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Special Issue

Transtracheal jet ventilation in the ‘can’t intubate can’t oxygenate’ emergency: a systematic review

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Abstract

Background: Transtracheal jet ventilation (TTJV) is recommended in several airway guidelines as a potentially life-saving procedure during the ‘Can’t Intubate Can’t Oxygenate’ (CICO) emergency. Some studies have questioned its effectiveness.
Methods: Our goal was to determine the complication rates of TTJV in the CICO emergency compared with the emergency setting where CICO is not described (non-CICO emergency) or elective surgical setting. Several databases of published and unpublished literature were searched systematically for studies describing TTJV in human subjects. Complications were categorized as device failure, barotrauma (including subcutaneous emphysema), and miscellaneous. Device failure was defined by the inability to place and/or use the TTJV device, not patient survival.
Results: Forty-four studies (428 procedures) met the inclusion criteria. Four studies included both emergency and elective procedures. Thirty studies described 132 emergency TTJV procedures; 90 were CICO emergencies. Eighteen studies described 296 elective TTJV procedures. Device failure occurred in 42% of CICO emergency vs 0% of non-CICO emergency (P<0.001) and 0.3% of elective procedures (P<0.001). Barotrauma occurred in 32% of CICO emergency vs 7% of non-CICO emergency (P<0.001) and 8% of elective procedures (P<0.001). The total number of procedures with any complication was 51% of CICO emergency vs 7% of non-CICO emergency (P<0.001) and 8% of elective procedures (P<0.001). Several reports described TTJV-related subcutaneous emphysema hampering subsequent attempts at surgical airway or tracheal intubation.
Conclusions: TTJV is associated with a high risk of device failure and barotrauma in the CICO emergency. Guidelines and recommendations supporting the use of TTJV in CICO should be reconsidered.

Key words: airway management; emergencies; respiration, artificial

Transtracheal jet ventilation (TTJV) is the introduction of pressurized oxygen usually through a narrow-bore cannula cricothyroidotomy. 'Narrow-bore cannula' has been variously defined as <4 mm[1] (10 gauge), or <2 mm[2] (14 gauge). While TTJV is sometimes used during elective head and neck procedures, it has also been advocated as a rescue procedure during emergency airway management. Current Difficult Airway Society (DAS) guidelines recommend scalpel cricothyroidotomy as the favored technique in the 'Can't Intubate, Can't Oxygenate' (CICO) scenario. Notwithstanding, TTJV through a narrow-bore cannula cricothyroidotomy is also included in the DAS CICO recommendations, but limited to clinicians experienced with this technique in their routine clinical practice.[1] This recommendation is similar to the Canadian guidelines.[3] The DAS paediatric CICO guidelines include TTJV as an option in children one to eight yr old.[4] The ASA has published difficult airway guidelines over three decades[5–7] and includes TTJV as an option during a CICO emergency. TTJV for the CICO emergency is advocated in Australia[8] and is mentioned as an option in airway guidelines from Germany[9] and Italy.[10]

Some studies have suggested a high incidence of failure and barotrauma with the use of TTJV.[2 11] The National Audit Project 4[2] reported 12 failures in the 19 attempts at narrow-bore cannula cricothyroidotomy with jet ventilation. In a review of airway-related malpractice claims that had reached legal settlement and were registered in the Anaesthesia Closed Claims Project,[11] Peterson reported that of the nine TTJV procedures performed during CICO emergencies, eight were complicated by barotrauma and all had poor outcomes.

Despite its inclusion in many published airway guidelines to manage the CICO emergency, the benefit of TTJV is unclear. Given this uncertainty we performed a systematic review of its use in clinical practice. Our primary goal was to determine the complication rates of TTJV use in the CICO emergency setting and compare them with the complication rates of those occurring in the emergency setting, where CICO is not described (the non-CICO emergency) and the elective surgical settings. Complications were categorized as device (thus technique) failure, occurrence of barotrauma including subcutaneous emphysema, or miscellaneous (e.g., cardiovascular collapse or bleeding). Device failure was defined by the inability to place and/or use the TTJV device and not by patient survival.

Methods

This study was registered with the International Prospective Register of Systematic Reviews February 16, 2015 (Registration #CRD42015016605) and conducted following the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) statement.[12]

Search strategy

We searched the following databases: Medline (1946 - March 2016), EMBASE (1974-March 2016), Cochrane Database of Systematic Reviews, ACP Journal Club, Database of Abstracts of Reviews of Effects, Cochrane Central Register of Controlled Trials, Cochrane Methodology Register, Health Technology Assessment, and the NHS Economic Evaluation Database. Searches were conducted on March 10th 2015 and repeated on August 28th, December 17th 2015, and March 30th 2016.

Search strategies were constructed separately for each source, based on the search interface and a balance of search sensitivity and specificity. The keywords 'transtracheal', 'trans-tracheal', 'cricothyrotomy', and 'cricothyroidotomy' were used for the Cochrane suite of databases and the unpublished literature searches. The keywords 'airway management', 'oxygenat*', and 'ventilat*' were added to the Medline and EMBASE search strategies, along with the subject headings 'airway management' (MeSH) and 'respiration control' (EMTREE) in order to increase search specificity in these databases. The Cochrane and unpublished literature search strategy mirrored the Medline/EMBASE search strategy as closely as possible, by capturing the transtracheal/cricothyrotomy aspect without further limiting the search results. The Cochrane/unpublished literature search strategy has greater sensitivity than the Medline/EMBASE search strategy, without sacrificing the original design and intent for this systematic review. The full search strategies can be found in Appendix 1. Bibliographies from narrative reviews were hand searched for further potential articles.

Unpublished literature

The unpublished literature was searched in the conference abstracts indexed by EMBASE from 1974 to March 2016 (which included the International Anaesthesia Research Society conference abstracts), and through the conference websites, conference journals or personal communication with conference organizers (see Acknowledgements Section) of the inaugural 2015 World Airway Management Meeting, ASA (2000-March 2016), the Canadian Anesthesiologists' Society (2007-March 2016), the Society for Airway Management (2005; 2007-March 2016) and the Difficult Airway Society (2012–2014). Although the last ten yr of society abstracts were requested from these societies, only certain yr were available. The Anaesthesia Closed Claims Project was also searched by written data request to the project administrator. Clinical leaders in the field of airway management were also contacted for abstracts from the above-listed meetings, further documented patients that may not have appeared in either published or unpublished scientific sources, or for clarification of details regarding their publications (see Acknowledgement Section).

