A Meta-Analysis of Prehospital Airway Control Techniques Part II: Alternative Airway Devices and Cricothyrotomy Success Rates

Michael W. Hubble, PhD, NREMT-P, Denise A. Wilfong, PhD, NREMT-P, Lawrence H. Brown, MPH&TM, Attila Hertelendy, NREMT-P, Randall W. Benner, MEd, NREMT-P

Abstract

Background. Airway management is a key component of prehospital care for seriously ill and injured patients. Oral endotracheal intubation (OETI) is the definitive airway of choice in most emergency medical services (EMS) systems. However, OETI may not be an approved skill for some clinicians or may prove problematic in certain patients because of anatomic abnormalities, trauma, or inadequate relaxation. In these situations alternative airways are frequently employed. However, the reported success rates for these devices vary widely, and established benchmarks are lacking. **Objective.** We sought to determine pooled estimates of the success rates of alternative airway devices (AADs) and needle cricothyrotomy (NCRIC) and surgical cricothyrotomy (SCRIC) placement through a meta-analysis of the literature. **Methods.** We performed a systematic literature search for all English-language articles reporting success rates for AADs, SCRIC, and NCRIC. Studies of field procedures performed by prehospital personnel from any nation were included. All titles were reviewed independently by two authors using prespecified inclusion criteria. Pooled estimates of success rates for each airway technique were calculated using a random-effects meta-analysis model. **Results.** Of 2,005 prehospital airway titles identified, 35 unique studies were retained for analysis of AAD success rates, encompassing a total of 10,172 prehospital patients. The success rates for SCRIC and NCRIC were analyzed across an additional 21 studies totaling 512 patients. The pooled estimates (and 95% confidence intervals [CIs]) for intervention success across all clinicians and patients were as follows: esophageal obturator airway–esophageal gastric tube airway (EOA-EGTA) 92.6% (90.1%–94.5%); pharyngeotracheal lumen airway (PTLA) 82.1% (74.0%–88.0%); esophageal-tracheal Combitube (ETC) 85.4% (77.3%–91.0%); laryngeal mask airway (LMA) 87.4% (79.0%–92.8%); King Laryngeal Tube airway (King LT) 96.5% (71.2%–99.7%); NCRIC 65.8% (42.3%–83.59%); and SCRIC 90.5% (84.8%–94.2%). **Conclusions.** We provide pooled estimates for prehospital AAD, NCRIC, and SCRIC airway interventions. Of the AADs, the King LT demonstrated the highest insertion success rate (96.5%), although this estimate is based on limited data, and data regarding its ventilatory effectiveness are lacking; more data are available for the ETC and LMA. The ETC, LMA, and PTLA all had similar—but lower—success rates (82.1%–87.4%). NCRIC has a low rate of success (65.8%); SCRIC has a much higher success rate (90.5%) and should be considered the preferred percutaneous rescue airway. **Key words**: EMS; paramedic; prehospital; cricothyrotomy; airway management; alternative airway devices

PREHOSPITAL EMERGENCY CARE 2010;14:515–530

Introduction

Appropriate and effective airway management is fundamental in the prehospital resuscitation of critically ill and injured patients, and failure to establish a patent airway in the field is associated with negative outcomes in some patients.[1,2] The preference for oral endotracheal intubation (OETI) is predicated on the notion that a cuffed endotracheal tube will protect the lungs from aspiration and provide a means for effective ventilation of the lungs. However, the safety and efficacy profile of prehospital OETI has been challenged in the last decade,[3–5] and a meta-analysis of the published literature suggests suboptimal prehospital OETI placement success rates when performed by nonphysician clinicians in certain patient groups.[6] Furthermore, OETI may not be an approved skill for some clinicians.

In the absence of personnel qualified to perform OETI, or if OETI proves problematic, alternative airways are frequently employed. The most common airway devices used either as an alternative primary airway or as a rescue airway when OETI fails include the following: esophageal obturator airway (EOA); esophageal gastric tube airway (EGTA); pharyngeotracheal lumen airway (PTLA); esophageal-tracheal Combitube (ETC), laryngeal mask airway (LMA); and King Laryngeal Tube airway (King LT; King

Received January 31, 2010, from the Emergency Medical Care Program (MWH, DAW), Western Carolina University, Cullowhee, North Carolina; Anton Breinl Centre for Public Health and Tropical Medicine (LHB), James Cook University, Townsville, Queensland, Australia; EMS Management Program (AH), College of Business, Eastern New Mexico University, Roswell, New Mexico; and Bitonte College of Health & Human Services (RWB), Youngstown State University, Youngstown, Ohio. Revision received April 12, 2010; accepted for publication April 15, 2010.

Presented in part at the National Association of EMS Physicians annual meeting, Phoenix, Arizona, January 2010.

