Kinking of Catheters during Translaryngeal Jet Ventilation: A Bench Model Investigation of Eight Devices

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Objective: *To evaluate oxygen flow through several transtracheal devices in native and right angle kinked states.*
Material and Method: *Eight catheter-over-needle, and two oxygen conveyance devices (Enk Flow Modulator 10L/min flow and Manujet III Jet device 15, 30, 50 psi) were examined. Oxygen flow from each catheter was measured five times with three insufflation patterns [continuous insufflation, one second insufflation/ one second pause (1:1), one second insufflation/three second pause (1:3)] in both native, and 90 degree kinked condition.*
Results: *During continuous insufflation, all but the 20G catheter delivered flows of more than 7L/m with all conveyance pressures. With a 1:1 insufflation/pause ratio, catheters smaller than 16G were able to deliver 7L/min flow only with driving pressures of 30 and 50 psi. With a 1:3 insufflation ratio, no catheter could deliver adequate flow with 15 psi(manujet) or with the Enk Flow modulator. Only the Cook catheter and 14G Ravussin were capable at 30 psi. Only the Cook Transtracheal Jet Ventilation Catheter could deliver adequate flow in kinked position, but only at 50 psi.*
Conclusion: *Needle-catheters designed for vascular access are marginally capable of effective TJV. The Cook Transtracheal Jet Ventilation catheter proved to be the most robust device in the kinked state, but only when combined with a high-pressure oxygen conveyance system.*

Keywords: *Jet ventilation, Kinking catheters*

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Translaryngeal Jet ventilation (TJV) is one of several invasive airway techniques that have been recommended for patient rescue in the cannot intubate/ cannot ventilate (CNI/CNV) scenario(1). The technique involves the blind placement of a small gauge catheter through the cricothyroid membrane or cricotracheal ligament and injection of oxygen under pressure. It has been associated with poor outcomes. This is true in situations where TJV is attempted by untrained personnel or there is near or complete upper airway obstruction, and when the appropriate equipment is not immediately available. Despite this, needle TJV may be the quickest and simplest of the emergency invasive techniques, and is employed by the anesthesiologist in this most dire of clinical situations(2).

Unfortunately, the literature in TJV continues to discuss the use of unproven technologies including a variety of hollow catheter-over-needles passed through the superficial tissues and into the larynx or trachea, and conductive devices for regulating and delivering oxygen(2-8). Catheters designed for duties other than TJV may be too small or resist oxygen flow for reasons related to catheter diameter and length, material characteristics, or other design features. Secondly, non-specialized catheters may be more prone to kinking resulting in complete or partial gas flow obstruction(9).

Using a bench model, the authors sought to evaluate oxygen flow through several transtracheal devices that have been described in the literature(9). Because catheter kinking has been proposed as a common cause of TJV failure, the authors measured gas flow in native and right angle kinked states.

Material and Method

Eight needle-catheters and two oxygen conveyance devices were examined (Table 1). Because no animal or patient models were used in the present study, institutional ethical board approval was not

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Table 1. List of catheter devise

Catheter devise (length)
[1]Angiocatheter: 20g (3.18cm), 18g(4.45cm), 16g (5.08cm), 14g (5.08cm)
[2]Cook Transtracheal Jet Ventilation Catheter: 15g (5cm)
[3]Ravussin Catheter: 16g (4cm), 14 g(5.3cm), 13g (7cm),
Oxygen conveyance device
[3]Manujet III Jet device: 15, 30, 50 psi
[2]Enk Flow Modulator: 10L/min flow

[1] Smiths medical international, UK
[2] Cook Critical Care, Bloomfield, IN
[3] VBM Medical, Inc, Noblesville, Indiana

sought. A Wright Spirometer was fitted to the distal end of an 18-inch length of 1" diameter PVC piping. A mid-length 45-degree joint in the piping was introduced to reduce jetted currents into the spirometer. The proximal end of the piping was fitted with a latex diaphragm, through which each of the catheter devices was inserted 1 cm (as measured from the catheters distal orifice). A new latex diaphragm was used for each test. A small amount of surgical lubricant was placed at the diaphragm puncture site to detect air-leak. The spirometer assembly was mounted on a tabletop vice-stand (Fig. 1). The Wright Spirometer was read to 0.01 liters per minute accuracy.

