The Importance of Transtracheal Jet Ventilation in the Management of the Difficult Airway

Jonathan L. Benumof, M.D.,* Mark S. Scheller, M.D.†

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Inadequate Oxygenation and ventilation is responsible for 50–75% of cardiac arrests following the administration of anesthesia. A majority (55–93%) of these intraoperative ventilatory cardiac arrests have resulted in death or brain death. The recent introduction of preanesthesia equipment checklists, inspired oxygen analyzers, disconnect alarms, pulse oximetry, and end-tidal capnography should allow the earlier detection (and, therefore, usually rectification) of inadequate oxygenation and/or ventilation. The response to the detection of inadequate oxygenation and/or ventilation is to ventilate the lungs with oxygen via mask or endotracheal tube. However, when one cannot ventilate via mask, or intubate the trachea (hereafter referred to as cannot ventilate/intubate), even if one is aware of a life-threatening gas exchange problem, and has no immediately available alternative plan, then death is inevitable. For the purpose of this paper, cannot ventilate via mask means that a fully trained and/or reasonably experienced anesthetist cannot cause a life-sustaining amount of gas exchange to occur despite the fact that anterior jaw thrust and/or oropharyngeal and/or nasopharyngeal airways are being used, and cannot intubate means that the same anesthetizing individual cannot pass an endotracheal tube through the vocal cords within a life-sustaining period of time.

The cannot ventilate/intubate situation has been responsible for a previously irreducible 1–28% of all deaths associated with anesthesia. Thus, the incidence of cardiac arrest has ranged from 1.7 to 7.8/10,000 anesthetics, the incidence of death has ranged from 0.9 to 7.9/10,000 anesthetics, and the incidence of cannot ventilate/intubate has ranged from 0.01 to 2.0/10,000 anesthetics. In our hospital in the last 6 yr, the incidence of the cannot ventilate/intubate situation has been approximately 1.0/10,000 anesthetics.

There is widespread agreement in the literature that percutaneous transtracheal jet ventilation (TTJV) using a large iv catheter inserted through the cricothyroid membrane is a simple, relatively safe, extremely effective treatment of choice for the desperate cannot ventilate/intubate situation. Compared with percutaneous cricothyroidotomy and tracheostomy, establishment of percutaneous TTJV is much quicker and simpler. Unfortunately, TTJV is not immediately available in the majority of anesthetizing locations in the United States; “immediately available” means that there is already present a dedicated high pressure oxygen source and the necessary preassembled materials to connect the high pressure source to the hub of an iv catheter. The purpose of this article is to show that TTJV is indeed an effective, simple, and inexpensive solution to the cannot ventilate/intubate problem, and, therefore, can be and should be immediately available in every anesthetizing location.

* Professor of Anesthesiology.
† Assistant Professor of Anesthesiology.

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Address reprint requests to Dr. Benumof: Anesthesia Research Lab, T-001, University of California San Diego, La Jolla, California 92093.

Transtracheal Jet Ventilation

MECHANISM OF ACTION AND PROOF OF EFFICACY

TTJV through a suitable cannula (16- or 14-G catheter) can potentially provide oxygen for exchange in the alveoli by two mechanisms. The first, and most important, is by bulk flow of gas through the cannula. The second is by translaryngeal entrainment of room air via the Venturi principle, depending on the degree of airway patency above the jet. Studies in models and in experimental animals have demonstrated that gas flow through a 16-G cannula in response to a driving pressure of 50 psi is approximately 500 ml/s.21 Even in the absence of additional translaryngeal gas entrainment via the Venturi effect, this flow rate is clearly adequate to provide excellent ventilation and oxygenation. This is evidenced by numerous animal studies22-24 as well as human studies and case reports documenting normocarbia or hypocarbia and hyperoxia in both elective surgical patients and patients with complete upper airway obstruction managed with TTJV for varying periods of time.25-27

