obtained, a 33-year-old man had an arrest after a long fall and a 60-year-old man was found dead on a transit-system train. Of the 21 patients with nontraumatic cardiac arrest, 2 were women (age, 78 and 81 years) and 19 were men (median age, 58 years; range, 44 to 86). Nineteen were travelers, one was an airport employee, and one was a visitor.

Excluding the patient with trauma and the man who was found dead on the train, there were 20 patients with witnessed cardiac arrest. Although pulseless, two patients presented with some organized electrocardiographic activity. The remaining 18 (90 percent) presented with ventricular fibrillation; this group comprised both women and 16 men. The characteristics of these 18 patients are provided in Table 1.

Outcome of Defibrillation

The automated defibrillator functioned correctly in all 18 patients with ventricular fibrillation, immediately determining the need for and delivering shocks. In all 18 patients, the defibrillators were retrieved and operated by travelers or airport employees before the arrival of the emergency-medical-services crews. In the cases of four of the seven patients who died, the defibrillator was not immediately accessible (e.g., two patients on airplanes) or was not accessed within five minutes after collapse. Three others remained in persistent ventricular fibrillation and eventually died despite rapid use of the defibrillators (within five minutes). Two of these patients received seven and nine defibrillator shocks, respectively, before the paramedics arrived.

Eleven of the patients with ventricular fibrillation regained spontaneous circulation and eventually regained consciousness. Four returned to consciousness before the paramedics arrived, two during transport, two in the emergency department, and another three after hospitalization. For 9 of these 11 patients, defibrillators were retrieved and used by bystanders within five minutes. The other two did not receive a shock for seven minutes, but they received immediate cardio-pulmonary resuscitation. All 11 had good neurologic outcomes before discharge (with a cerebral performance category of 1), and 10 were alive at one year. One patient died of other sequelae weeks after cardiac arrest. The long-term survival rate with a good neurologic outcome among all 18 patients with ventricular fibrillation was 56 percent (regardless of the location of cardiac arrest), and it was 67 percent among the 12 patients who underwent defibrillation within five minutes.

Characteristics of the Rescuers and Complications of Defibrillation

With two exceptions, the operators of the defibrillators were good Samaritans (airline passengers or airport employees) who had no duty to act, and all used the defibrillators voluntarily and correctly (Table 1). In 6 of the 11 cases in which patients were successfully resuscitated and regained consciousness, the defibrillator users had neither operated an automated external defibrillator previously nor been trained in its use, although three were physicians. No complications occurred. One of the 53 defibrillators was stolen during the two-year period.
DISCUSSION

The results of this study demonstrate the lifesaving potential of public access to defibrillation. Most of the patients with ventricular fibrillation in the study were resuscitated within minutes by good Samaritans who had immediate access to an automated defibrillator. The overall one-year survival rate with a good neurologic outcome regardless of location was 56 percent. In contrast, survival rates are estimated to be less than 5 percent with the use of conventional, “rapid-response” emergency medical services. Traditionally, most resuscitated patients are still comatose on hospital admission, and typically, more than half never regain consciousness. Our results reflect a substantial change in that traditional clinical course.

Given the expected lifetime of the defibrillators installed by the HeartSave Program (a minimum of about 10 years), the cost of the program at the three Chicago airports, including the devices, cabinets, alarm systems, and quality-assurance measures, averages about $35,000 a year. On the basis of our results, this figure translates to a cost of about $3,000 per patient and about $7,000 per life saved. Our finding that the majority of patients who underwent successful defibrillation were conscious before reaching the hospital also has implications for the immediate use of medical resources (such as the need for mechanical ventilation and treatment in the intensive care unit) and for long-term cost effectiveness. Nevertheless, further economic analyses are needed to confirm these potential cost savings.

Despite the central role of the automated defibrillator, the performance of cardiopulmonary resuscitation by bystanders may also have contributed to the good outcomes in this study. All survivors received cardiopulmonary resuscitation, and one received cardiopulmonary resuscitation for 10 minutes between episodes of ventricular fibrillation before eventually being resuscitated. Even under optimal conditions, some time elapses before the first shock can be delivered. In one case, two HeartSave personnel who were standing next to an automated defibrillator...
witnessed the collapse. Still, it took at least two minutes for these experts to ready the patient and the equipment. These considerations and the role of basic cardiopulmonary resuscitation must be kept in mind when program designers are calculating predicted response intervals. In the cases of four of the seven patients for whom defibrillation was unsuccessful, the arrest occurred far from the main terminal and ticket-counter areas, and the response was thus delayed. Previous work has made clear the inverse association between the time needed to respond and survival. Of the patients who collapsed in a terminal for whom a defibrillator was retrieved and used within five minutes, 75 percent were resuscitated and rapidly regained consciousness.