The oxygen conveyance devices were calibrated between each catheter test. A Manujet III (VBM Medical, Inc, Noblesville, Indiana) jet device was attached to an E-cylinder oxygen tank with at least 1,000 PSI pressure, via a pin-indexed Omeda/Ohio adaptor. An electronic pressure gauge (Universal pressure meter, Bio-Tek Instruments, Winooski, VT) was used to calibrate the static pressure output of the Manujet III jet device at each output pressure tested (15, 30 and 50 psi). An Enk Flow Modulator (Cook Critical Care, Bloomfeild, Indiana) was attached via non-compliant oxygen tubing and an oxygen nipple adaptor to a Timeter flow meter (Timeter Instrument Corporation, Lancaster, Pennsylvania) mounted by DISS threaded connector to the yoke of an E-cylinder oxygen tank with at least 1000 PSI pressure. The flow meter was adjusted before each catheter test so that 10 liters of flow was measured via the Wright Spirometer during one minute of continuous Enk Flow Modulator occlusion. The output ends of both the Manujet III jet device and the Enk Flow Modulator were connected to the same 100 cm long low compliance tubing. A second stand supported the distal end of the low compliance tubing at the height of the mid-diaphragm of the PVC-spirometer model. This arrangement allowed the authors to puncture the diaphragm with each needle-catheter, remove the needle, and move the low compliance tubing into position. Leur-locking the catheter to the low-compliance tubing supported its position in the diaphragm.

Cumulative gas flow was measured over a one-minute period using the following insufflation patterns with each of the two oxygen sources, continuous insufflation, one second insufflation and one second pause (1:1) and one second insufflation and three second pause (1:3)(11). Each test was repeated five times. Flow through the oxygen sources was triggered manually to simulate the use of the devices during airway resuscitation. An electronic metronome was used by the investigator to time insufflation triggering and pause durations.

In preparation for the kinked catheter test, each catheter was initially bent 180 degrees at its midpoint by drawing together the proximal and distal ends. The kink was then relaxed to 90 degrees. Plastic tape was used to maintain this angle. Cumulative gas flow was measured over a one minute period using the

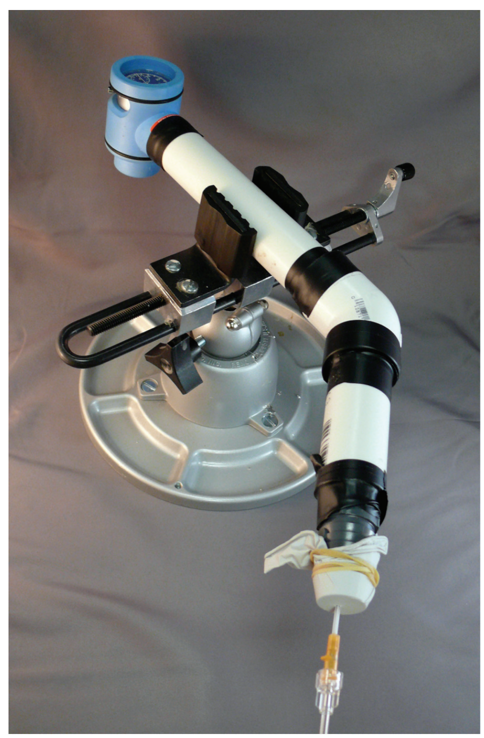

Fig. 1 Bench model to measure flow through catheters in kinked and non-kinked states. The picture was taken by the author

1:3 insufflation/pause pattern. Descriptive statistics were used to summarize the data set.