In the presence of a completely patent glottis, gas entrainment via the Venturi effect may significantly contribute to total tracheal gas flow, adding as much as 40% more gas to that delivered from the TTJV cannula alone.21 However, unless the glottis is nearly completely patent, it appears that translaryngeal entrainment (of room air) makes a negligible contribution to total tracheal gas flow in patients managed with TTJV. This contention is supported by two observations. First, arterial blood gas data in animals as well as healthy patients without lung disease who are managed with TTJV demonstrate PaO2 values consistent with ventilation with 100% oxygen (no entrainment of room air).22,23,24 Second, it is likely that negative airway pressure cephalad to the TTJV cannula causes the glottic or periglottic structures to collapse into the glottic aperture, thereby further or completely obstructing an already partially obstructed or compromised airway and preventing translaryngeal entrainment of room air.21

Peak inspiratory airway pressures during TTJV will depend upon the cross-sectional area of the trachea, the driving pressure, the diameter, length, and cross-sectional area of the orifice(s) of the cannula, the degree of outflow obstruction, the compliance of the lungs and chest wall, and the inspiratory time. In animal studies (normal dogs) in which distal airway pressure was measured during TTJV through a 16-G needle, it was demonstrated that low frequency ventilatory rates, e.g., <30 breaths/min, produced peak airway pressures between 20 and 50 cmH2O.21 These peak airway pressures varied linearly with driving pressure when inspiratory time was held constant. Tidal volume also varied linearly with driving pressure. In addition, the tidal volumes and peak inspiratory pressures observed during TTJV were similar to those observed with conventional positive-pressure ventilation via an endotracheal tube.

ACCEPTABLE TRANSTRACHEAL JET VENTILATION SYSTEMS

Many systems have been suggested for TTJV, and, in particular, a great deal has been written about how to connect a transtracheal catheter to a ventilatory source.22,28-41 Distillation of this literature reveals that there are three basic acceptable TTJV systems that work reliably and can be easily and inexpensively assembled from readily available materials. "Acceptable" is defined as a system that has enough oxygen pressure and circuit stiffness (noncompliance) to easily achieve adequate ventilation (a normal PaCO2). The first acceptable TTJV system consists of a jet injector (blow gun) powered by regulated (table 1) or unregulated (table 2) central wall oxygen pressure. The advantage of using central wall pressure to power the jet injector (provided the system is already plugged in) is the guaranteed immediate availability of a preassembled reliable, tightly jointed system to connect to the transtracheal catheter. The advantage of regulated wall pressure is the ability to minimize barotrauma, especially in pediatric patients. The presence or absence of a regulator requires a different connection between the wall oxygen pressure source and the air hose leading to the jet injector and a moderate difference in price for the system (table 1 compared with table 2). To ensure that the jet injector, which also has industrial uses, is free of an oil coating or residue, the jet injector is always soaked in acetone (which dissolves oil) after it arrives from the manufacturer. All nonthreaded connections should be bound with wire or plastic ties.

The second TTJV system consists of a jet injector powered by an oxygen tank regulator (table 3). The advantage of this system is that it is mobile and can be used in anesthetizing locations that do not have a central (wall) source of high pressure oxygen. However, for this system to be effective, it must be standing by or brought to these anesthetizing locations prior to the induction of anesthesia. As with the first TTJV system, the presence or absence of an additional regulator (below 50 psi) has obvious barotrauma implications. Possible residual jet injector oil should be scavenged by acetone soak and all nonthreaded joints should be bonded together.