This project received no external funding.

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

Address correspondence to: Michael W. Hubble, PhD, NREMT-P, Emergency Medical Care Program, 122 Moore Building, Western Carolina University, Cullowhee, NC 28723. e-mail: mhubble@email.wcu.edu

doi: 10.3109/10903127.2010.497903

Systems, Noblesville, IN). Because these devices are predominately alternatives to OETI, they are collectively known as alternative airway devices (AADs). Other rescue airway techniques include the percutaneous approaches of needle cricothyrotomy (NCRIC) and surgical cricothyrotomy (SCRIC). The reported success rates for AADs vary widely (62%–100%), and similar variation is found in reports of NCRIC (25%–77%) and SCRIC (62%–100%).[7–12]

The wide variation in reported success rates of AAD and percutaneous airways may partially be explained by the specific technique or device employed (e.g., King LT vs. LMA), training and experience of the clinician, setting, type of airway (primary vs. rescue airway), and patient characteristics such as trauma vs. nontrauma and cardiac arrest vs. nonarrest. Unfortunately, most investigations of prehospital airway management are small and include heterogeneous patient populations, settings, and clinicians, which obscure the true procedural success rates. As more emergency medical services (EMS) systems embrace AADs in lieu of OETI, it is important to have a clear appreciation for the true success rates of these devices across a variety of patient characteristics and clinical settings. Consequently, we sought to determine pooled insertion success rates for alternative prehospital airways across varied yet homogeneous groupings of patient characteristics, clinician credentials, and practice settings using meta-analytic techniques.

TABLE 1. Advanced Airway Device–Related Search Terms

Airway search terms
King airway [tw]
King [tw]
pharyngeotracheal airway [tw]
pharyngeal-tracheal airway [tw]
PTLA [tw]
laryngeal mask airway [tw]
EMS search terms
emergency medical technicians [mh]
emergency medical services [mh]
ambulances [mh]
air ambulances [mh]
paramedic [tw]
prehospital [tw]
pre-hospital [tw]
out-of-hospital [tw]
out of hospital [tw]
Boolean search strings
prehospital AND . . .
paramedic AND . . .
field AND . . .
. . . *King tube*
. . . *King airway*
. . . *pharyngeal tracheal airway*
. . . *pharyngeal-tracheal airway*
. . . *pharyngeotracheal airway*
. . . *PTLA*
. . . *LMA*
. . . *laryngeal mask airway*
. . . *esophageal-tracheal airway*
. . . *Combitube*

EMS = emergency medical services; LMA = laryngeal mask airway; [mh] = Medical Subject Heading (MeSH); PTLA = pharyngeotracheal lumen airway; [tw] = text word.

METHODS

This systematic review and meta-analysis received exemption from institutional review board (IRB) monitoring from Western Carolina University and, to the extent possible, was designed to conform to the recommendations of the Quality of Reporting of Meta-Analysis (QUOROM) statement.[13] The detailed search, selection, data abstraction, and analytic methodology has been previously reported, and is briefly summarized below.[6]

Search Strategy

The search strategy was designed to identify all reports concerning out-of-hospital airway management, from which we could then isolate papers regarding AADs, SCRIC, and NCRIC performed by prehospital personnel in the field. The complete search strategy incorporated 75 Medical Subject Headings (MeSH), text words, Boolean strings, and combined commands; the search terms and phrases specific to AADs, SCRIC, and NCRIC are shown in Table 1. The search was limited to English-language articles, but international papers were not otherwise excluded. The search was originally conducted on November 20, 2008, and was updated on July 6, 2009. The bibliographies of selected studies were also reviewed to identify any additional relevant studies. Study authors were not contacted in an attempt to identify additional unpublished studies.

Screening Process

All titles identified by the search were distributed among the study team for independent review by two authors; only those titles for which both reviewers indicated a lack of relevance were excluded. The abstracts of the retained papers were then subjected to an identical independent review process. Papers retained from the abstract review then underwent a review of the full manuscript. Discrepancies in decisions about relevance were resolved by consensus. Interrater reliability at each of these steps, including prior to consensus discussions in the final step, was measured using the kappa statistic.

Selection

All published reports of airway procedures performed by emergency medical technicians (EMTs) and paramedics (including their international equivalents), nurses, or physicians practicing in the prehospital environment were included. Studies conducted on cadavers or manikins, studies not conducted in a field setting (e.g., procedures performed in an emergency department or a surgical suite), and any studies that did not include sufficient data to calculate a procedural success rate were excluded. Randomized controlled trials (RCTs), cohort studies, and retrospective chart reviews were eligible for inclusion. Collective reviews, letters, and editorials were excluded. Where studies reported duplicate or overlapping data, preference was given to the broadest study with the most detailed data.