Three patients remained in fibrillation despite a rapid response. All three had diabetes and were described as obese in medical records. Other data have suggested that obesity and diabetes may decrease the success of external defibrillation. We did not systematically collect data on these clinical features, and thus we cannot address their frequency among patients who underwent successful defibrillation.

The program we studied has some unique advantages. Although most cardiac arrests occur at home (70 to 80 percent), airports may be the public places with the highest concentration of cardiac arrests. O'Hare is used by many thousands of persons daily, including many health professionals and other persons who are likely to know how to perform cardiopulmonary resuscitation and who thus may feel more comfortable acting in such situations. Three of the seven rescuers without training or experience in the use of an automated external defibrillator had medical degrees. Thus, it is not known whether these results can be generalized to other public places that may be less frequented by health professionals.

Previous studies have demonstrated that targeted nonmedical personnel can be trained as part of their job descriptions to use automated external defibrillators in public venues, including casinos and airplanes. Our findings showed that bystanders will voluntarily aid persons with cardiac arrest and can do so successfully, even without prior training in the use of defibrillators. The survival rates were similar to (or exceeded) those in prior studies. Although many rescuers were airport employees (i.e., custodians, customs or immigration officials, or wheelchair assistants), the majority had taken cardiopulmonary-resuscitation courses voluntarily and had no specific duty to act. Studies demonstrate that even sixth-grade children can use automated external defibrillators without prior instruction. In our study, 6 of the 11 successfully resuscitated patients were resuscitated by persons who had neither previously operated an automated defibrillator nor been specifically trained in its use. Although three had medical degrees and another was a health professional, this attribute does not imply that such persons have a duty to act or are comfortable using an unfamiliar device.

Although training in cardiopulmonary resuscitation and the use of automated external defibrillators is strongly encouraged for everyone, our findings suggest that the lack of such training should not constrain attempts to use a defibrillator in emergencies. Given the safety of these devices and our results, reasonable public health strategies would be to promote good Samaritan laws; encourage the development of less expensive, more user-friendly automated defibrillators for public deployment in appropriate locations; and undertake aggressive public-education campaigns that promote the idea that anyone is capable of immediate action in such situations.

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ABSTRACT

In this discussion, two principal types of ambulance deployment systems were compared and contrasted: 1) the multipurpose, sole-provider all–advanced life support (all-ALS) ambulance system in which all ambulance-related services (emergent and nonemergent) for a city or region are provided by one fleet of ambulances, each of which is staffed by ALS providers (paramedics); and 2) the tiered ambulance system (tiered) in which some 911 ambulances are staffed by paramedics and others are staffed by basic emergency medical technicians (EMT-Bs) who provide basic life support (BLS) care. When managed with advanced system status management (SSM) techniques, the multipurpose, sole-provider all-ALS ambulance system can significantly reduce response intervals while simultaneously providing both fiscal and operational efficiencies. It can also be used to readily integrate and expand the scope of services for the ambulance provider service, such as interfacility transfers, thus increasing revenues. On the other hand, in large urban centers, the tiered ambulance system can be used to reduce response intervals to critical calls, primarily through the use of sophisticated dispatch triage protocols. This approach requires fewer paramedics in the system and appears, in some systems, to also provide medical care advantages in terms of skills utilization for individual ALS providers as well as a more concentrated focus for medical supervision. Therefore, both of these deployment systems can offer certain advantages depending on local emergency medical services (EMS) system needs as well as the local philosophy of health care delivery. Applicability must therefore be considered in terms of local service demands and other factors that affect the EMS system, including catchment population, statutory and jurisdictional issues, available funding, accessibility of receiving facilities, and medical quality concerns. Key words: advanced life support; tiered-response; ambulance; emergency medical services; EMS; paramedics; public safety.