The third TTJV system utilizes the anesthesia machine flush valve as the jet injector. The anesthesia machine flush valve can be powered by either a wall or tank high pressure oxygen source and will generate a pressure that approaches line pressure. The fresh gas outlet of the anesthesia machine (now an industrywide standard 15-
**TABLE 1. Transtracheal Jet Ventilation Systems Using Regulated Wall O₂ Pressure.**

<table>
<thead>
<tr>
<th>Transtracheal Jet Ventilation (TTJV) Systems</th>
<th>Component-to-Component Schematic</th>
<th>Part</th>
<th>Company</th>
<th>Model Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTJV using jet injector powered by regulated central wall O₂ pressure</td>
<td><img src="image" alt="Component-to-Component Schematic" /></td>
<td>1 Chemetron wall O₂ quick disconnect+ 1/4&quot; OD hose barb</td>
<td>Tri-Anim</td>
<td>11-01-0003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 Chemetron O₂ hose</td>
<td>Tri-Anim</td>
<td>15-11-0001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 1/4&quot; ID hose barb+ 1/8&quot; NPT adapter</td>
<td>Western Enterpr.</td>
<td>MH-7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 Miniregulator gauge 0–50 psi</td>
<td>Bird</td>
<td>2322</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bird</td>
<td>6765</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 1/8&quot; NPT male reducing adapter+ 1/4&quot; NPT female adapter</td>
<td>Western Enterpr.</td>
<td>MA-9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 Air hose 25'</td>
<td>Lawson or Sears</td>
<td>81070 or 9HT16224</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 Jet injector</td>
<td>Lawson or Sears</td>
<td>11903 or 9HT16235</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 1/8&quot; NPT male adapter+ 1/4&quot; ID hose barb</td>
<td>Western Enterpr.</td>
<td>MH-7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9 Tygon tubing R-3603 3/8&quot; OD, 1/4&quot; ID</td>
<td>Cole-Parmer</td>
<td>6406-50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 1/4&quot; hose barb+male luor lok</td>
<td>Becton-Dickinson</td>
<td>9067</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 Intravenous catheter with standard hub</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Photograph of system**

Dashed lines = hose barbs; Dotted lines = threaded screw connection; Solid lines = male-female connection; NPT = National Pipe Thread. The parts list is the one used in our hospital.

Relevant addresses and telephone numbers of manufacturing and distributing companies for ordering parts are listed in Appendix II. Total cost = $145. Mr. Ron Rusk, personal communication.

* All non-threaded connections should be bonded together with wire or plastic ties (see photographs).
Table 2. Transtracheal Jet Ventilation Systems Using Unregulated Wall O₂ Pressure.*

<table>
<thead>
<tr>
<th>Transtracheal Jet Ventilation (TTJV) Systems</th>
<th>Component-to-Component Schematic</th>
<th>Part</th>
<th>Company</th>
<th>Model Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTJV using jet injector powered by unregulated central wall O₂ pressure</td>
<td><img src="image" alt="Diagram" /></td>
<td>1. Chemetron wall O₂ quick disconnect + 1/8&quot; ID NPT male adapter</td>
<td>Tri-Anim</td>
<td>11-01-0007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. 1/8&quot; NPT male adapter + 1/4&quot; reducing coupling</td>
<td>Lawson</td>
<td>5308</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Air hose 25'</td>
<td>Lawson or Sears</td>
<td>81070 or 9HT16224</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Jet injector</td>
<td>Lawson or Sears</td>
<td>11903 or 9HT16235</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. 1/8&quot; NPT male adapter + 1/4&quot; ID hose barb</td>
<td>Western Enterpr.</td>
<td>MH-7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Tygon tubing R-5603 3/8&quot; OD, 1/4&quot; ID</td>
<td>Cole-Parmer</td>
<td>6408-50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7. 1/4&quot; hose barb male luer lok</td>
<td>Becton-Dickinson</td>
<td>9067</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8. Intravenous catheter with standard hub</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Photograph of system

▶▷▷ ◀ = hose barb; □□□□ = threaded screw connection; □ = male-female connection; NPT = National Pipe Thread. The parts list is the one used in our hospital.

Relevant addresses and telephone numbers of manufacturing and distributing companies for ordering parts are listed in Appendix II. Total cost = $83. Mr. Ron Rusk, personal communication.