Quality Assessment

Because most quality assessment tools commonly employed in meta-analysis are specifically designed for evaluating RCTs, the quality of each study included in this meta-analysis was evaluated using an assessment tool devised by the authors (Table 2).[13] The tool is a 10-item scale that evaluates study design, setting, patient population, personnel, and verification of successful placement of the airway device. All quality criteria were scored on a binary (0/1) scale, with the exception of "Verification of successful placement," for which scores ranged from 0 to 2. Potential summary scores ranged between 0 and 10. Quality scores were independently assigned by two authors, with discrepancies resolved by consensus.

Data Extraction

The following variables were extracted from each study: airway device or procedure; clinical characteristics of the patient population (e.g., cardiac arrest vs. nonarrest, trauma vs. nontrauma); credentials of the personnel; setting in which the procedure was performed; mechanism for verifying successful placement; whether the airway interventions were used for primary airway control or as a rescue airway; and the number of successful and unsuccessful airway placements. Data were independently abstracted by at least two authors. Disconcordant opinions regarding abstracted data were resolved by discussion until consensus was attained. In cases in which consensus could not be achieved regarding data abstraction, differences were adjudicated by a third author.

Data Analysis

The primary outcome variable was the pooled proportion (and 95% confidence interval [CI]) for successful placement of each airway device. The proportion of successful placements was defined as the number of patients in whom a patent airway was established divided by the number of patients in whom an airway procedure was attempted, regardless of the number of placement attempts.

All data were analyzed using the Comprehensive Meta-Analysis software package, version 2.0 (Biostat, Inc., Englewood, NJ). Because of variations in the design, setting, and patient populations of the selected studies, a random-effects model was used for pooling study results.[14] Subgroup analysis was performed when it was possible to isolate certain patient groups (e.g., evaluating trauma patients and nontrauma patients independently), clinician credentials (e.g., ground paramedic vs. air medical personnel), and airway function (primary vs. rescue airway).

Heterogeneity was explored through the use of the Cochrane Q test for heterogeneity and the I^2 statistic. Publication bias was evaluated with funnel plots and the Egger regression test.

TABLE 2. Study Quality Assessment Tool Used to Assess the Quality of Included Studies

Criteria	Points
Study design	
Retrospective or before–after design	0
Prospective design	1
Clinician	
Credentials of clinicians not clearly stated or mixed	0
Clearly defined homogeneous group	1
Patient mix	
Patient population undefined or mixture of trauma and medical patients	0
Clearly defined homogeneous group	1
Setting	
Mixture of hospital, air, and field settings	0
Homogeneous field or air setting	1
Verification of successful placement	
Undefined or clinical verification only (breath sounds, chest rise, etc.)	0
Verified by a single objective criterion (colorimetric $ETCO_2$ detector, continuous capnography, oxygen saturation)	1
Verified by two or more objective criteria or ED physician	2
Age	
Patient population undefined or mixture of adult and pediatric patients	0
Clearly defined homogeneous group	1
Cardiac arrest	
Patient population undefined or mixture of arrested/nonarrest patients	0
Clearly defined homogeneous group	1
Drug-assisted intubation	
Undefined or mixture of drug-assisted, non–drug-assisted, and rapid-sequence intubations	0
Clearly defined homogeneous group	1
Rescue airway	
Undefined or device used as both primary and rescue airway technique	0
Clearly defined homogeneous group	1
Total score	10

ED = emergency department; $ETCO_2$ = end-tidal carbon dioxide.

RESULTS

Trial Flow

Figure 1 shows the screening process and the results at each step in the format recommended by the

QUOROM statement.[13] There was moderate to substantial interrater reliability for the reviews, with increasing kappa values at each step of the process.

The initial PubMed search strategy identified 2,005 citations relevant to prehospital airway techniques. Of these, 171 met our criteria for reporting any type of advanced prehospital airway intervention; 35 studies encompassing a total of 10,172 prehospital patients specifically addressed AADs and 21 studies totaling 512 patients reported SCRIC and NCRIC success rates.

Study Characteristics

An overall summary of the characteristics for AAD, SCRIC, and NCRIC studies retained in the analysis is shown in Table 3. Because of their similarities, we treated the EOA and EGTA as a single AAD group. As some of the studies evaluated more than one airway intervention, the 56 studies included a total 64 analyses. Most studies involved prospective data collection (60.9%), ground EMS setting (62.5%), interventions performed by nonphysician clinicians (56.2%), and intubator self-verification of successful placement (68.7%).

Quantitative Data Synthesis

Summary data for the primary and subgroup analyses are shown in Table 4.