Study selection

Independently and in duplicate, two authors reviewed all abstracts. A third author arbitrated disagreements. We included any study that reported at least one human subject of any age undergoing elective or emergency TTJV. As this systematic review is focused on TTJV use in clinical practice, animal, cadaver, mannequin, and lung-modeling studies were excluded. Animal models were excluded because their differing laryngeal and sub-laryngeal anatomy could impact success and complications of TTJV, in both simulated CICO and non-CICO scenarios, compared with humans. Cadaver studies, in both simulated CICO and non-CICO scenarios, were also excluded as many of our study parameters (e.g., occurrence of barotrauma, cardiovascular collapse or bleeding) would not be apparent in such a model. Also excluded were studies examining high-frequency jet ventilation, as this technique is not part of any published airway guideline. Articles were limited to those published in English or French.

Data extraction

We abstracted the following data from the included studies: emergency or elective TTJV, patient characteristics, catheter type, ventilation device and strategy, oxygen-driving pressure and complications. Emergency TTJV was further subdivided into studies describing a CICO emergency, and those where emergency TTJV use occurred without CICO being described.

Complications abstracted included device failure, barotrauma, or other miscellaneous complication(s). Device failure was defined as the failure to place the device in the airway, dislodgment of the cannula from the airway, kinking or breaking of the cannula, or dislodgement of the cannula hub from the oxygenation device.[2] Other complications were categorized as barotrauma of any type (e.g. pneumothorax, pneumomediastinum, subcutaneous emphysema) or other miscellaneous recorded complications (e.g. cardiovascular collapse or bleeding). The total number of procedures with one or more complication was also recorded.

Data synthesis and analyses

We compared the proportion of procedures where the TTJV device failed or complications were described (e.g. barotrauma or not barotrauma) in each of the following three groups: TTJV in CICO emergencies, TTJV in non-CICO emergencies and TTJV use in elective surgery. These groups were compared using Fisher's exact test; a difference between groups of $P<0.05$ defined significance.

Results

Database searching yielded 959 articles. In addition to 15 duplicate citations, 729 articles were excluded on initial abstract screening. From the unpublished literature, nine studies were identified.[2,13–19] In total, 239 studies underwent full text review and 192 were subsequently excluded. Three studies that initially met inclusion criteria were excluded on more detailed review.[20–22] Smith's 1976 study[22] included the identical number of procedures and clinical details as that of his 1975 study,[23] which was included. In two studies by Jacobs,[20,21] TTJV was performed on terminally ill patients with no described indication and no reporting of ethics board approval, therefore these studies were excluded. In total, from both unpublished and published literature, 44 studies (428 procedures) met inclusion criteria (Fig. 1).

Four studies described both elective and emergency procedures,[23–26] therefore the number of studies in each category are not additive. Emergency TTJV was described in 30 studies[2,11,13–19,23–43] totaling 132 procedures. Of the 30 emergency studies, two studies[23,26] included procedures for both CICO and non-CICO indications, therefore the number of studies in each group are not additive. Twenty-three studies[2,11,13–15,17–19,23–26,33–43] (90 procedures) described CICO as the indication for emergency TTJV (Table 1). Nine of the emergency TTJV studies[16,23,26–32] (42 procedures) did not describe CICO as the indication for TTJV (Table 2). TTJV in elective surgery was described in 18 studies[23–26,44–57] totaling 296 procedures (Table 3).

In the 23 studies describing 90 TTJV procedures in CICO emergencies (Table 1), device failure was recorded in 38 (42%), barotrauma occurred in 29 (32%), and miscellaneous complications in 8 (9%). The total number of procedures with one or more complication was 46 (51%). Sixty (67%) of the 90 CICO emergency procedures were found in four[2,11,13,43] of the 23 retrieved studies.