Results

When oxygen flow was continuous, all catheters greater than 20G were capable of delivering seven liters or more of oxygen flow over a period of one minute, at all pressures using the Manujet III device, and with the Enk flow modulator (Table 2). The 20G catheter could not deliver 7L/min or greater oxygen flow with a 15 psi driving pressure, but achieved this threshold with all other continuous oxygen trials. With a 1:1 insufflation/pause ratio, catheters smaller than 16G were able to deliver 7L/min flow only when driving pressures of 30 psi and 50 psi were delivered by the Manujet III jet device. The 16G catheter did not reach this threshold with a 1:1 ratio using the Enk Flow Modulator. With a 1:3 ratio, no catheter could deliver adequate flow with 15 psi as well as with the Enk Flow Modulator, while only the Cook catheter and 14G Ravussin catheter were capable at 30 psi and all catheters greater than 18G were capable at 50 psi. With the introduction of a 90-degree angle, only the Cook Transtracheal Jet Ventilation Catheter was capable of delivering 7L/m or more oxygen, and only at 50 psi.

Discussion

The American society of Anesthesiologist algorithm for management of the difficult airway is intended to guide the practitioner through a practical, expeditious and evidence based pathway when managing both recognized and unanticipated difficult airway patients[1]. After the induction of anesthesia in a patient who subsequently cannot be managed with tracheal intubation or facemask/supra-glottic airway ventilation, the algorithm's emergency branch terminates in the recommendation of invasive techniques of oxygenation and ventilation. Despite this, reviews of the closed claims database have revealed that clinicians avoid these techniques and when employed, they are often used too late to effect outcome. Jet oxygenation/ventilation via a translaryngeal catheter can be life saving[8]. However, the infrequent occurrence of this scenario has led many clinicians to be ill-prepared, and, as described by authorities in the field of airway management, these situations leave little time for training, reading of instructions and assembly of equipment[11].

A number of authors have described techniques and devices that rely on non-specialized, improvised equipment for the performance of

Table 2. Liters per minute flow via each catheter with each insufflation device and insufflation/pause pattern. Each entry is the average of 5 data points

	Pressure 15				Pressure 30				Pressure 50				Enk 15 l/min			
	90□ (1:3)	(1:3)	(1:1)	1 min	90□ (1:3)	(1:3)	(1:1)	1 min	90□ (1:3)	(1:3)	(1:1)	1 min	90□ (1:3)	(1:3)	(1:1)	1 min
20 G angio	0.00	1.53	3.19	5.19	0.77	2.88	5.91	9.42	1.42	4.35	8.96	14.89	0.38	2.62	4.50	9.14
18 G angio	0.00	2.36	4.84	7.88	0.60	4.26	8.56	13.73	1.19	6.21	12.41	21.16	0.48	3.69	4.46	8.24
16 G angio	0.31	3.27	7.33	11.67	0.85	5.44	11.60	20.66	1.55	8.71	16.42	30.88	0.46	3.47	6.58	15.40
14 G angio	0.00	3.69	7.78	13.21	0.00	6.28	13.99	24.09	1.69	9.63	19.78	35.14	0.23	3.86	7.36	15.21
Cook TJV cath	3.13	4.49	7.36	13.40	5.33	7.84	14.77	24.99	7.81	9.41	19.83	37.29	3.53	3.72	7.35	15.13
VBM 16	0.54	3.62	7.44	12.07	1.20	6.07	12.79	21.37	1.96	8.78	17.99	31.75	1.26	4.62	7.41	15.44
VBM 14	0.32	3.94	8.00	12.82	0.85	7.17	14.02	23.16	1.68	9.96	20.31	33.90	1.11	4.73	6.95	15.48
VBM 13	0.00	3.83	8.10	12.67	0.44	6.73	15.05	23.16	0.97	9.48	19.37	35.84	1.12	3.99	7.36	15.46

TJV[3-8,12,13]. These devices may take undue time to assemble and few perform adequately. Anticipatory assembly of "home-made" devices does not assure their competency[6]. In a clinical situation where significant morbidity and mortality is common, the use of non-dedicated, self-constructed devices should be questioned[3].