Esophageal Obturator Airway–Esophageal Gastric Tube Airway

Eight studies reported a total of 1,833 patients who received EOA-EGTA attempts across all clinicians.[15–22] The quality scores for these studies ranged from 2 to 8, with a mean (± standard deviation [SD]) of 5.56 (±1.81). Details of the EOA-EGTA studies are shown in Appendix 1. Substantial heterogeneity existed in the group of studies (Q statistic $\chi^2 = 21.36$, $p = 0.008$; $I^2 = 62.5\%$). The funnel plot exhibited moderate symmetry and the results of the Egger test for publication bias were nonsignificant ($t = 1.44$, $p = 0.193$) (Fig. 2). The pooled insertion success rate for this group was 92.6% (CI: 90.1%–94.5%) (Fig. 3). Among the nonphysician clinician group (which includes nonphysician air medical personnel), there was little difference in the pooled success rates among the various subgroups of patient characteristics. There were no reports that specifically identified the EOA-EGTA as a rescue airway. There were also no published reports of EOA-EGTA use by physicians.

Pharyngeotracheal Lumen Airway

Only a single study reported the clinical placement success rates of the PTLA (Appendix 2).[23] This study

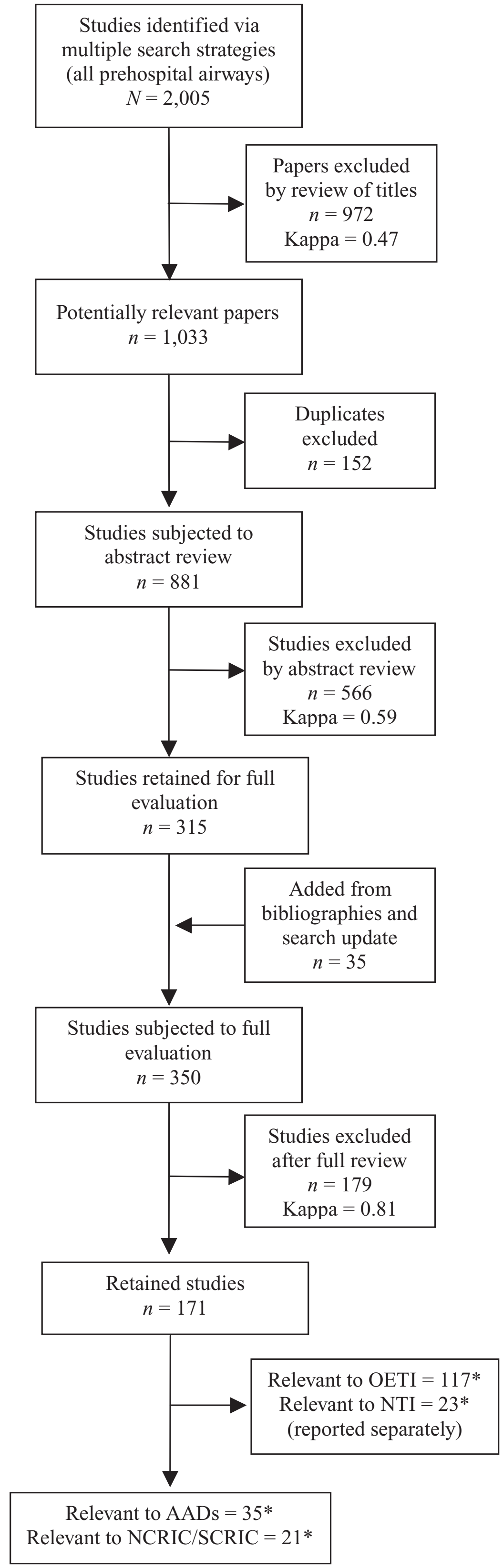


FIGURE 1. Search strategies and results for each airway procedure. *Some studies reported multiple techniques. AAD = advanced airway device; NTI = nasotracheal intubation; NCRIC/SCRIC = needle cricothyrotomy/surgical cricothyrotomy; OETI = oral endotracheal intubation.