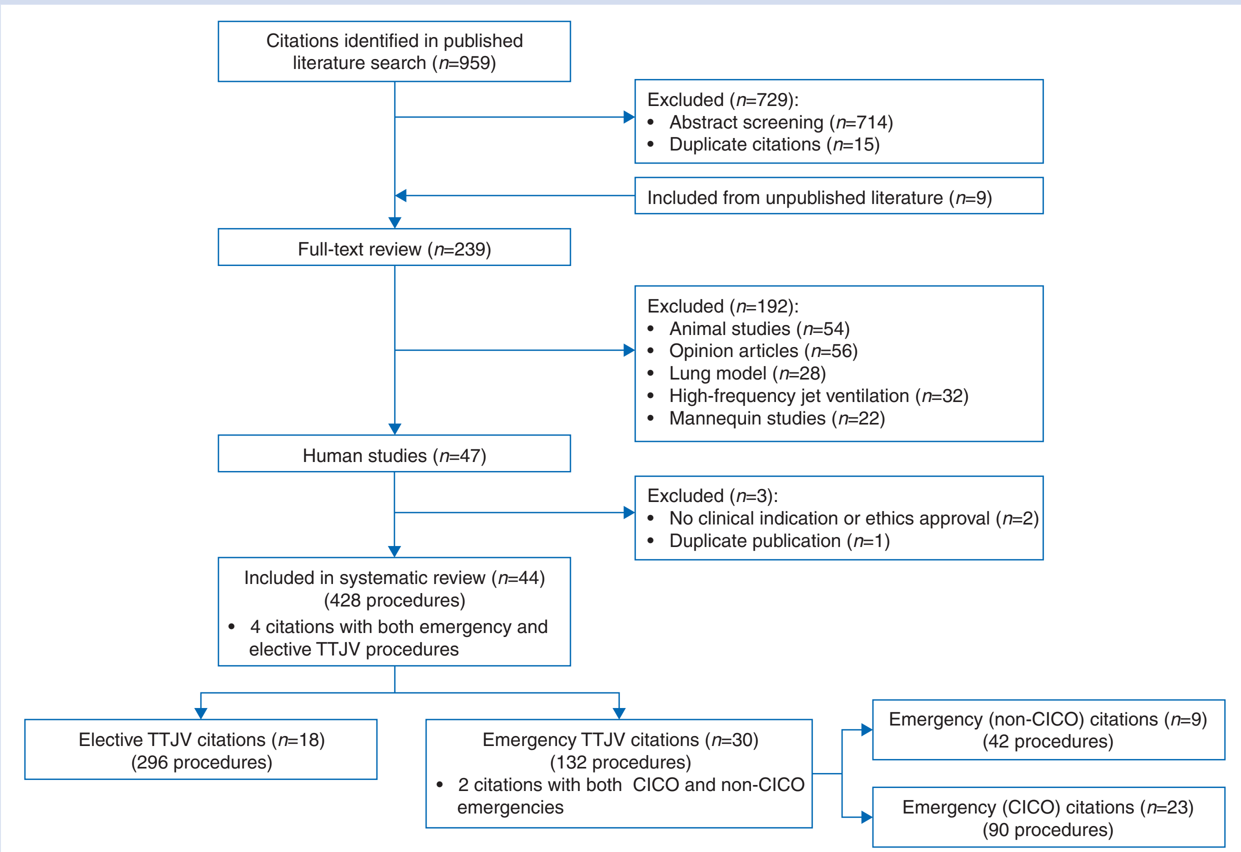

Fig 1 Flow chart of the study.

Table 1 TTJV use in CICO emergencies. ENT, otolaryngology surgery; M, male F, female; g, gauge; kPa, kilopascals; psi, pounds per square inch

Author, Yr (no. of procedures)	Clinical Circumstances	Age, Gender	Cannula size, Type	Oxygenation: Oxygen pressure kPa/psi, jets/min	Complications (#)
Patel, 1999[44] (29)	Intensive care patients, no other details	49–82 M	12 g, 14 g	340 kPa/50 psi, 12–20 jets/min	Device failure (6) Barotrauma (4)
NAP 4[2] (19)	No details	No details	No details	No settings stated	Device failure (12) Barotrauma (6) Difficult tracheal intubation (1)
Peterson, 2005[11] (9)	No details	No details	No details	No settings stated	Device failure (8) Barotrauma (8)
Benumof, 1989[35] (5)	Extubation failure, Elective ENT elective, Caesarean section	34–66, M&F	14 g	'Unregulated wall pressure', no other settings stated	None
Parmet, 1998[43] (3)	No details	No details	14 g	340 kPa/50 psi, no other settings stated	Device failure (2) Barotrauma (2) Cardiac arrest (1)
Weymuller, 1987[26] (3)	Angioedema, ENT, Extubation failure	Incomplete details	16 g	340 kPa /50 psi, 40 jets/min	Device failure (1) Barotrauma (1)
Unpublished Anesthesia Closed Claims Project[13] (3)	No details	No details	No details	No settings stated	Device failure (3) Barotrauma (2) Difficult surgical airway (1)
Koch, 1990[40] (2)	Extubation failure	19 M, 34 F	No details	No settings stated	None
Metz, 1996[41] (2)	Cardiac surgery, Transplant surgery	1. 72 M 2. 48 M	14 g	N/A Equipment failure	Device failure (2)
Smith, 1975[23] (2)	ENT	66 M, 58 M	14 g	340 kPa /50 psi, 'intermittent' jets	Barotrauma (2) Difficult surgical airway (1) Carotid puncture (1)
Augoustides, 2007[34] (1)	Post-CEA haematoma	78 M	16 g	Anaesthesia flush valve- no other settings stated	None
Boughezala, 1997[36] (1)	Oesophageal dilation	56 M	14 g	Manual jet ventilator, no settings stated	None
Bourreli, 1984[37] (1)	ENT	62 F	14 g	410 kPa/60 psi, 12 jets/min	Barotrauma (1)
Bowdle, 1987[38] (1)	ENT	60 M	14 g	340 kPa /50 psi, no other settings stated	Tracheostomy site fire including TTJV catheter (1)
Christodoulides, 2014[17] (1)	Sepsis, hypoxia	2 M	No details	Manual jet ventilator, no settings stated	None
Divatia, 2002[39] (1)	Extubation failure	66 F	14 g	270 kPa/40 psi, 10–12 jets/min	None
McLeod, 2005[25] (1)	ENT	64 M	14 g VBM©	100 kPa/15 psi, 30 jets/min	None
Mesbah, 2013[18] (1)	Supraglottic mass	62 M	Quicktrach© II	'High flow jet ventilation', no other settings stated	Device failure (1) Barotrauma (1)
Newlands, 1996[42] (1)	ENT	42 F	14 g	340 kPa/50 psi, no other settings stated	Device failure (1) Barotrauma (1) Cervical vertebral osteomyelitis (1)

Continued

Table 1 *Continued*

Author, Yr (no. of procedures)	Clinical Circumstances	Age, Gender	Cannula size, Type	Oxygenation: Oxygen pressure kPa/psi, jets/min	Complications (#)
Prado, 2015[19] (1)	Foreign body in airway	68 M	14 g	340 kPa /50 psi, 'low frequency' jetting	None
Smith, 1974[24] (1)	Dental	6 F	16 g Teflon©	207 kPa/30 psi, 10 jets/min	None
Western Australia Coroner's Report 2001[14] (1)	Extubation failure	39 M	14g VBM©	No settings stated	Device failure (1)
Western Australia Coroner's Report 2003[15] (1)	General surgery	31 F	14 g	No settings stated	Device failure (1) Barotrauma (1) Difficult surgical airway (1)
TOTAL: 90 patients					1. Device Failure 38 (42%) 2. Barotrauma 29 (32%) 3. Misc. Complications 8 (9%) 4. Total number of procedures with any complication 46 (51%)

In the nine studies describing 42 TTJV procedures in non-CICO emergencies (Table 2), no device failures were recorded, barotrauma occurred in three (7%) and miscellaneous complications in two (5%). The total number of procedures with one or more complication was three (7%).

