



## 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 Several databases of published and unpublished literature were searched systematically for studies describing TTJV in human subjects.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 <sup>1</sup> (10 gauge), or  $<2$  mm <sup>2</sup> (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.<sup>1</sup> This recommendation is similar to the Canadian guidelines.<sup>3</sup> The DAS paediatric CICO guidelines include TTJV as an option in children one to eight yr old.<sup>4</sup> The ASA has published difficult airway guidelines over three decades<sup>5-7</sup> and includes TTJV as an option during a CICO emergency. TTJV for the CICO emergency is advocated in Australia<sup>8</sup> and is mentioned as an option in airway guidelines from Germany<sup>9</sup> and Italy.<sup>10</sup>

Some studies have suggested a high incidence of failure and barotrauma with the use of TTJV.<sup>2, 11</sup> The National Audit Project 4<sup>2</sup> 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,<sup>11</sup> 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

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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.<sup>12</sup>

### 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.<sup>2</sup> 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**

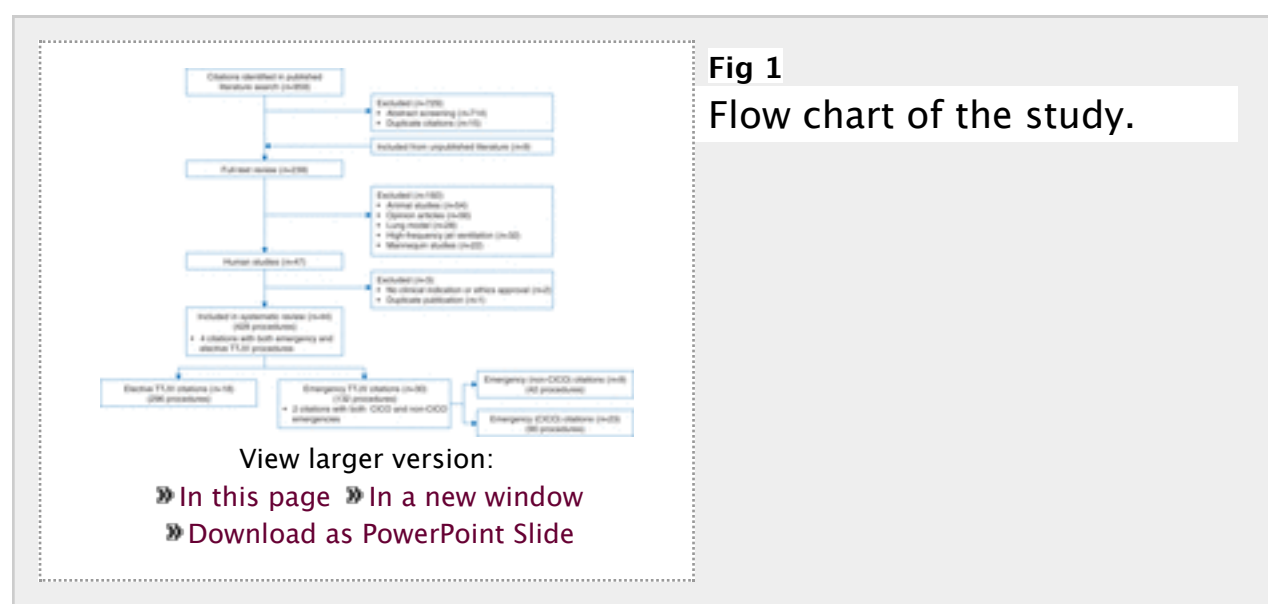
We compared the proportion of procedures where the TTJV device failed or complications were described (e.g. barotrauma or not barotrauma) in each of the following three groups: TTJV in CICO emergencies, TTJV in non-CICO emergencies and TTJV use in elective surgery. These groups were compared using Fisher's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

## **Results**

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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.<sup>2, 13-19</sup> 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.<sup>20-22</sup> Smith's 1976 study<sup>22</sup> 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).

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

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

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

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.

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<sup>58</sup> 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.<sup>2, 13, 15, 26</sup> This resulted in at least one death.<sup>13</sup>

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.

View this table: » In this window » In a new window	<b>Table 4</b> 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
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## Discussion

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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.<sup>58</sup> 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'<sup>59, 60</sup> 'simple'<sup>61-63</sup> or 'reliable'<sup>64</sup> but provided no evidence. The myriad of suggested homemade devices<sup>65-72</sup> 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<sup>61</sup> and presented.<sup>73</sup> In an editorial criticizing this practice, Frerk and colleagues<sup>74</sup> 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,<sup>1, 3</sup> this skill may not be generalizable to the CICO emergency.

In the largest case series in our systematic review of TTJV use, Patel<sup>44</sup> 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 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<sup>75, 76</sup> or anaesthesia<sup>77</sup> 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).<sup>2</sup> 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  $\leq 2$  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  $\geq 4$  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.<sup>78</sup> 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,<sup>79–81</sup> consistent with the proportion of failed cannula cricothyroidotomy attempts in NAP4.

The Anaesthesia Closed Claims Project<sup>82</sup> contributed 12 TTJV procedures in CICO emergencies to our review. Nine procedures, occurring between the years 1985–1999, were published by Peterson.<sup>11</sup> Three additional procedures were identified between 2000 and 2012 by data request to the Anaesthesia Closed Claims Project administrator.<sup>13</sup> 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 anaesthetists 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.<sup>8</sup> However, one unexpected finding of the present review related to reports of TTJV-associated subcutaneous emphysema<sup>2, 13, 15, 26</sup> 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,<sup>77</sup> and 3–8:1,000 tracheal intubation attempts in the emergency department setting.<sup>75, 76</sup> Thus, we expected to find more emergency TTJV procedures in the literature. For example, the Difficult Airway Society paediatric CICO guidelines<sup>4</sup> 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.<sup>17, 27</sup> Reporting and publication bias against publishing complications, or poor outcomes,<sup>58</sup> 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.<sup>7–10</sup>

TTJV has been recommended for more than twenty years as a potentially life-saving procedure in a CICO emergency.<sup>5–8</sup> In the NAP4 study, it was found that 'anaesthetists almost exclusively chose cannula techniques' when faced with a CICO scenario.<sup>2</sup> TTJV remained the second choice after a wide-bore wire-guided cannula technique in a recent CICO survey study of Canadian anaesthetists.<sup>83</sup> 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.<sup>1</sup> Our study lends support to this recommendation, given the high rate of complications associated with TTJV in the CICO emergency.

#### Authors' contributions

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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

#### Declaration of interest

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None declared.

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#### Appendix 1

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##### **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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