An aspect of the TJV circuit which demands attention is the catheter used to transverse the superficial tissues and cricothyroid ligament, to enter the larynx. Though the use of intravenous catheters continues to be described in the literature, catheter kinking is a significant cause of device failure[8,9]. Specialized jet ventilation catheters use kink resistant mechanics, or manufactured contours to reduce this complication[9]. In a bench model similar to the one presented, Sdrales and Benumof found that a 15 to 30 degree caudad insertion angle reduced the incidence of catheter kinking[9]. These authors did not measure the affect of catheter kinking, but presumed it would severely limit gas flow. In the current study, all devices except the wire reinforced Cook Transtracheal Jet Ventilation Catheter manifested severe reductions in gas flow with the introduction of a 90-degree mid-shaft kink. Only the highest conveyed pressure applied in the present study (50 psi), using the Manujet III jet device, delivered seven or more L/minute of flow through this catheter under the kinked condition. At lower pressures, gas conveyance through the kinked Cook Trantracheal Jet Ventilation Catheter did not reach the 7 L/minute threshold, yet some gas flow was maintained. For all practical purposes, gas flow was halted in all other catheters when a 90-degree kink was introduced. The Cook Transtracheal Jet Ventilation Catheter's resistance to complete obstruction is attributed to both the spiral wire reinforcement of the catheter's lumen, as well as the properties of the Teflon material of which it is constructed. The Cook Transtracheal Jet Ventilation Catheter performed better than a larger gauge (15G vs. 14G), similar length (5 cm vs. 5.08 cm) angiocatheter under non-kinked conditions. Similarly constructed catheters, though not tested in the present study, might be expected to perform equally well (*e.g.*, Arndt Emergency Cricothyrotomy Catheter Set, Cook Critical Care, Bloomfield, IN). The Ravussin catheters used in the present are manufactured with a gradual 15-degree curve from their lure-lock connector to distal orifice[14]. This feature of the Ravussin catheters likely serves to reduce kinking based on the finding of Sdrales and Benumoff[9]. It is possible that kinking of less than 90 degrees can occur during TJV rescue and some of the tested catheters might perform adequately under these *in vivo* conditions. The authors chose a 90-degree angulation as a convenient standard for the present study, knowing that this would not replicate all clinical situations.

For the presented model, the authors chose seven liters per minute as the threshold for a catheter-oxygen conveyance system to be capable of TJV. A review of the literature revealed no clear, empirically derived minute volume that would be necessary to maintain both oxygenation and ventilation in an adult via a TJV route. Yealy et al suggested that a minute ventilation of 7.5 liters per minute maintains normocapnea in a nonstressed adult[15]. It has also been suggested that an alveolar ventilation of 4.2 liters/minute (*i.e.*, excluding dead-space) is necessary[16]. The threshold choice is complicated by several issues, which the authors and other authors, did not attempt to address, including volume entrained from the upper airway and the likely physiologic state and oxygen and ventilation requirements of an anesthetized patient in a CNI/CNV condition. The results of this study should be considered in light of these limitations.

Low minute volume gas conductance, whether due to small catheter size, insufficient driving pressure or catheter kinking, does not rule out successful resuscitation with TJV. In the presented study, the Enk Flow Modulator failed to deliver the threshold gas volume during the 1:3 insufflation/pause pattern. Despite this, *in vivo* studies, utilizing swine models have found the Enk Flow Modulator capable in this regard[17]. The present study did not consider the up-stream entrainment of gas due to the venturi effect of jet injection, which might account for the successful use of the Enk Flow modulator in these more sophisticated studies[18]. Additionally, the tracheal injection of oxygen at flows as low as two liters per minute has been shown to maintain full oxygenation in swine for up to one hour, despite significant hypercapnea and respiratory acidosis, suggesting that in the unkinked state nearly all of the systems tested could act as a short term bridge to a definitive airway[16].