* All nonthreaded connections should be bonded together with wire or plastic ties (see photographs).

mm male outlet) is connected to noncompliant oxygen supply tubing by a standard 15-mm endotracheal tube adapter which fits a 4-mm ID endotracheal tube (table 4). The noncompliant oxygen supply tubing allows for bypass of the compliant reservoir bag and corrugated tubing of the anesthesia circle system. This third TTJV system is completed by connecting the oxygen supply tubing to the TTJV catheter; although this may be accomplished in many ways, our permanent TTJV sets have a bonded Luer lock/hose barb connector (3, table 4). As a quick makeshift alternative, the TTJV catheter/O₂ supply tubing connection can be accomplished by cutting the barrel
TABLE 3. Transtracheal Jet Ventilation Systems Using O₂ Tank Regulator.*

<table>
<thead>
<tr>
<th>Transtracheal Jet Ventilation (TTJV) Systems</th>
<th>Component-to-Component Schematic</th>
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</tr>
</thead>
<tbody>
<tr>
<td>TTJV using jet injector powered by O₂ tank regulator</td>
<td><img src="#" alt="Diagram of TTJV system" /></td>
<td><strong>1.</strong> Tygon tubing R–3603+ 3/8 OD, 1/4&quot; ID</td>
<td>Cole-Parmar</td>
<td>6408–50</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>2.</strong> 1/4&quot; ID hose barb+ 1/4&quot; NPT female adapter</td>
<td>Western Enterpr.</td>
<td>MH–7</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>1. 2</strong> DISS swivel nut adapter+ 1/4&quot; NPT female adapter</td>
<td>Western Enterpr.</td>
<td>M24–35</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>3.</strong> Air hose 25'</td>
<td>Lawson or Sears</td>
<td>81070 or 9HT16224</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>4.</strong> Jet injector</td>
<td>Lawson or Sears</td>
<td>11903 or 9HT16235</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>5.</strong> 1/8&quot; NPT male adapter+ 1/4&quot; ID hose barb</td>
<td>Western Enterpr.</td>
<td>MH–7</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>6.</strong> Tygon tubing R–3603 3/8&quot; OD, 1/4&quot; ID</td>
<td>Cole-Parmar</td>
<td>6408–50</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>7.</strong> 1/4&quot; hose barb male luer lok</td>
<td>Becton-Dickinson</td>
<td>9067</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>8.</strong> Intravenous catheter with standard hub</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Photograph of system

![Photograph of TTJV system](#)

- ▶▶▶ = hose barb; │││ = threaded screw connection; — — = male-female connection; NPT = National Pipe Thread. The parts list is the one used in our hospital.
- Relevant addresses and telephone numbers of manufacturing and distributing companies for ordering parts are listed in Appendix II.
- Total cost = $73. Mr. Ron Rusk, personal communication.
- * All nonthreaded connections should be bonded together with wire or plastic ties (see photographs).

...of a 1-ml syringe with a scissors and inserting the cut end of the barrel into the oxygen supply tubing and the other uncut standard male end into the standard female iv catheter hub (also 3, table 4). The advantage of this system is that it can be quickly assembled from three readily available materials, is inexpensive, and can be used wherever...

<table>
<thead>
<tr>
<th>Transtracheal Jet Ventilation (TTJV) Systems</th>
<th>Component-to-Component Schematic</th>
<th>Part</th>
<th>Company</th>
<th>Model Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTJV using anesthesia machine fresh gas outlet and flush valve</td>
<td>![Diagram of TTJV system]</td>
<td>1. 15-mm ET tube adapter for 4-mm ID ET tube</td>
<td>Many companies</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. O₂ supply tubing</td>
<td>Many companies</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. 1/4&quot; hose barb male luer lok or 3 out-off 1-ml syringe</td>
<td>Becton-Dickinson</td>
<td>9067</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Intravenous catheter with standard hub</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Photograph of system

>>> = hose barb; <<< = threaded screw connection; — = male-female connection; NPT = National Pipe Thread. The parts list is the one used in our hospital.