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A community’s ambulance system logically includes all resources involved in providing ambulance services, regardless of the phone number dialed to initiate service (e.g., 911 vs nonemergency transfer number). The question of whether the public is best served by integrating or segregating service delivery in response to these two access paths is central to choosing between the flexible production strategy (i.e., a single fleet of all-purpose ambulances) and the specialized production strategy (i.e., two or more specialized fleets or “tiers,” each intended to serve a distinct segment of the ambulance service market).

Two major types of ambulance systems for delivering prehospital emergency care have been developing in the United States since the 1970s. One is the all–advanced life support (all-ALS) system, in which all ambulance services for a city or region are provided by one fleet of ambulances, each of which is staffed by paramedics. The other is the tiered-response system, which may involve several fleets of ambulances in which some ambulances are staffed by emergency medical technicians (EMTs) with basic life support (BLS) training and others are staffed by paramedics. This paper discusses the advantages and disadvantages of each system.

THE ALL-ALS SYSTEM

The true all-ALS ambulance systems are all-ALS systems in which a single fleet of ALS ambulances provides all 911 and non-911, emergency and nonemergency, scheduled and unscheduled ambulance response and transportation for a community or region. Exceptions may be those air and ground critical care transports that operate clinically beyond the capabilities of a paramedic ambulance. These are related but separate markets, in the
same sense that wheelchair and courtesy car transports are also related but separate markets.

The all-ALS ambulance system is most effective within the context of a full service contract involving all the services listed above as well as an advanced system status management (SSM) program, a technique by which ambulance staffing and deployment are linked to the predicted temporal demand for service. An SSM program can be difficult to implement and maintain. However, it can improve response time reliability, customer service, and economic efficiency. Within the traditional configuration of SSM, operation of a two-tiered system is more difficult.

Throughout most of the United States, ambulance system design is the product of local government policy. In making these decisions, elected officials may address or ignore the question of value, depending on competition for local tax dollars. Where dollars are scarce, a choice must be made: either impose budgetary restrictions and compromise service or implement a more efficient (as determined by dollars to service ratio) system.

Findings from a recent unpublished survey of 13 all-ALS systems, including several regional systems, appear to emphasize the economic advantages of an all-ALS system. Services within the systems surveyed included 911 and seven-digit telephone access, medical priority dispatch service (MPDS), emergency and nonemergency ambulance service, interfacility and long-distance patient transport, special events coverage, and 5% to 10% out-of-area response. The total population of these markets was 7,043,000 and the annual cost for all-ALS systems was $129,249,000. The average monthly per-capita cost was $153 ($18.36 per year), ranging from about $1.20 to $2.20 ($14.40 to $26.40 per year). The cost per unit hour ranged from $37 to $110. In all but one of the 13 systems, more than 80% of costs are recovered from fee-for-service billings.

Tiered systems may require several times the level of local tax support available to these types of multipurpose, sole provider all-ALS ambulance systems, even when user fees are approximately the same. Local tax subsidies can range from $12 to $26 per capita per year and most fall into the range of $15 to $20. Local tax support for all-ALS ambulance systems can be as low as zero to $5 or $6 per capita per year. The question, therefore, is not whether tiered-response systems provide something of value. The question is whether alternative system structures given the same financial resources will deliver more. Since all-ALS ambulance systems can be funded at a level much lower than that of typical tiered systems, that question is open. To justify current funding differences, however, tiered systems would have to provide service dramatically superior to that of all-ALS ambulance systems. Whether they do is a matter of debate. It is a case of “competitive value” i.e., best service from the dollars available.

A multipurpose, sole-provider all-ALS system under one administrative authority has many other advantages. It is especially useful in regional, multijurisdictional systems, where units should be interchangeable. Under such circumstances, it can improve productivity and on-time reliability. It allows full accountability, since all units in the regional system, including emergency, nonemergency, interfacility, and often fire units, have a single medical director and integrated financial control. It has the potential to enhance disaster capability, since many ALS units can be deployed quickly. In a tiered system, a BLS unit could potentially be sent to a scene in which ALS might have been used, and the system could occasionally lose money because the procedures may not be billed as “ALS.” This problem does not arise as often in all-ALS systems, resulting in increased fee-for-service revenues. Some of the cost-efficiencies and enhanced revenues of an all-ALS system may therefore help to equip ambulances with new technologies more readily.