The application of the present study to clinical use of TTJV may be limited. Kinking to 90° may not occur under clinical conditions, and some catheters may still deliver adequate oxygen flows. Avoiding a higher degree of kinking is very important. The 1:3 insufflation/pause pattern was chosen to mimic clinical TTJV. An insufflation pressure 30 psi might need a 14G or greater size catheter. If 16G catheter is used, 50 psi should be available. The catheters smaller than 16G are not recommended for TJV.

TJV is an effective method of patient rescue in the dire CNI/CNV situation. Because significant patient harm can be accentuated by both a delay to perform, and improper application of this technique it is incumbent on the clinician to be prepared for this contingency. In any clinical setting where apnea or airway obstruction may be encountered or induced, advanced preparation in terms of both readiness to apply TJV and the availability of appropriate equipment should be compulsory. Unfortunately, because it is a rare event, clinicians and healthcare facilities are often unprepared when CNI/CNV does occur. The expense of oxygen conductive devices and specialized TJV catheters are minor compared to other costs in the operating room, as well as to the morbidity, which may be prevented

In summary, the authors found that needle-catheters designed for vascular access are marginally capable of effective TJV and are prone to complete obstruction in the likely event of kinking. The Cook Transtraceheal Jet Ventilation catheter proved to be the most robust device in the kinked state, but only when combined with a high pressure oxygen conveyance system. The manufactured contours of the Ravussin catheters are likely to make this device more capable in an *in vivo* trial, as compared to the bench–model observations.

Potential conflicts of interest

None.

References

1. Practice guidelines for management of the difficult airway: an updated report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. Anesthesiology 2003; 98: 1269-77.
2. Marr JK, Yamamoto LG. Gas flow rates through transtracheal ventilation catheters. Am J Emerg Med 2004; 22: 264-6.
3. Ryder IG, Paoloni CC, Harle CC. Emergency transtracheal ventilation: assessment of breathing systems chosen by anaesthetists. Anaesthesia 1996; 51: 764-8.
4. Patel RG. Percutaneous transtracheal jet ventilation: a safe, quick, and temporary way to provide oxygenation and ventilation when conventional methods are unsuccessful. Chest 1999; 116: 1689-94.
5. Boyce JR, Peters G. Vessel dilator cricothyrotomy for transtracheal jet ventilation. Can J Anaesth 1989; 36: 350-3.
6. Metz S, Parmet JL, Levitt JD. Failed emergency transtracheal ventilation through a 14-gauge intravenous catheter. J Clin Anesth 1996; 8: 58-62.
7. Langeron O, Amour J, Vivien B, Aubrun F. Clinical review: management of difficult airways. Crit Care 2006; 10: 243.
8. Fassl J, Jenny U, Nikiforov S, Murray WB, Foster PA. Pressures available for transtracheal jet ventilation from anesthesia machines and wall-mounted oxygen flowmeters. Anesth Analg 2010; 110: 94-100.
9. Sdrales L, Benumof JL. Prevention of kinking of a percutaneous transtracheal intravenous catheter. Anesthesiology 1995; 82: 288-91.
10. Hauswald M, Ong G, Yeoh E. Percutaneous needle cricothyroidotomy with repetitive airway obstruction. Am J Emerg Med 1995; 13: 623-5.
11. Vadodaria BS, Gandhi SD, McIndoe AK. Comparison of four different emergency airway access equipment sets on a human patient simulator. Anaesthesia 2004; 59: 73-9.
12. Wong DT, Lai K, Chung FF, Ho RY. Cannot intubate-cannot ventilate and difficult intubation strategies: results of a Canadian national survey. Anesth Analg 2005; 100: 1439-46, table.
13. Vanner R. Emergency cricothyrotomy. Curr Anaesth Crit Care 2001; 12: 238-43.
14. Ravussin P, Freeman J. A new transtracheal catheter for ventilation and resuscitation. Can Anaesth Soc J 1985; 32: 60-4.
15. Yealy DM, Stewart RD, Kaplan RM. Myths and pitfalls in emergency translaryngeal ventilation: correcting misimpressions. Ann Emerg Med 1988; 17: 690-2.
16. Black IH, Janus SA, Grathwohl KW. Low-flow transtracheal rescue insufflation of oxygen after profound desaturation. J Trauma 2005; 59: 344-9.
17. Yildiz Y, Preussler NP, Schreiber T, Hueter L, Gaser E, Schubert H, et al. Percutaneous transtracheal emergency ventilation during respiratory arrest: comparison of the oxygen flow modulator with a hand-triggered emergency jet injector in an animal model. Am J Emerg Med 2006; 24: 455-9.
18. Benumof JL, Scheller MS. The importance of transtracheal jet ventilation in the management of the difficult airway. Anesthesiology 1989; 71: 769-78.