Relevant addresses and telephone numbers of manufacturing and distributing companies for ordering parts are listed in Appendix II.

Total cost = $6. Mr. Ron Rusk, personal communication.

* All nonthreaded connections should be bonded together with wire or plastic ties (see photographs).

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there is an anesthesia machine. To be effective, it must be readily available before a cannot ventilate/intubate situation develops (i.e., always). At the time of writing, the approximate total costs for the TTJV systems in tables 1-4 were $145, $83, $73, and $6, respectively.

**SHORTCOMINGS OF ALTERNATIVE TRANSTRACHEAL SYSTEMS**

There are two other ways to ventilate and/or oxygenate lungs by the transtracheal route that have been described, but they both fail to achieve true, and therefore, effective jet ventilation. The first of these suboptimal methods consists of using the anesthesia machine oxygen flush valve (powered by either wall or tank oxygen) and the anesthesia circle system corrugated tubing to deliver the oxygen to the transtracheal catheter. In this instance the compliant reservoir bag and corrugated tubing absorbs, by distension, most of the jet from the anesthesia machine fresh gas outlet and prevents effective ventilation of the lungs. Thus, with this system, the $\text{Paco}_2$ can be expected to increase; unfortunately, TTJV studies using this system have not been performed, and so the exact rate of $\text{Paco}_2$ increase is not known. The second method is predictably even less effective and consists of manually ventilating the lungs by vigorously squeezing a self-inflating reservoir bag. In this instance it is impossible to achieve a significant amount of ventilation through the
TRANSTRACHEAL JET VENTILATION

IV catheter and the \( P_{aCO_2} \) increases at a rate of 4 mmHg/min,\textsuperscript{25} which is close to the rate of \( CO_2 \) increase of 6 mmHg/min during apneic oxygen insufflation in animals anesthetized with barbiturates.\textsuperscript{23}

Although we strongly recommend using one of the three acceptable TTJV systems discussed above, and do not recommend using one of the two transtracheal systems mentioned in this section, it should be mentioned that both of the methods described here can provide some, although questionably adequate, oxygenation that is certainly better than continuing with a life-threatening cannot ventilate/intubate situation. Consequently, if either of these latter two methods must be used, it should be mentioned that the standard 15-mm elbow connector at the end of an anesthesia circle system and at the end of a self-inflating reservoir bag can be connected to the transtracheal IV catheter in two ways: 1) by inserting the male end of a 15-mm endotracheal tube adapter that fits a 3-mm ID endotracheal tube directly into the standard female hub of the IV catheter,\textsuperscript{32,39} and 2) by inserting the male end of a plungerless 3- or 5-ml syringe into the standard female hub of the IV catheter, and the male end of a 15-mm endotracheal tube adapter that fits an 8-mm and a 10-mm ID endotracheal tube, respectively, into the empty barrel of the syringe.\textsuperscript{30,33} Still, even with these kinds of connections, if one is suddenly confronted with a cannot ventilate/intubate situation, and is otherwise not ready for the situation, it will take significant extra time and hands to find the parts for these connections, for what is in the end analysis, not the best transtracheal ventilation system.

One could argue that an indication to use a transtracheal catheter reservoir bag system would be in cases in which the upper airway (i.e., cephalad to the cricothyroid membrane) was totally obstructed.\textsuperscript{24} In cases of total upper airway obstruction, inability to expel the TTJV gas from the lungs would greatly increase the risk of barotrauma due to gas trapping and lung hyperexpansion. With a transtracheal catheter reservoir bag system, only small amounts of oxygen can be delivered to the alveolar space per unit time (but, perhaps, still sufficient to maintain a life-sustaining level of oxygenation), with a significantly reduced risk of barotrauma.\textsuperscript{35} However, one could equally well argue that small amounts of oxygen could also be delivered to the alveolar space by true TTJV (by either jet injector or anesthesia machine valve with any kind of tubing) by simply using slow respiratory rates and short jet injection times (i.e., low I:E ratios). In any case of total upper airway obstruction, all percutaneous transtracheal ventilation systems must be converted to a formal cricothyroidotomy or tracheostomy tube, and the lungs must be well ventilated with conventional intermittent positive pressure ventilation as soon as possible.