TABLE 3. Study Design and Population Characteristics*

Study Characteristics	EOA-EGTA ($n = 9$)	PTLA ($n = 1$)	ETC ($n = 16$):	LMA ($n = 12$)	King LT ($n = 3$)	NCRIC ($n = 4$)	SCRIC ($n = 18$)
Design							
Prospective	7 (77.8%)	1 (100%)	13 (81.3%)	9 (75.0%)	2 (66.7%)	1 (25%)	5 (26.6%)
Before–after	0	0 (0%)	1 (6.2%)	0	0	0	0
Retrospective	2 (22.2%)	0 (0%)	2 (12.5%)	3 (25.0%)	1 (33.3%)	3 (75%)	14 (73.4%)
Subjects (n)							
Minimum–maximum	27–594	117	6–1,712	9–3,016	27–93	2–13	3–69
Median (IQR)	179 (140)	—	61 (133)	48 (105)	30 (33)	6 (6)	16 (28)
Mean ± SD	203 (± 169)	—	223 ± 434	319 (± 853)	49 (± 37)	6.75 (± 4.86)	25.16 (± 23.02)
Quality score							
Minimum–maximum	2–8	6	3–10	2–8	3–7	2–5	1–7
Median (IQR)	6(2)	—	6 (4)	5 (2)	6 (2)	3 (2)	3 (3)
Mean ± SD	5.56 (± 1.81)	6.0 (*n*/*a*)	6.59 (± 2.40)	4.75 (± 1.71)	5.33 (± 2.08)	3.00 (± 1.41)	3.21 (± 1.72)
Clinician							
Physician	0	0	3 (18.8%)	4 (30.0%)	0	1 (25%)	2 (10.5%)
Paramedic	5 (55.6%)	0	6 (37.5%)	4 (30.0%)	1 (33.3%)	2 (50%)	5 (23.3%)
Nurse	0	0	1 (6.2%)	0	1 (33.3%)	0	2 (10.5%)
EMT/EMT-I	2 (22.2%)	1 (100%)	4 (25.0%)	1 (8.3%)	0	0	0
Mixed/not specified	2 (22.2%)	0	2 (12.5%)	3 (25.0%)	1 (33.3%)	1 (25%)	10 (52.6%)
Patient mix							
Nontrauma	5 (55.6%)	0	3 (18.8%)	2 (16.6%)	0	0	0
Trauma	1 (11.1%)	0	4 (25.0%)	0	0	1 (25%)	4 (21.1%)
Mixed/not specified	3 (33.3%)	1 (100%)	10 (62.5%)	10 (83.3%)	3 (100%)	3 (75%)	15 (78.9%)
Setting							
Ground	9 (100%)	1 (100%)	13 (81.3%)	8 (66.6%)	2 (66.7%)	2 (50%)	5 (26.3%)
Air	0	0	1 (6.2%)	2 (16.6%)	1 (33.3%)	0	9 (47.4%)
Mixed/not specified	0	0	2 (12.5%)	2 (16.6%)	0	2 (50%)	5 (26.3%)
Verifier							
Intubator	8 (88.9%)	0	8 (50.0%)	10 (83.3%)	3 (100%)	3 (75%)	11 (57.9%)
ED physician	0	1 (100%)	7 (43.8%)	1 (8.3%)	0	0	4 (21.1%)
Mixed/not specified	1 (11.1%)	0	1 (6.2%)	1 (8.3%)	0	1 (25%)	4 (21.1%)
Verification method							
Clinical assessment	3 (33.3%)	0	3 (18.8%)	1 (8.3%)	2 (66.7%)	1 (25%)	3 (15.8%)
Objective methods†	0	0	3 (18.8%)	1 (8.3%)	0	0	1 (5.3%)
Multiple methods‡	0	0	4 (25.0%)	3 (25.0%)	1 (33.3%)	1 (25%)	4 (21.1%)
Not specified	6 (66.7%)	1 (100%)	6 (37.5%)	7 (58.3%)	0	2 (50%)	11 (57.9%)
Patient ages							
Adult (>12 years old)	6 (66.7%)	0	7 (43.8%)	4 (25.0%)	3 (100%)	1 (25%)	4 (21.1%)
Pediatric (≤12 years old)	0	0	0 (0.0%)	1 (8.3%)	0	1 (25%)	0
Mixed/not specified	3 (33.3%)	1 (100%)	9 (56.2%)	7 (58.3%)	0	2 (50%)	15 (78.9%)
Perfusion							
Cardiac arrest	6 (66.7%)	0	5 (31.3%)	3 (25.0%)	2 (66.7%)	0	0
Nonarrest	0	0	3 (18.8%)	0 (0.0%)	0	0	1 (5.3%)
Mixed/not specified	3 (33.3%)	1 (100%)	8 (50.0%)	9 (75.0%)	1 (33.3%)	4 (100%)	18 (94.7%)
Intervention							
Primary airway	3 (33.3%)	1 (100%)	2 (12.5%)	1 (8.3%)	2 (66.7%)	0	0
Rescue airway	0	0	10 (62.5%)	4 (25.0%)	0	2 (25%)	8 (42.1%)
Mixed/not specified	6 (66.7%)	0	5 (31.3%)	7 (58.3%)	1 (33.3%)	2 (25%)	11 (57.9%)