In the 18 studies describing TTJV in 296 elective surgical procedures (Table 3), device failure was recorded in one (0.3%), barotrauma in 23 (8%) and miscellaneous complications in three (1%). The total number of procedures with one or more complication was 24 (8%).

There was a marked heterogeneity[58] in the technique of TTJV. Where documented, there was significant variation in type and size of cannula, oxygenation source, driving pressure and jetting frequency in all three groups (Tables 1, 2 and 3). In some reports, emergency TTJV-associated subcutaneous emphysema obscured front-of-neck landmarks, hampering subsequent efforts at definitive surgical airway or tracheal intubation.[2 13 15 26] This resulted in at least one death.[13]

The proportion of complications in the three groups; emergency CICO, emergency non-CICO and elective surgery, were compared (Table 4). A higher proportion of TTJV procedures were associated with device failure (P<0.001), barotrauma (P<0.001), miscellaneous complications (P=0.001), and the occurrence of one or more complications (P<0.001) in the CICO emergency compared with the other two groups.

Discussion

Our systematic review of TTJV revealed that this technique is used in both emergency and elective surgical situations, with the former being used in both CICO and non-CICO and emergencies. We demonstrated a higher proportion of device failure and barotrauma complications in the CICO emergency situation, compared with either the non-CICO emergency or elective surgical settings.

In this review, we found a marked heterogeneity in the technique of TTJV.[58] When described, we found that the pressure settings, transtracheal catheter type and size, ventilation device and ventilation strategy differed widely. This may be related to the varied equipment recommendations found in the literature. Forty-two excluded publications recommended various combinations of equipment for emergency TTJV as 'easy'[59 60] 'simple'[61–63] or 'reliable'[64] but provided no evidence. The myriad of suggested homemade devices[65–72] may have contributed to the high rate of device failure found in our review, as equipment is perhaps used for the first time in an emergency situation. Unproved suggestions continue to be published[61] and presented.[73] In an editorial criticizing this practice, Frerk and colleagues[74] observed 'No-one would expect a pilot to learn how to make an emergency landing in a aeroplane made out of cardboard boxes in a coffee room while their colleague pretended to be air traffic control'.

There are several possible explanations for the higher rate of complications in the emergency CICO situation. The inability to facemask ventilate or perform tracheal intubation is often associated with partial or complete upper airway obstruction. In this scenario, obstruction to exhalation may lead to breath stacking and barotrauma when TTJV is used. Even if a practitioner is experienced with TTJV in the elective setting,[1 3] this skill may not be generalizable to the CICO emergency.

In the largest case series in our systematic review of TTJV use, Patel[44] described 29 consecutive emergency TTJV procedures based on CICO emergencies, in a medical intensive care unit at a Veterans Affairs Hospital in the United States. By protocol, TTJV

Table 2 TTJV use in non-CICO emergencies. ENT, otolaryngology surgery; M, male F, female; g, gauge; kPa, kilopascals; psi, pounds per square inch

Reference (no. of procedures)	Clinical Circumstances	Age, Gender	Cannula size, Type	Oxygenation: Oxygen pressure (kPa/psi), jets/min	Complications (#)
Smith 1975[23] (26)	Respiratory distress	13–65 M, details for all patients not included	14 g	340 kPa/50 psi, no other settings stated	Barotrauma (1)
Weymuller 1987[26] (7)	7 various emergencies	Incomplete details	16 g	340 kPa/50 psi, 40 jets/min	Barotrauma (1) Difficult tracheal intubation as a result of SCE (1)
Chandradeva 2005[29] (2)	Upper airway infection	54 M, 54 F	14 g VBM©	300 kPa/44 psi, no other settings stated	None
McHugh 2007[32] (2)	Cervical spine fracture, trauma	54 M, 26 M	16 g	340 kPa/50 psi, 14–16 jets/min	None
Baraka 1993[28] (1)	Angioneurotic oedema	26 M	16 g	340 kPa/50 psi, no other settings stated	None
Eyrich 1992[30] (1)	Foreign body below vocal cords	56 F	18 g followed by 14 g central venous catheter	170 kPa/25 psi, no other settings stated	None
Guo 2011[31] (1)	Foreign body	15 M	13 g Ravussin©	No settings stated	None
Love 2014[16] (1)	Respiratory distress from unknown airway mass	49 F	No details stated	No settings stated	None
Wagner 1985[33] (1)	Foreign body	65 M	14 g	340 kPa/50 psi, 60 jets/min	Barotrauma (1) Haemoptysis (1)
TOTAL: 42 procedures					1. Device Failure 0 2. Barotrauma 3 (7%) 3. Misc. Complications 2 (5%) 4. Total number of procedures with any complication 3 (7%)

Table 3 TTJV use in elective surgery. ENT, otolaryngology surgery; M, male F, female; g, gauge; kPa, kilopascals; psi, pounds per square inch