INDIVIDUAL EXAMPLES OF THE PROBLEM/
THE SOLUTION

We installed the second acceptable TTJV system (jet injector powered by unregulated wall pressure) in all anesthetizing locations in our hospital approximately 5 yr ago. In the past 5 yr, we have treated five patients whose lungs, as defined in the Introduction, could not be ventilated via mask and in whom tracheal intubation could not be performed: all five patients had a brief period of severe decreased pulse oximeter saturation (\( Sp_{O_2} \)), which was quickly reversed by the immediate administration of TTJV. The following is a brief summary of each case.

**Case 1.** A previously healthy 34-yr-old woman developed moderate edema of the face and upper airway following fluid overload during repair of a lacerated femoral vein. The patient’s trachea was extubated after she was completely awake, but she immediately evidenced complete airway obstruction. Insertion of oral and nasal airways accompanied by attempts at bag and mask ventilation were of no benefit. Attempts at reintubation were unsuccessful, and TTJV was instituted as the oxygen saturation fell below 60%. There was prompt return of \( Sp_{O_2} \) to 100% with TTJV, which was continued until a tracheostomy could be performed.

**Case 2.** Anesthesia and paralysis were induced with thiamylal/suxcinylcholine in a preeclamptic term patient about to undergo emergency cesarean section. Following induction of anesthesia, it was not possible to ventilate the lungs with a bag and mask or to intubate the trachea due to a combination of a small mouth, receding chin, and what appeared to be generalized edema of the laryngeal aperture. Institution of TTJV promptly reversed severe hemoglobin desaturation and provided adequate ventilation until a fiberoptic assisted intubation could be performed.

**Case 3.** The lungs of a 66-yr-old woman with a supraglottic tumor could not be ventilated with a bag and mask, nor could the trachea be intubated following induction of anesthesia. \( Sp_{O_2} \), which had decreased to less than 60%, was restored to 100% within 4TTJV breaths. Adequate ventilation was maintained until the surgeons completed a tracheostomy.

**Case 4.** A previously healthy 32-yr-old male, whose trachea had been easily intubated preoperatively awake with a blind nasotracheal technique, and who had undergone placement of monowire arch bars for a mandibular fracture, had his trachea extubated during a period of emergence excitement (bucking on the endotracheal tube, but still not responding to commands). Following extubation, it was not possible to ventilate the lungs using a bag and mask. During attempts at reintubation no recognizable structures were visualized. \( Sp_{O_2} \) decreased to less than 20%. Institution of TTJV resulted in prompt return of \( Sp_{O_2} \) to 100%. TTJV was continued while racemic epinephrine and a beta-2 agonist bronchodilator were administered directly through the transtracheal catheter. After approximately 5 min of TTJV spontaneous ventilation resumed, and after 10 min of TTJV the patient completely awoke and experienced no further respiratory difficulty.