*Totals may exceed 100% because some studies reported multiple subanalyses.
†Capnography, capnometry, etc.
‡Multiple objective methods (capnometry, colorimetric $ETCO_2$ detector, pulse oximetry, etc.).
ED = emergency department; EMT = emergency medical technician; EOA-EGTA = esophageal obturator airway–esophageal gastric tube airway; ETC = esophageal-tracheal Combitube; $ETCO_2$ = end-tidal carbon dioxide; IQR = interquartile range; King LT = King Laryngeal Tube; LMA = laryngeal mask airway; n/a = not applicable; NCRIC = needle cricothyrotomy; PTLA = pharyngeotracheal lumen airway; SCRIC = surgical cricothyrotomy; SD = standard deviation.

reported the use of the PTLA by emergency medical assistants in British Columbia. The PTLA was used as a rescue airway among a mixture of 117 trauma and nontrauma patients, some of whom were in cardiac arrest. The overall success rate was 82.1% (CI = 74.0%–88.0%).

Esophageal-Tracheal Combitube

Insertion of an ETC was reported in 16 studies, with attempts in 4,243 patients.[7,22–36] The quality score for the studies ranged from 3 to 10, with a mean of 6.59 (±2.40). Details of the ETC studies are shown in Appendix 3. Substantial heterogeneity existed in the overall group of studies (Q statistic $\chi^2 = 359$, p = 0.000; $I^2 = 95.0\%$). The funnel plot exhibited only mild asymmetry (Egger t = 0.579, p = 0.570) (Fig. 2). The pooled success rate across all patients and all clinicians was 85.4% (CI = 77.3%–91.0%) (Fig. 4). Nonphysician clinicians attempted ETC insertion in 4,099 patients, with a pooled success rate of 83.0% (CI = 72.7%–90.0%). When the ETC was used as a rescue airway, the pooled success rate for nonphysicians was 81.8%

TABLE 4. Subgroup Analysis Results, Success Rate (%) and 95% Confidence Interval

Patient Group	All Clinicians	All Nonphysicians*	Ground Paramedics	Nonphysician Flight Crews*	Physicians
EOA-EGTA					
All	—	92.6 (90.1–94.5)	92.2 (89.9–94.1)	—	—
Trauma only	—	96.3 (77.9–99.5)	—	—	—
Nontrauma only	—	91.9 (88.5–94.3)	92.6 (90.7–94.1)†	—	—
Cardiac arrest only	—	92.5 (89.6–94.7)	92.6 (90.7–94.1)†	—	—
PTLA					
Rescue airway only	—	82.1 (74.0–88.0)	—	—	—
ETC					
All	85.4 (77.3–91.0)	83.0 (72.7–90.0)	80.2 (55.8–92.9)	—	92.5 (70.3–98.5)
Trauma only	—	91.5 (80.8–96.5)	94.9 (87.3–98.1)	95.5 (55.2–99.7)‡	—
Nontrauma only	91.7 (79.6–96.9)	87.7 (66.9–96.2)	93.1 (91.8–94.2)	—	97.1 (90.5–99.2)†
Cardiac arrest only	87.4 (77.9–93.2)	84.6 (72.5–92.0)	80.0 (47.8–94.6)	—	97.1 (90.5–99.2)†
Nonarrest only	—	95.0 (88.0–98.0)	94.9 (87.3–98.1)	95.5 (55.2–99.7)‡	—
Rescue airway only	81.9 (74.4–87.5)	81.8 (73.3–88.1)	83.6 (61.8–94.1)	95.5 (55.2–99.7)‡	83.8 (59.0–94.9)
LMA					
All	87.4 (79.0–92.8)	82.7 (70.0–90.8)	83.1 (67.8–91.9)	96.2 (59.7–99.8)	95.5 (88.5–98.3)
Nontrauma only	—	—	79.8 (46.1–94.8)†	—	—
Cardiac arrest only	86.3 (60.7–96.3)	—	79.8 (46.1–94.8)†	—	98.7 (82.2–99.9)
Rescue airway only	86.2 (66.7–95.1)	83.9 (41.9–97.4)	—	96.2 (59.7–99.8)	88.9 (50.0–98.5)
King LT airway‡¿					
All	—	96.5 (71.2–99.7)	—	—	—
Cardiac arrest only	—	96.0 (41.7–99.9)	99.5 (92.0–1.00)	—	—
NCRIC					
All	65.8 (42.3–83.5)	55.6 (24.5–82.9)	53.8 (12.1–90.8)	—	76.9 (47.8–92.4)
Trauma only	—	50.0 (5.9–94.1)	—	—	—
Rescue airway only	—	34.1 (8.2–74.9)	25.0 (3.4–76.2)	—	—
SCRIC					
All	90.5 (84.8–94.2)	90.4 (83.3–94.6)	90.8 (84.3–94.8)	90.9 (75.4–97.0)	97.1 (66.4–99.8)
Trauma only	92.2 (70.6–98.3)	91.8 (61.5–98.7)	94.0 (83.0–98.1)	90.8 (21.0–99.7)	—
Nonarrest only	—	—	—	83.3 (19.4–99.0)	—
Rescue airway only	90.3 (78.5–96.0)	89.0 (75.2–95.6)	90.9 (56.1–98.7)	89.8 (56.0–98.4)	—