Reference (no. of procedures)	Clinical circumstances	Patient Characteristics (Age, Gender)	Cannula size, Type	Oxygenation: Oxygen pressure, jets/min	Complications (#)
Boyce 2005[48] (87)	ENT	39–80 M & F	18 g, 16.5 cm vessel dilator	170–200 kPa/25–30 psi, 10–15 jets/min	Barotrauma (2) Haematoma (1)
Layman 1983[54] (60)	ENT	5–50 M & F	14 or 16 g	No settings stated	Barotrauma (6)
Smith 1975[23] (52)	ENT	10–71 M & F	14 g	No settings stated	Barotrauma (6)
Gulleth 2005[52] (43)	ENT	37–88 M & F	13 g VBM©	No settings stated	Barotrauma (2)
Smith 1974[27] (12)	ENT	23–71 M & F	14,16,18 g	340 kPa/50 psi, no other settings stated	Barotrauma (3)
Spoerel 1971[57] (12)	Various surgeries	22–60 M & F	16 g Teflon©	340 kPa/50 psi, 12–16 jets/min	Haematoma (1)
Patel 2004[55] (10)	Maxillofacial	29–72 M & F	13 g Ravussin©	340 kPa/50 psi, no other settings stated	None
Boyce 1989[47] (8)	ENT	No details	18 g, 16.5 cm vessel dilator	15–25 jets/ min, no other settings stated	None
Weymuller 1987[26] (3)	ENT	55–65 M & F	16 g	Pressure not stated, 40 jets/min	None
Ames 1998[45] (1)	ENT	53 M	14 g Ravussin©	No settings stated	Device failure (1) Barotrauma (1)
Baraka 1986[46] (1)	ENT	17 F	18 g	410 kPa/60 psi, no other settings stated	None
Carden 1976[49] (1)	ENT	27 M	14 g	200 kPa/30 psi, TV stated as 800 cc	Barotrauma (1)
Cook 2005[50] (1)	ENT	83 M	13 g Ravussin©	No settings stated	None
Cook 2006[51] (1)	ENT	52 F	13 g Ravussin©	200 kPa/29 psi, no other settings stated	Barotrauma (1) Cardiovascular depression (1)
Layman 1983[53] (1)	ENT	14 F	14 g	340 kPa /50 psi, no other settings stated	None
McLeod 2005[25] (1)	ENT	88 M	14 g VBM©	150 kPa/22.5 psi, 30 jets/min, pause pressure 25 cmH2O	None
Smith 1973[56] (1)	ENT	66 F	16 g Teflon©	340 kPa/50 psi, 16 jets/min	None
Smith 1974[24] (1)	ENT	11 F	16 g Teflon©	270 kPa/40 psi, 10 jets/min	None
TOTAL: 296 Procedures					1. Device Failure 1 (0.3%) 2. Barotrauma 22 (8%) 3. Misc. Complications 3 (1%) 4. Total number of procedures with any complication 24 (8%)

Table 4 Comparison of complications in emergency TTJV (CICO), emergency TTJV (non-CICO) and TTJV in elective surgery. TTJV, transtracheal jet ventilation; CICO, can't intubate, can't oxygenate

	Emergency TTJV (CICO)	Emergency TTJV (non-CICO)	TTJV in elective surgery	P-value
Total number of procedures	90	42	296	
Device Failure, *n* (%)	38 (42)	0	1 (0.3)	<0.001
Barotrauma, *n* (%)	29 (32)	3 (7)	22 (8)	<0.001
Miscellaneous complications, *n* (%)	8 (9)	2 (5)	3 (1)	0.001
Procedures with any complications, *n* (%)	46 (51)	3 (7)	24 (8)	<0.001

was performed after failed tracheal intubation (two or more attempts) and the failure to maintain oxygen saturation >90% by facemask ventilation. During the 53-month (1994–1998) retrospective study period, there were 352 tracheal intubation procedures; TTJV was instituted in 8% of these because of CICO emergencies. This is a much higher rate of CICO than is usually reported in either the emergency medicine[75 76] or anaesthesia[77] literature. TTJV was instituted by house staff in five of the 29 patients, and the remainder by the attending medical intensive care physician. In the series, device failure (failure to cannulate or catheter kinking) was reported in six of 29 patients (21%) and barotrauma in four (14%).

The rate of failure of TTJV in CICO emergencies was also high in the prospective 4th National Audit Project (NAP4).[2] This audit of airway-related morbidity and mortality was conducted throughout all 309 National Health Services hospitals, over a one-year time period (2008–2009). During the audit, 19 TTJV procedures were performed via narrow-bore (usually ≤2 mm in diameter) cannulae for CICO emergencies, of which 12 (63%) failed and six resulted in barotrauma, including three occurrences of subcutaneous emphysema. Wide-bore cannulae (usually ≥4 mm in diameter, used without TTJV) failed in three of seven uses (43%). An open surgical technique performed by surgeons was almost 100% successful. This may represent a superiority of the open surgical technique over percutaneous techniques, or may also reflect the need to improve anaesthetists' training and preparedness in performing surgical airway with their chosen technique, to a level of competence closer to that of our surgical colleagues. NAP4 identified multiple mechanisms of TTJV failure, including equipment, training, insertion technique and ventilation technique. Human factors and crisis resource management may also play a role.[78] Of note, a number of recent studies have found that anaesthetists fail to accurately identify the cricothyroid membrane by external palpation in a high percentage of patients,[79–81] consistent with the proportion of failed cannula cricothyroidotomy attempts in NAP4.

The Anaesthesia Closed Claims Project[82] contributed 12 TTJV procedures in CICO emergencies to our review. Nine procedures, occurring between the years 1985–1999, were published by Peterson.[11] Three additional procedures were identified between 2000 and 2012 by data request to the Anaesthesia Closed Claims Project administrator.[13] All Anaesthesia Closed Claims Project patients are based on closed legal proceedings and are thus retrospective in nature. In addition, given that the Anaesthesia Closed Claims Project is based on anesthetists involved in malpractice proceedings, the findings may be biased towards negative outcomes of a particular clinical situation and/or procedure.

TTJV has been recommended as a temporizing strategy before open or surgical front-of-neck access.[8] However, one unexpected finding of the present review related to reports of TTJV-associated subcutaneous emphysema[2 13 15 26] obscuring airway landmarks, causing subsequent difficulty with definitive surgical airway access or tracheal intubation. Thus, in addition to its high risk of failure, TTJV may impede further efforts to secure a definitive airway.