ผลของการหักพับของสายสวนระหว่างการช่วยหายใจด้วยเจ็ททางหลอดลม: การทดสอบสายสวน 8 ชนิดในแบบจำลอง

วริยา สุขุประการ, William H Rosenblatt

***วัตถุประสงค์**: เพื่อประเมินการไหลของออกซิเจนจากการให้ออกซิเจนทางหลอดลมด้วยสายสวนแบบต่าง ๆ ทั้งแบบไม่หักพับ และหลังจากถูกหักพับ 90 องศา*

***วัสดุและวิธีการ**: ผู้นิพนธ์ทำการศึกษาการใช้เข็มที่หุ้มด้วยสายสวน 8 แบบ และอุปกรณ์ให้ออกซิเจน 2 ชนิด (เครื่องมือปรับการไหลของออกซิเจน (Enk) ด้วยอัตราการไหล 10 ลิตร/นาที และอุปกรณ์ยิงเจ็ทรุ่น Manujet III ด้วยแรงดัน 15, 30 และ 50 psi) ปริมาณออกซิเจนที่ไหลผ่านสายสวนแต่ละชนิดจะถูกวัด 5 ครั้ง ในการให้ออกซิเจน 3 รูปแบบได้แก่ แบบให้การไหลของออกซิเจนต่อเนื่องตลอดเวลา, แบบให้มีการไหลของออกซิเจน 1 วินาที สลับกับการหยุด 1 วินาที (1:1), แบบให้มีการไหลของออกซิเจน 1 วินาที สลับกับการหยุด 3 วินาที (1:3) ทั้งในแบบที่สายสวนไม่หักพับ และหักพับ 90 องศา*

***ผลการศึกษา**: ขณะให้มีการไหลของออกซิเจนต่อเนื่องตลอดเวลาสายสวนที่มีขนาดมากกว่า 20G จะสามารถให้ออกซิเจนไหลผ่านได้ไม่ต่ำกว่า 7 ลิตร/นาที ด้วยอุปกรณ์ให้ออกซิเจนทั้ง 2 ชนิด ระหว่างการให้ออกซิเจน แบบ 1:1 สายสวนที่มีขนาดเล็กกว่า 16G จะให้การไหล 7 ลิตร/นาที เฉพาะเมื่อใช้แรงดัน 30 และ 50 psi หากให้ออกซิเจนแบบ 1:3 จะได้การไหลของออกซิเจนที่เพียงพอด้วย Cook catheter และ 14G Ravussin ที่แรงดันอย่างน้อย 30 psi กรณีมีการหักพับมีเพียง Cook catheter ที่แรงดัน 50 psi เท่านั้นที่สามารถเกิดการไหลของออกซิเจนได้เพียงพอ*

***สรุป**: เข็มและสายสวนที่ออกแบบมาสำหรับให้สารน้ำทางหลอดเลือดดำนั้นพอจะสามารถใช้ในการช่วยหายใจด้วยเจ็ททางหลอดลมได้ ส่วน Cook catheter นั้นได้รับการพิสูจน์แล้วว่ามีความแข็งแรงถึงแม้จะถูกหักพับ แต่จะใช้ช่วยหายใจได้อย่างเพียงพอก็ต่อเมื่อใช้แรงดันออกซิเจนสูง*