**Case 5.** A 55-yr-old woman with a history of a subglottic tumor developed dyspnea at rest. An inhalation induction was performed and despite repeated laryngoscopies, neither the vocal cords nor the glottic opening could be identified. Following an unsuccessful attempt at rigid bronchoscopy, it became impossible to ventilate the lungs with a bag and mask. \( Sp_{O_2} \) decreased below 60%, at which time TTJV was instituted. \( Sp_{O_2} \) promptly increased to 98%. TTJV was continued until the glotic opening could be identified by air bubbles emanating from the trachea, which permitted insertion of an endotracheal tube.
In these five patients, different causes resulted in a common inability to ventilate the lungs via mask or to intubate the trachea (case 1, upper airway obstruction; case 2, anatomic difficulties plus laryngeal edema; case 3, supraglottic tumor; case 4, laryngospasm; case 5, subglottic and airway edema). In all cases following decreased $Sp_O_2$, TTJV was instituted within 1 min, which increased $Sp_O_2$ within another minute. In no case were arterial blood gases determined during TTJV because the purpose of the TTJV was strictly resuscitative, and in all cases the TTJV was soon converted to an effective type of permanent ventilation. In the five patients, TTJV permitted four different successful therapeutic options (tracheostomy (cases 1 and 3), intubation over fiberoptic bronchoscope (case 2), conventional orotracheal intubation (case 5), and administration of racemic epinephrine and bronchodilator, and allowing the patient to further wake up (case 4)). We cannot be certain of the ultimate outcome had TTJV not been immediately available and instituted in these cases, but given the gravity of these situations, it seems reasonable to postulate that the TTJV was indeed life-saving.

Elective Use of Transtracheal Jet Ventilation

To facilitate operations involving the airway. In 1967 Sanders demonstrated that the lungs of paralyzed patients could be adequately ventilated using a high pressure source of oxygen (50 psi) through a small cannula in an open bronchoscope.42 Using a variety of technical modifications, ventilation of the lungs of paralyzed patients during laryngoscopy (ventilating laryngoscope43,44 and various small catheters inserted between the vocal cords45,46) was soon achieved. TTJV was introduced in 197121; because TTJV leaves the entire airway from the vocal cords to the face accessible for surgical manipulation, it is not surprising that TTJV has been used for virtually every conceivable type of operation on these structures.25,47

To permit safe intubation of the trachea with a standard endotracheal tube by another route (prevent the cannot ventilate/intubate situation). In situations in which an increased risk of developing a cannot ventilate/intubate situation can be identified, elective institution of TTJV may prevent the development of a life-threatening gas exchange problem while a more secure permanent airway is being established. Elective insertion of an iv catheter through the cricothyroid membrane and use of TTJV is entirely compatible with a subsequent conventional orotracheal or nasotracheal intubation, fiberoptic aided intubation, retrograde intubation technique, and formal tracheostomy.

Indeed, one report described prophylactic TTJV, which guaranteed adequate ventilation in a patient whose trachea was known to be difficult to intubate; the TTJV enabled the patient to be anesthetized, paralyzed, and the trachea to be intubated in a safe and nonemergent manner.48 In another report concerning a 13-yr-old girl with ankylosis of the temporomandibular joint secondary to a fractured mandible, TTJV was electively instituted prior to the induction of anesthesia, and the trachea was intubated with the aid of a fiberoptic bronchoscope safely and nonemergently after the induction of anesthesia and paralysis (see case 2).49 Thus, it appears that TTJV can prevent the development of a life-threatening gas exchange problem in patients whose lungs are difficult to ventilate and whose trachea is difficult to intubate, and who also require general anesthesia; the technique permits uninterrupted ventilation and oxygenation while allowing unhurried access to the patient’s upper airway.

Complications of Transtracheal Jet Ventilation

The incidence of serious complications resulting from elective use of TTJV is relatively low and appears to be primarily limited to tissue emphysema. For example, Monnier et al.27 provided ventilation for 65 patients undergoing laser endoscopic treatment of laryngeal and subglottic lesions with high frequency TTJV. The cannulae were introduced into the trachea under endoscopic guidance. In this series only one complication occurred. This was due to dislodgement of the cannula and resulted in cervicomedialstitial emphysema, which was successfully treated by needle aspiration. Smith et al.29 also described complications following elective use of TTJV in 52 patients prior to surgery. The only complications described were subcutaneous emphysema (9.6%) and mediastinal emphysema (1.9%).