There are several limitations to our systematic review that deserve consideration. CICO is reported to occur in approximately 1:12 500 general anaesthetics,[77] and 3–8:1,000 tracheal intubation attempts in the emergency department setting.[75 76] Thus, we expected to find more emergency TTJV procedures in the literature. For example, the Difficult Airway Society paediatric CICO guidelines[4] include TTJV as an option in children one to eight yr of age, yet our review identified only two procedures in this age group during a CICO emergency.[17 27] Reporting and publication bias against publishing complications, or poor outcomes,[58] may have contributed to the relative paucity of emergency TTJV procedures identified in our systematic review. Alternately, it may be that TTJV is simply not commonly used in the CICO scenario, despite its inclusion in several guidelines.[7–10]

TTJV has been recommended for more than twenty years as a potentially life-saving procedure in a CICO emergency.[5–8] In the NAP4 study, it was found that 'anaesthetists almost exclusively chose cannula techniques' when faced with a CICO scenario.[2] TTJV remained the second choice after a wide-bore wire-guided cannula technique in a recent CICO survey study of Canadian anaesthetists.[83] In contrast, the 2015 Difficult Airway Society guidelines recommend an open surgical technique over either narrow or wide-bore cannula techniques, based on an increased probability of success.[1] Our study lends support to this recommendation, given the high rate of complications associated with TTJV in the CICO emergency.

Authors' contributions

Study design/planning: L.V.D., B.B.S., J.A.L., I.R.M., M.F.M., D.E.G.
Study conduct: L.V.D., B.B.S., J.A.L., I.R.M., M.F.M., D.E.G.
Data analysis: L.V.D., B.B.S., J.A.L., I.R.M., M.F.M., D.E.G.
Writing paper: L.V.D., B.B.S., J.A.L., I.R.M., M.F.M., D.E.G.
Revising paper: all authors

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Declaration of interest

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References

1. Frerk C, Mitchell V, McNarry A, *et al*. Difficult Airway Society 2015 Guidelines for management of the unanticipated difficult intubation in adults. *Br Aournal Anaesth*. 2015; **115**: 827–48
2. Cook T, Woodall N, Frerk C. 4th National Audit Project (NAP4): Major complications of airway management in the UK. 2011. https://rcoa.ac.uk/nap4
3. Law JA, Broemling N, Cooper RM, *et al*. The difficult airway with recommendations for management - Part 1 - Intubation encountered in an unconscious/induced patient. *Can J Anesth* 2013; **60**: 1089–118
4. Black A, Flynn P, Popat M, Smith H, Thomas M, Wilkinson K. APA DAS Cannot intubate and cannot ventilate (CICV) in a paralysed anaesthetised child aged 1-8 years. http://www.das.uk.com/files/APA3-CICV-FINAL.pdf
5. Caplan R, Benumof J, Berry F, *et al*. Practice guidelines for management of the difficult airway. *Anesthesiology*. 1993; **78**: 597–602
6. Caplan R, Benumof J, Berry F, *et al*. Practice guidelines for management of the difficult airway. *Anesthesiology*. 2003; **98**: 1269–77
7. Apfelbaum JL, Hagberg CA, Caplan RA, *et al*. Practice guidelines for management of the difficult airway. *Anesthesiology*. 2013; **118**: 251–70