Note: Some articles included aggregated data that encompassed subcategories that could not be explicitly extracted.
*Includes paramedics, nurses, other EMS personnel, and other allied health professionals.
†Study addressed nontrauma cardiac arrest.
‡Study addressed rescue airway procedures in nonarrest trauma patients.
EMS = emergency medical services; EOA-EGTA = esophageal obturator airway–esophageal gastric tube airway; ETC = esophageal-tracheal Combitube; King LT = King Laryngeal Tube; LMA = laryngeal mask airway; NCRIC = needle cricothyrotomy; PTLA = pharyngeotracheal lumen airway; SCRIC = surgical cricothyrotomy.

(CI = 73.3%–88.1%), which was slightly lower than the 87.9% (CI = 47.4%–98.3%) success rate when ETC was used as a primary airway. Nonphysician air medical crews demonstrated the highest success rate (95.5%, CI = 55.2%–99.7%), followed by physicians (92.5%, CI = 70.3%–98.5%).

Laryngeal Mask Airway

Across all clinician and patient groups, LMA insertion was reported in 12 studies, with attempts in 3,829 patients.[22,23,35,37–45] Quality scores ranged from 2 to 8, with a mean of 4.75 (±1.71). Details of the LMA studies are shown in Appendix 4. Substantial heterogeneity existed in the overall group of studies (Q statistic $\chi^2 = 172.71$, $p = 0.000$; $I^2 = 93.6\%$), and the funnel plot exhibited moderate symmetry (Egger t = 0.189, p = 0.854) (Fig. 2). The pooled success rate for LMA insertion across all patients and clinicians was 87.4% (CI: 79.0%–92.8%) (Fig. 5). The pooled success rate for all nonphysician clinicians was 82.7% (CI = 70.0%–90.8%). The success rate was higher for LMA insertions by nonphysician flight crews (96.2%, CI = 59.7%–99.8%) and for physicians (95.5%, CI = 88.5%–98.3%). When LMA was used as a rescue airway, the pooled success rate for all clinicians was 86.2% (CI = 66.7%–95.1%). There was little difference in the success rate between cardiac arrest and nonarrest patients.

King Laryngeal Tube Airway

King LT insertion was reported in three studies, with placement attempted in 150 patients.[8,46,47] Quality scores ranged from 3 to 7, with a mean of 5.33 (±2.08). Details of the King LT studies are shown in Appendix 5. Substantial heterogeneity existed in the overall group of studies (Q statistic $\chi^2 = 7.52$, $p = 0.023$; $I^2 = 73.4\%$), and the funnel plot exhibited moderate asymmetry, but did not reach statistical significance (Egger t = 4.19, p = 0.149) (Fig. 2). The pooled success rate for King LT insertion was 96.5% (CI: 71.2%-99.7%) across all patients and clinicians (Fig. 6). Only a single study reported results for King LT insertion exclusively by paramedics, with a success rate of 99.5% (CI = 92.0%–100%).