The incidence of complications from TTJV used to treat emergency respiratory distress is undoubtedly higher. Smith et al.29 also reported a 29% incidence of complications in 28 patients managed with TTJV to provide an airway in an emergency. These complications included subcutaneous emphysema (7.1%), mediastinal emphysema (3.6%), exhalation difficulty (14.3%), and arterial perforation (3.6%). None of these complications were fatal.

Barotrauma with resultant pneumothorax has been reported with both TTJV and translaryngeal jet ventilation.24,25,51-55 Therefore, it is clearly necessary to document breath sounds as well as chest inflation and deflation following institution of TTJV and to assume that any change in cardiovascular parameters, such as hypotension, tachycardia, or bradycardia, may be secondary to pneumothorax. Clearly, the risk of pneumothorax is much in-
creased in cases of total airway obstruction because gas cannot escape from the lungs in a normal manner (i.e. the natural airway).

Other complications, such as esophageal puncture, bleeding, hematoma, and hemoptyis, have been reported following TTJV. In addition, it appears that damage to tracheal mucosa may occur following TTJV, especially if the gas is not humidified. We studied five pigs in which we managed ventilation for approximately 2 h with single orificed transtracheal catheters using three different methods of nonhumidified gas delivery to the cannula. In all animals the posterior wall of the trachea clearly demonstrated macroscopic evidence of irritation and microscopic evidence of mucosal erosion. However, Kain and Smith did not find any tracheal damage in dogs the lungs of which were subjected to 50 h of nonhumidified high frequency TTJV in which 14-G multiorificed catheters were used. Nonetheless, the possibility of causing tracheal mucosal ulceration should certainly be considered, particularly if TTJV is attempted through single orificed catheters without humidification for prolonged periods of time.

Conclusion

Presently, there is a baseline incidence of 1–28% of intraoperative deaths that are caused by a cannot ventilate/intubate situation, which cannot be remedied by simply improved monitoring. The quickest, easiest, most efficacious solution to the problem is TTJV through an iv catheter. The mechanism of efficacy is by mass movement of gas from the jet itself as well as by air entrainment by the Venturi principle, and the lungs of healthy and critically ill patients have been successfully ventilated by this method. The systems of choice, in descending order of preference, are jet injector powered by regulated wall or oxygen tank pressure, jet injector powered by unregulated wall or tank oxygen pressure, and anesthesia machine flush valve using noncompliant tubing from the fresh gas outlet. Much less efficacious transtracheal ventilation systems consist of anesthesia machine flush valve using the compliant tubing of the anesthesia circle system (with reservoir bag) and connecting a reservoir bag directly to the transtracheal catheter. In our hospital the use of TTJV in patients whose lungs could not be ventilated or intubated may have significantly reduced morbidity and mortality. Additional applications of TTJV are to facilitate upper airway surgery, intubation via conventional laryngoscopy, antegrade fiberoptic bronchoscopy or via initial retrograde intubation technique, cricothyroidotomy, and tracheostomy. Nevertheless, there are a number of serious TTJV complications, and this life-saving procedure should only be undertaken in desperate emergencies or in carefully thought-out elective situations. However, because desperate cannot ventilate/intubate emergencies will continue to occur in association with anesthesia, we recommend that every anesthetizing location should have the immediate availability of TTJV.

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References


Appendix

Addresses and Telephone Numbers of Companies Listed in Tables 1-4

Tri-Anim Health Services, Inc.
1630 Flower Street
P. O. Box 3823
Glendale, California 91201
(818) 545-7329

Cole-Parmer Instrument Co.
7425 North Oak Park Avenue
Chicago, Illinois 60648
(800) 323-4340

Western Enterprises
33672 Pin Oak Parkway
Ayon Lake, Ohio 44012
(216) 993-2171

Lawson Products
1237 West Walnut Street
Compton, California 90220
(213) 637-1237

Division of Becton-Dickinson & Co.
Rutherford, New Jersey 07070
(201) 460-2000

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