Certain paramedics may prefer the mixture of emergency and nonemergency work that comes with an all-ALS system. Although only about half of a paramedic’s case load may be 911 emergency patients, the paramedic may see more emergency patients (ALS and BLS) than does a counterpart in a tiered system because individual ambulances in all-ALS systems might be utilized more often. The percentage of cases requiring ALS still remains low, however.

The Tiered-response System

In early pioneer emergency medical services (EMS) programs, such as Seattle’s Medic One service, it was found that paramedic response interval correlated well with survival after cardiac arrest. It seemed logical to conclude that increasing the number of paramedics could improve response times. As a result, there was understandable enthusiasm for placing paramedics on every ambulance in many venues and thus providing universal access to the highest level of prehospital care.

However, it was eventually recognized that the vast majority of 911 calls do not require ALS intervention (<5%) and cardiac arrest accounts for fewer than 1-2% of EMS calls. No more than 15% of patients need any type of ALS procedure or monitoring. In other words, paramedics (ALS providers) are not needed for the great majority of EMS calls. In retrospect, basic EMTs could safely manage as many as 90% of calls.

This, in part, was the reason for the development of multi-tiered response systems. Also, the EMS Act of 1973 added impetus to this approach. Embedded in the EMS Act of 1973 were the assumptions that the tiered system structure was desirable and that there was the need for substantial ongoing local tax support. Local commitment to provide ongoing subsidy for the system was a prerequisite to receive an EMS Act grant award. This is still reflected in present Medicare regulations and payment practice.

Nevertheless, analysis was not performed on all-ALS ambulance systems or other alternative systems prior to the adoption of the act. No studies of patterns of demand, alternate methods, or economic modeling were done, and with an increasing number of publications
in the 1970s that correlated paramedic response intervals and survival, a growing enthusiasm evolved for “all-paramedic” ambulance systems. By the 1980s, many large cities (Los Angeles, Chicago, Houston, Dallas, Phoenix, etc.) began to operate all-paramedic 911 ambulances. Also, to improve response intervals even further, the number of ALS ambulances in the fleet was increased as well. Generally, the more reimbursable non-emergency services were left to the private ambulance sector. It wasn’t until the early 1980s that the system managers began to question whether the public is best served when emergency services are financially and operationally separated from nonemergency services, or whether an all-ALS system was superior to a tiered ALS/BLS ambulance service.

In the 1980s, because of steadily rising costs, attempts were made in some venues to move away from a relatively nonstructured approach of simply placing increasing numbers of all-ALS ambulances at fixed locations. In some venues, this was approached by exploring the concept of the “multipurpose,” sole-provider all-ALS system previously described. In other venues, it was approached by implementing tiered ambulance response systems. The tiered-response system can be structured to include anywhere from two to four (or more) tiers of ambulance service, depending on how the different types of calls for service are handled.

As an example, the city of Houston (population, 1.7 million) addressed the problem of improving response intervals by creating a triage procedure to spare paramedics for critical cases. In the mid-1980s, cardiac arrest survival rates were extremely low and the annual rate of paramedic attrition was between 15% and 20%. Houston at that time had a three-tiered ambulance system (i.e., a fleet of fire-based ALS ambulances doing 911 work, plus multiple fleets of private ALS units doing some of interfacility work, plus multiple fleets of private BLS ambulances doing the remaining non-911 work. However, from the emergency (911) response point of view, the system was “all-ALS.”

Nevertheless, despite this presumed advantage, the county medical society was concerned about low survival rates. There was a widespread perception that the EMS program existed not so much to save lives but to provide an expensive public medical transportation service. Expanding or even just maintaining the 35 paramedic-staffed 911 ambulances was increasingly expensive and it was becoming economically difficult to add more ambulances to the system. Alternative methods were sought.