8. Heard AMB, Green RJ, Eakins P. The formulation and introduction of a 'can't intubate, can't ventilate' algorithm into clinical practice. *Anaesthesia* 2009; **64**: 601–8
9. Piepho T, Cavus E, Noppens R, *et al*. S1 Guidelines on airway management: Guideline of the German Society of Anesthesiology and Intensive Care Medicine. *Anaesthesist* 2015; **64**: 859–73
10. Petrini F, Accorsi A, Adrario E, *et al*. Recommendations for airway control and difficult airway management. *Minerva Anestesiol*. 2005; **71**: 617–57
11. Peterson G, Domino KB, Caplan RA, Posner KL, Lee LA, Cheney FW. Management of the difficult airway. *Anesthesiology* 2005; **103**: 33–9
12. Moher D, Shamseer L, Clarke M, *et al*. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev* 2015; **4**: 1
13. Posner KL. *Anesthesia Closed Claims Project, TTJV Data 2000–2012*. *March*, 2015
14. Western Australia Coroner's Act. R R Patient J.pdf. 2001
15. Western Australia Coroner's Act. R R Patient R.pdf. 2003
16. Love S, Oti C, Kakar V. Transtracheal jet ventilation in failed intubation; not just a rescue intervention. In: *Difficult Airway Society Annual Meeting Abstracts*. 2014; 61
17. Christodoulides G, Coates A, Dulai R. A case of difficult intubation in a pediatric patient with I-Cell disease, mucolipidosis type II. In: *Difficult Airway Society Annual Meeting Abstracts*. 2014; 45
18. Mesbah A, Atayi M. Airway obstruction from an insidious supraglottic mass. In: *Difficult Airway Society Annual Meeting Abstracts*. 2013; 26
19. Prado R, Amaral N, Malito M, Perin D. Airway obstruction and rescue jet ventilation in a distorted difficult airway: case report. In: *World Airway Management Meeting*. 2015; 280
20. Jacobs H. Emergency percutaneous transtracheal catheter and ventilator. *J Trauma* 1972; **12**: 50–5
21. Jacobs H, Smyth N, Witorsch P. Transtracheal catheter ventilation: clinical experience in 36 patients. *Chest* 1974; **65**: 36–40
22. Smith RB, Babinski M, Klain M, Pfaeffle H. Percutaneous transtracheal ventilation. *J Am Coll Emerg Physicians* 1976; **5**: 765–70
23. Smith RB, Schaer WB, Pfaeffle H. Percutaneous transtracheal ventilation for anaesthesia and resuscitation: A review and report of complications. *Can J Anesth* 1975; **22**: 607–12
24. Smith RB, Myers E, Sherman H. Transtracheal ventilation in paediatric patients case reports. *Br J Anaesth* 1974; **46**: 313–4
25. McLeod ADM, Turner MWH, Torlot KJ. Safety of transtracheal jet ventilation in upper airway obstruction. *Br J Anaesth* 2005; **94**: 560–1
26. Weymuller EAJ, Pavlin EG, Paugh D, Cummings CW. Management of difficult airway problems with percutaneous transtracheal ventilation. *Ann Otol Rhinol Laryngol* 1987; **96**: 34–7
27. Smith RB. Transtracheal Ventilation During Anesthesia. *Anesth Analg* 1974; **53**: 225–8
28. Baraka A, Sibai AN, Azar IA, Zaytoun G. Transtracheal jet ventilation in an adult patient with severe hereditary angioneurotic edema. *Middle East J Anaesthesiol* 1993; **12**: 171–5
29. Chandradeva K, Palin C, Ghosh SM, Pinches SC. Percutaneous transtracheal jet ventilation as a guide to tracheal intubation in severe upper airway obstruction from supraglottic oedema. *Br J Anaesth* 2005; **94**: 683–6
30. Eyrich JE, Riopelle JM, Naraghi M, Orleans N. Elective Transtracheal Jet Ventilation for Bronchoscopic Removal of Tracheal Foreign Body. *South Med J* 1992; **85**: 1017–9
31. Guo C-S, Poon Y-Y, Peng J-P. Bilateral vocal cord immobility caused by a plastic slice: Image and anesthetic management. *Int J Pediatr Otorhinolaryngol Extra* 2011; **6**: 238–9
32. McHugh R, Kumar M, Sprung J, Bourke D. Case Reports: Transtracheal jet ventilation in management of the difficult airway. *Anaesth Intensive Care Med* 2007; **35**: 406–8
33. Wagner DJ, Coombs DW, Doyle SC. Percutaneous transtracheal ventilation for emergency dental appliance removal. *Anesthesiology* 1985; **62**: 664–6
34. Augoustides JG, Groff BE, Mann DG, Johansson JS. Difficult airway management after carotid endarterectomy: utility and limitations of the Laryngeal Mask Airway. *J Clin Anesth* 2007; **19**: 218–21
35. Benumof JL, Scheller MS. The importance of transtracheal jet ventilation in the management of the difficult airway. *Anesthesiology* 1989; **71**: 769–78
36. Boughezala S, Choufane S, Lemogne M. Ventilation transtracheale de sauvetage. *Ann Fr Anesth Reanim* 1997; **16**: 553
37. Bourreli B, Bigot A, Wesoluch M, Souron R. Pneumomediastin et emphyseme sous-cutane au decours d 'une ventilation translaryngee par oxygene pulse Mediastinal and subcutaneous emphysema secondary to emergency translaryngeal jet ventilation. *Ann Fr Anesth Reanim* 1984; **3**: 377–9
38. Bowdle TA, Glenn M, Colston H, Eisele D. Bowdle 1987 intraoperative fire during emergency conversion of ttjv catheter to trach.pdf. *Anesthesiology* 1987; **66**: 697–8
39. Divatia JV, Bhadra N, Kulkarni AP, Upadhye SM. Failed intubation managed with subcricoid transtracheal jet ventilation followed by percutaneous tracheostomy. *Anesthesiology* 2002; **96**: 1519–20
40. Koch E, Benumof JL. Percutaneous transtracheal jet ventilation: An important airway adjunct. *Am Assoc Nurse Anesth J* 1990; **58**: 337–9
41. Metz S, Parmet JL, Levitt JD. Failed emergency transtracheal ventilation through a 14-gauge intravenous catheter. *J Clin Anesth* 1996; **8**: 58–62
42. Newlands SD, Makielski KH. Cervical osteomyelitis after percutaneous transtracheal ventilation and tracheotomy. *Head Neck* 1996; **18**: 295–8
43. Parmet JL, Colonna-Romano P, Horrow JC, Miller F, Gonzales J, Rosenberg H. The laryngeal mask airway reliably provides rescue ventilation in cases of unanticipated difficult tracheal intubation along with difficult mask ventilation. *Anesth Analg* 1998; **87**: 661–5
44. Patel RG. Percutaneous Transtracheal Jet Ventilation* A Safe, Quick, and Temporary Way To Provide Oxygenation and Ventilation When Conventional Methods Are Unsuccessful. *Chest J* 1999; **116**: 1689–94
45. Ames W, Venn P. Complication of the transtracheal catheter. *Br J Anaesth* 1998; **81**: 825
46. Baraka A. Transtracheal Jet Ventilation during Fiberoptic Intubation under General Anesthesia. *Anesth Analg* 1986; **65**: 1091–2
47. Boyce JR, Peters G. Vessel dilator cricothyrotomy for transtracheal jet ventilation. *Can J Anesth*. 1989; **36**: 350–3
48. Boyce JR, Peters GE, Carroll WR, Magnuson JS, Mccrory A, Boudreaux AM. Preemptive vessel dilator cricothyrotomy aids in the management of upper airway obstruction. *Can J Anesth* 2005; **52**: 765–9
49. Carden E, Calcaterra T, Lechtman A. Pneumatocele of the Larynx: A Complication of Percutaneous TranstracheaI VentiIation. *Anesth Analg* 1976; **55**: 600–1
50. Cook T, Asif M, Sim R, Waldron J. Case Report Use of a ProSeal TM laryngeal mask airway and a Ravussin cricothyroidotomy needle in the management of laryngeal and subglottic