It was noted in meta-analyses of published reports that some cities with high survival rates did not operate all-ALS systems. Impressive outcomes were reported by Seattle and the Milwaukee suburbs, and both had tiered ALS/BLS ambulance services based in fire departments. The City of Houston reconsidered the way that it provided services. The system was to be changed from 35 paramedic units to 15 dedicated ALS units staffed by two paramedic partners, 15 dedicated BLS units staffed by two EMT cross-trained firefighters, and five hybrid ALS-BLS units assigned to outlying areas. By July 1987, a custom-designed, computerized dispatch triage system was in place that made it possible to forgo the use of ALS units in nearly half of the 911 calls (BLS only dispatch) and to forgo the use of ALS units for transport in about another 15% of calls, leaving ALS more available for critical calls. Undertriage was rare, including about ten of 35,075 patients in one analysis. In essence, Houston’s “all-ALS” 911 ambulance response system was replaced with a four-tiered ambulance system (i.e., by retaining the private ALS and BLS fleets, reducing the size of the ALS 911 fleet, and adding a BLS 911 fleet.

Paradoxically, despite half as many 911 ALS units, after the change-over, the response interval for paramedics to critical cases improved due to increased availability. Skills were also refined with increased opportunities to use them. For example, success with initial endotracheal intubation attempts rose from about 91% to 99.8%. Fewer paramedics translated into a savings of about $750,000 per year in training costs. Concurrently, use of the tiered system improved morale, as demonstrated by reversed attrition among paramedics. Also, it became more feasible for the medical director to focus effectively on the training needs of a small cadre of highly skilled, relatively busy people. In essence, although there were fewer paramedics, survival rates improved. Because of the existence of other variables, such as increased bystander CPR, it is impossible to know how much of this survival improvement was specifically attributable to changes in the ambulance deployment system. It is clear, however, that in urban settings, use of a tiered system of ALS/BLS ambulances can improve both skills and ALS response intervals for the critical calls in which they are needed.

There are small groups of patients who may be at risk in a tiered system. This includes those non-911 patients requiring ALS-level interfacility transfers by a tiered system in which the crews do not routinely respond to emergency calls and may not enjoy the caliber of medical oversight available to 911 crews. This also includes potential 911 patients who from faulty self-triage use a seven-digit direct access to non-911 fleets—a risk that can be avoided in certain single-provider all-ALS systems because all requests from the public, whether 911 or not, are answered by the same dispatch personnel using the same priority-dispatch protocols, regardless of call origin. However, these events are generally rare and low-risk.
It is difficult if not impossible to directly compare performance and cost-efficiency parameters between the all-ALS and tiered models because of the many variables associated with these systems. However, it is important to determine the potential strengths and weaknesses of each model and to consider how local factors might favor one over the other. This discussion will assist local EMS leaders in choosing a model that will provide the highest-quality service with the available resources.

**The Role of Dispatch**

Consideration should be given to the way in which different system factors affect the decision of whether to adopt a tiered or an all-ALS ambulance system. Each system should have some type of priority dispatch and call management program, assisted by decision trees.

The interaction between the sensitivity of triage and ambulance tiering is especially complex. The existence of highly sensitive triage may result in the overutilization of ALS personnel, even in a tiered system. In contrast, triage of limited sensitivity could conceivably result in underutilization of EMTs and could theoretically result in a delay in ALS care.

Effective medical direction is key to the dispatch aspect of all-ALS and tiered systems alike. The availability of utilization data, especially real-time data, is essential when SSM is in use, but any system should evaluate the number of units in use and the ways they are being deployed. In a sole-provider all-ALS system, SSM has been shown to increase system efficiency, particularly with regard to response time and unit utilization rates. However, a tiered system can also improve response intervals for critical calls.

**First Responders and Early Defibrillation**

The presence of first responders (FRs; personnel who respond in non-ambulance vehicles intending to treat until EMS arrives) does not constitute tiering for the purposes of this paper. However, the value of using FRs is recognized and strongly endorsed. The public safety response system should include a mechanism for providing early defibrillation, as this is one of the few prehospital care interventions proven to improve survival. The provider may be a formal component of the EMS agency or, as is more often the case, from another agency such as fire or police. Rural areas present a challenge to find responders who can reliably respond rapidly.

Some systems, such as those in San Francisco and San Diego, are conducting trials in the use of paramedics as the first responder. This approach, which has been used successfully in other major cities, is based on the concept of getting a high-level provider rather than the transport vehicle to the patient quickly. The paramedic can then triage the level of additional response needed and initiate treatment of critical patients. The efficacy and cost-effectiveness of this approach are not yet known. This model also does not constitute tiering for this discussion.

**The BLS Provider**

In both models the role of EMT-Basic and EMT-Intermediate providers should be carefully deliberated and defined. Should EMT-Bs serve as the second person on an ALS crew? If so, to what extent do they assist the paramedic in performing ALS procedures? In tiered systems, likewise, to what extent does the BLS unit crew assist the ALS crew? The answer to these questions depends on many local system and personnel factors. Clear guidelines should be provided and a quality improvement process put in place for EMT personnel.

**Tailoring Systems to Local Characteristics**

It is impossible to determine which approach to the provision of prehospital emergency care is universally preferable. Instead, the focus should be on identifying the ideal system for a specific area, based on the local situation. Several political factors, especially the nature of the current EMS provider(s) and regulations governing sole service provider of care, may limit what is done. The ultimate decision will be affected by the presence of volunteer units, private companies, unions, and fire companies. Some forms of SSM are inconsistent with the fire model, although they need not be. Demographic and geographic factors may also be important. A suburban system with a low population density might lack resources or it may need only one ambulance. In that setting, an all-ALS unit might be the best approach. The decision about which system to adopt will also be influenced by the types of services desired. If the stress is to be less on transport management and more on the provision of different types of medical care, it may be desirable to have other modalities available. Clearly, such a decision will have an impact on available resources.

**Personnel Factors**

A key question is whether a smaller number of paramedics in a system can improve competence. Fewer paramedic personnel can translate into more ALS experience per individual. This can refine particular skills and enhance decision making in patient management scenarios. Also, it is much easier to train smaller groups in sophisticated topics such as advanced airway procedures. Having a smaller group of paramedics makes it possible for the medical director to focus on specific areas of concern as well.

It can be argued that the adoption of SSM, with its beneficial effect on higher ambulance utilization rates, might make it possible for all-ALS system paramedics to maintain some of this competence. Also, an all-ALS system’s paramedics see the growing number of non-911 pa-
tients requiring paramedic-level support during transport (a result of hospital specialization, early discharge, and managed care repatriation). The experience managing these patients and related training may offset some of the skill degradation in the all-ALS systems.

However, the relatively lower proportion of 911 ALS call volume and the types of nonemergency calls that are received will also have an impact on whether skills are maintained. As stated before, the percentage of 911 ALS experiences is so low that SSM is unlikely to make up the difference.

Morale issues, which can affect job turnover, are potential concerns in both all-ALS and tiered systems. In an all-ALS system, paramedics may feel that their level of work is not consistent with what they have been trained and hired to do. In a tiered system, EMTs may resent always doing the routine tasks. Depending on the nature of the system, these issues may be ameliorated. For example, in a fire department system, it may be possible to rotate EMTs through fire service duties as well as ambulance obligations. Other creative solutions should always be considered.

**Outcome Factors**

Although several of the pioneer systems that have reported very good survival from sudden cardiac arrest were tiered 911 ambulance systems, it is difficult to determine whether these favorable outcomes were achieved because of tiering per se or because of other factors in the system. Identifying, today, how to save the most cardiac arrest patients is a complicated issue. SSM is attractive because it is geared to having an ALS unit always available for the next call. However, from a quality-of-care perspective, it is possible that even if the ALS response might occasionally be delayed, more patients could be saved by the presence of highly skilled paramedics who will respond well to 95% of calls, particularly with today’s availability of first responder defibrillation. In each system, it is important for responsible persons to assess their system on an ongoing basis to determine whether it is as good as it can be.

Whatever the nature of the call, research has also shown that witnesses expect emergency personnel to tell them what they have been doing for their loved one or friend. Therefore, always having paramedics respond to a call may better meet the expectations of most of the public. On the other hand, ultimately, patients want the best care possible, and if medical care quality is improved by tiering, then that consideration should take preference.

Determining the relationship between quality and cost-effectiveness in the two systems is difficult because it is easy to measure costs, while it is exceedingly difficult to measure real quality. However, it could be argued that a system that stresses cost-effectiveness can also afford a better system, which will ultimately result in improved quality of care.

The average costs cited indicate the potential for the economic efficiency of an all-ALS system, but to date, no head-to-head study comparing the two systems, their levels of quality and costs, has been conducted. Such a study, properly conducted, would be complex and expensive, but clearly worthwhile.