stenosis causing upper airway obstruction. *Br J Anaesth* 2005; **95**: 554–7
51. Cook TM, Bigwood B, Cranshaw J. Case Report: A complication of transtracheal jet ventilation and use of the Aintree intubation catheter during airway resuscitation. *Anaesthesia* 2006; **61**: 692–7
52. Gulleth Y, Spiro J. Percutaneous Transtracheal Jet Ventilation in Head and Neck Surgery. *Arch Otolaryngol Head Neck Surg* 2005; **131**: 886–90
53. Layman PR. Bypassing a problem airway. *Anaesthesia* 1983; **38**: 478–80
54. Layman P. Transtracheal ventilation in oral surgery. *Ann R Coll Surg Engl* 1983; **65**: 318–20
55. Patel C, Diba A. Measuring tracheal airway pressures during transtracheal jet ventilation: an observational study. *Anaesthesia* 2004; **59**: 248–51
56. Smith RB, MacMillan BB, Petruscak J, Pfaeffle HH. Transtracheal Ventilation for Laryngoscopy: A case report. *Ann Otolaryngol* 1973; **82**: 347–50
57. Spoerel WE, Narayanan PS, Singh NP. Transtracheal ventilation. *Br J Anaesth* 1971; **43**: 932–9
58. Møller AM. How to map the evidence: the development of the systematic review in anaesthesia. *Br J Anaesth* 2012; **109**: 32–4
59. Reich D, Schwartz N. An Easily Assembled Device for Transtracheal Oxygenation. *Anesthesiology* 1987; **66**: 437–8
60. Delaney W, Kaiser R. Percutaenous Transtracheal Jet Ventilation Made Easy. *Anesthesiology* 1991; **74**: 952
61. Gallagher TQ, Setlur J, Maturo S, Hartnick CJ. Percutaneous transtracheal needle insufflation: A useful emergency airway adjunct simply constructed from common items found on your anesthesia cart. *Laryngoscope* 2012; **122**: 1178–80
62. Gilder J. A Simple System for Transtracheal Ventil. *Anesthesiology* 1983; **58**: 106
63. Ho A. A simple anesthesia machine-driven transtracheal jet ventilation system. *Anesth Analg* 1994; **78**: 405
64. Bishop DG, Farina Z, Wise RD. Difficult airways: A reliable 'Plan b'. *South African J Anaesth Analg* 2011; **17**: 186–9
65. Aye L. Percutaneous Transtracheal Ventilation. *Anesth Analg* 1983; **62**: 330653
66. Chong C-F, Wang T-L, Chang H. Percutaneous transtracheal ventilation without a jet ventilator. *Am J Emerg Med* 2003; **21**: 507–8
67. Debenham T. Emergency transtracheal ventilation in the anesthesia or the casualty department. *Anaesthesia* 1985; **40**: 599–600
68. Kindopp A, Nair V. A new setup for emergency transtracheal jet ventilation. *Can J Anesth* 2001; **48**: 716–7
69. Meyer P. Emergency Transtracheal Jet Ventilation System. *Anesthesiology* 1990; **73**: 787–8
70. Patel R. Systems for Transtracheal Ventilation. *Anesthesiology* 1983; **59**: 165
71. Cameron PD, McMichan JC. Percutaneous Transtracheal Ventilation Simplified. *Anesth Analg* 1984; **63**: 168
72. Sprague D. Transtracheal Jet Oxygenator from Capnographic Monitoring Components. *Anesthesiology* 1990; **73**: 788
73. Shah S, Woo C, Liu Y, Lacey O. Can't intubate, can't ventilate in remote areas:A simple way of providing effective ventilation through needle cricothyroidotomy. In: *Difficult Airway Society Annual Meeting Abstracts* 2013
74. Frerk C, Frampton C. Cricothryoidotomy; time for change. *Anaesthesia* 2006; **61**: 921–3
75. Walls RM, Brown CA, Bair AE, Pallin DJ. Emergency airway management: A multi-center report of 8937 Emergency Department intubations. *J Emerg Med* 2011; **41**: 347–54
76. Stephens CT, Kahntroff S, Dutton RP. The success of emergency endotracheal intubation in trauma patients: a 10-year experience at a major adult trauma referral center. *Anesth Analg* 2009; **109**: 866–72
77. Kheterpal S, Martin L, Shanks AM, Tremper KK. Prediction and outcomes of impossible mask ventilation: a review of 50,000 anesthetics. *Anesthesiology* 2009; **110**: 891–7
78. Brindely PG, Beed M, Duggan LV, Hung O, Murphy MF. Updating our approach to the difficult and failed airway: time to 'stop and think'. *Can J Anaesth* 2016; **63**: 373–81
79. Aslani A, Ng SC, Hurley M, McCarthy KF, McNicholas M, McCaul CL. Accuracy of identification of the cricothyroid membrane in female subjects using palpation: An observational study. *Anesth Analg.* 2012; **114**: 987–92
80. Elliott DSJ, Baker PA, Scott MR, Birch CW, Thompson JMD. Accuracy of surface landmark identification for cannula cricothyroidotomy. *Anaesthesia* 2010; **65**: 889–94
81. Lamb A, Zhang J, Hung O, *et al*. Accuracy of identifying the cricothyroid membrane by anesthesia trainees and staff in a Canadian institution. *Can J Anaesth* 2015; **62**: 495–503
82. Closed Claims Project and Its Registries. http://depts.washington.edu/asaccp/welcome-anesthesia-closed-claims-project-its-registries
83. Wong DT, Mehta A, Tam AD, Yau B, Wong J. A survey of Canadian anesthesiologists' preferences in difficult intubation and 'cannot intubate, cannot ventilate' situations. *Can J Anaesth* 2014; **61**: 717–26

Appendix 1: Search strategies

Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) 1946 to Present

1. exp Airway Management/
2. airway management.ti,ab
3. oxygenat*.ti,ab
4. ventilat*.ti,ab
5. Or/1–4
6. transtracheal.ti,ab
7. trans-tracheal.ti,ab
8. cricothyrotomy.ti,ab
9. cricothyroidotomy.ti,ab
10. Or/6–9
11. And/5,10
12. Limit 11 to (english or French)

Embase 1974 to 2016 March 29

1. exp respiration control/
2. airway management.ti,ab
3. oxygenat*.ti,ab
4. ventilat*.ti,ab
5. Or/1–4
6. transtracheal.ti,ab
7. trans-tracheal.ti,ab
8. cricothyrotomy.ti,ab
9. cricothyroidotomy.ti,ab
10. Or/6–9
11. And/5,10
12. Limit 11 to (english language or french)

Cochrane Database of Systematic Reviews 2005 to March 23 2016
ACP Journal Club 1991 to March 2016
Database of Abstracts of Reviews of Effects 1st Quarter 2016
Cochrane Central Register of Controlled Trials February 2016
Cochrane Methodology Register 3rd Quarter 2012

Health Technology Assessment 1st Quarter 2016
NHS Economic Evaluation Database 1st Quarter 2016

1. transtracheal.ti,ab
2. trans-tracheal.ti,ab
3. cricothyrotomy.ti,ab
4. cricothyroidotomy.ti,ab
5. Or/1–4
6. limit 5 to (english or french) [Limit not valid in CDSR,ACP Journal Club,DARE,CLCMR,CLEED; records were retained]

Unpublished Literature
transtracheal OR trans-tracheal OR cricothyrotomy OR cricothyroidotomy

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