**Summary**

A major advantage of an all-ALS ambulance system is operational efficiency. By providing an ALS provider on every vehicle, an all-ALS system can obviate the need for intricate dispatch triage procedures as well as secondary triage actions at the scene (such as calling for another ambulance for the appropriate level of transport). Through advanced SSM techniques, the multipurpose, sole-provider all-ALS system can help to expand the scope of services for the ambulance service provider by being readily capable of integrating both interfacility transfers and unscheduled (e.g., 911) responses. In turn, this type of deployment can improve revenue generation and utilization times for individual ambulances without compromising response intervals. As a result, this approach can also provide a fiscal advantage as well as operational efficiency. User satisfaction may also be improved because of faster responses for all types of calls and, with a lesser need for public subsidy, governmental satisfaction may also be improved when contractual obligations are met (e.g., guaranteed minimal response intervals).

On the other hand, even with rapid response intervals, the all-ALS system may very well result in the dilution of clinical experience for individual paramedics. Because paramedic-level (ALS) skills are required in less than 10% of emergency 911 calls, individual paramedics in an all-ALS system may rarely get the opportunity to use such skills, particularly in those systems that staff each ambulance with two (or more) paramedics. Also, while interfacility transports may involve ALS monitoring, they rarely require that ALS procedures be performed, further diluting time concentrated on clinical skills experience. While additional training may help to address this problem to some degree, it is difficult to match the training achieved by more frequent advanced clinical experience.

In contrast, tiered 911 ambulance systems provide more frequent, intensive clinical exposure for individual paramedics. Tiered ambulance services have been utilized historically in systems with high survival rates, but this correlation may be confounded by other system variables. What have been demonstrated are improved performance of skills and improved response intervals to critical incidents.

Nevertheless, tiered ambulance deployment strategies may be best
suited for busy urban EMS systems and, considering the operational advantages that can be achieved in some multipurpose, sole-provider all-ALS systems, any cost savings may be only incremental. Tiered ambulance systems also require sophisticated dispatch programs, which must be accompanied by an aggressive continuous quality improvement approach. In addition, tiered systems also lead to inefficiencies such as the occasional need to dispatch an additional ambulance to a scene to provide the appropriate transport (i.e., BLS transport when paramedic care is not needed). Though a rare occurrence and balanced by the general increased availability of highly skilled paramedics, there is also the occasional risk of a BLS ambulance’s being dispatched to a scene in which a paramedic is needed as soon as possible. However, BLS units today carry automated defibrillators, obviating the major time-dependent concern for ALS utilization.

What appears to be the least effective and perhaps most costly is an “all-paramedic” 911 response system that is not involved in all aspects of the system (emergency 911 and nonemergency transports, interfacility transfers) and does not use the applicable state-of-the-art SSM. These systems do not take advantage of the skills and response interval advantages of certain tiered ambulance systems (e.g., Seattle, Houston, and Milwaukee), nor do they utilize the operational efficiencies of the sole-provider “all-ALS” system that uses sophisticated SSM and a single cadre of paramedics for all emergency and nonemergency transport needs.

In conclusion, both deployment systems, if implemented properly, can significantly reduce response intervals to critical calls, and both systems focus on the consideration of methodologies to improve cost-effectiveness, operational efficiencies, and better patient care. Ultimately, the appropriate choice of ambulance systems will depend on local service demands and other factors that affect the EMS system, including catchment population, statutory and jurisdictional issues, available funding, accessibility of receiving facilities, and concerns over the quality of medical care and medical supervision. An argument in support of a tiered system may become moot in a small community of 10,000 persons served by a single ambulance, while the feasibility of an all-ALS system may be compromised if local ordinances do not allow for “sole-service” ambulance providers. In the end, both deployment strategies reflect the need for engaging expert medical supervision (e.g., full-time medical direction) and sophisticated management and technological tools in EMS systems. As stewards of public health care for their constituents, local community leaders must therefore become increasingly knowledgeable about advanced SSM concepts, appropriate dispatch triage procedures, and, accordingly, those integral quality assurance indicators that will ensure proper and continuous system modifications.

Many different levels of ambulance services and transport modes, including nonambulance transport modes, are now in use. Many EMS systems are performing other services as well. Although it is helpful to compare the pros and cons of all-ALS and tiered systems, the most beneficial discussion might also focus on emerging models for delivering out-of-hospital care and determining how they should be integrated into traditional health care systems. These new realities invite the development of broader and more comprehensive terminology.

References