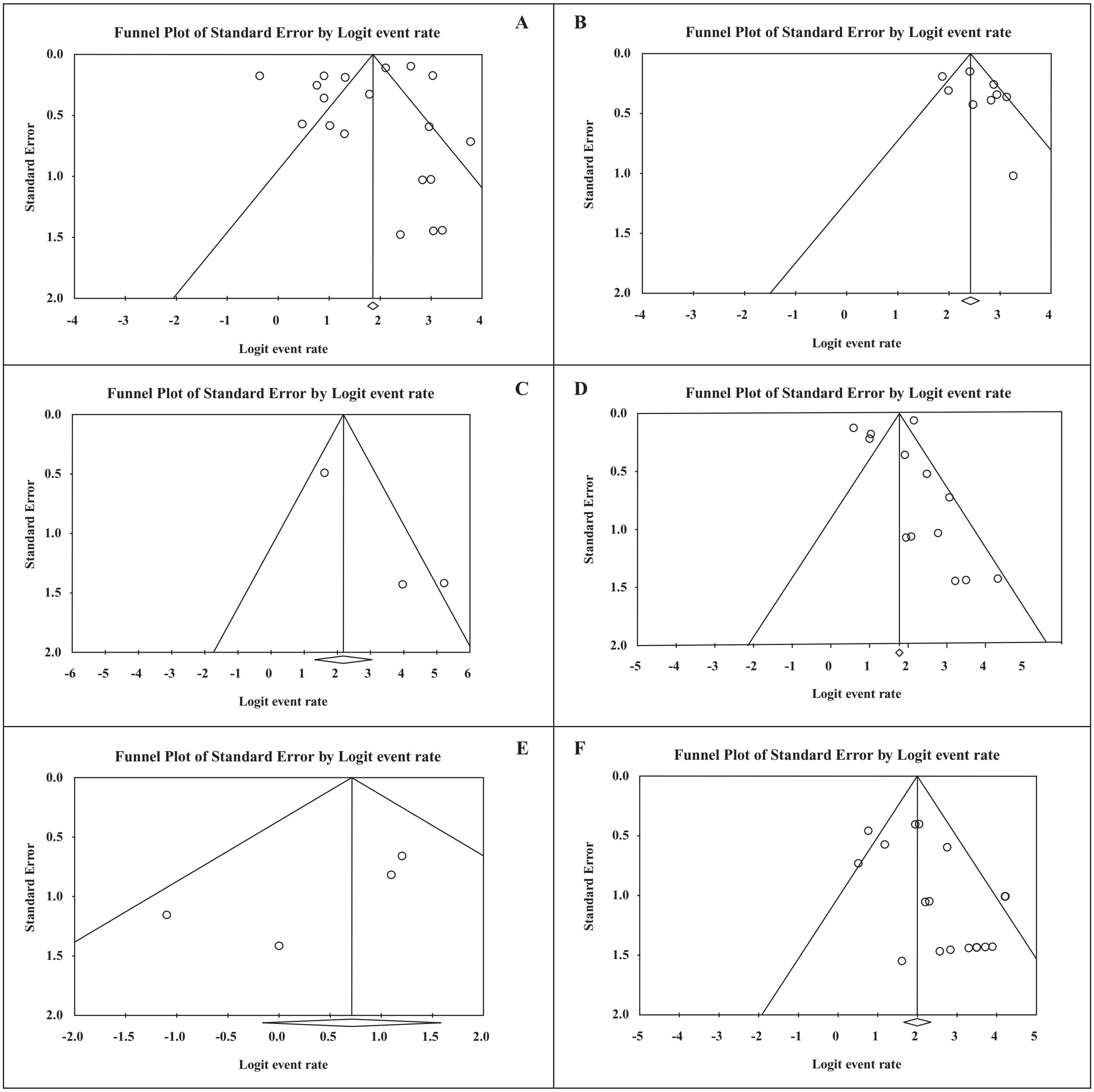


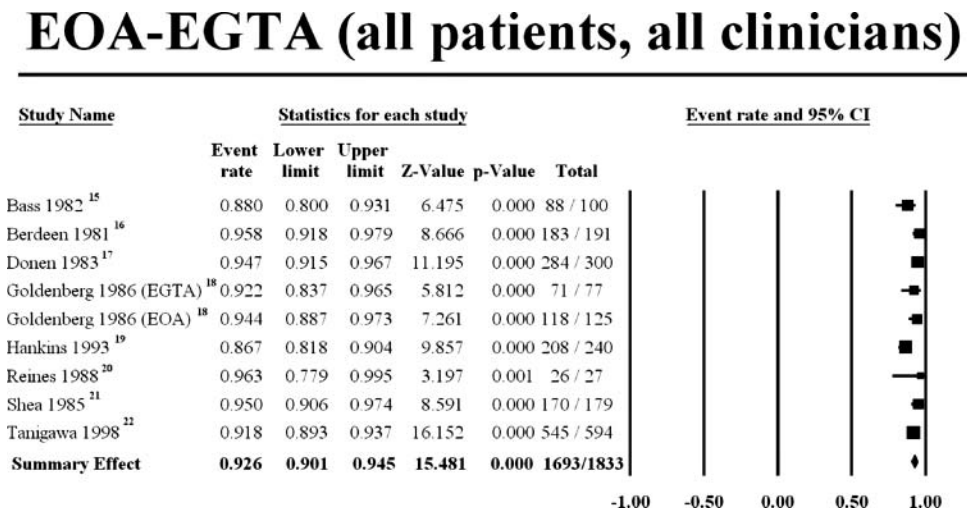
FIGURE 2. Funnel plot assessment of publication bias: **A**) esophageal-tracheal Combitube; **B**) esophageal obturator airway–esophageal gastric tube airway; **C**) King LT; **D**) laryngeal mask airway; E) needle cricothyrotomy; and **F**) surgical cricothyrotomy.

Needle Cricothyrotomy

Four studies reported a total of 27 patients who received NCRIC attempts across all clinicians.[9,10,12,48] The quality scores for the NCRIC studies ranged from 2 to 5, with a mean of 3.00 (±1.41). Details of the NCRIC studies are shown in Appendix 6. There was minimal heterogeneity in the group of studies (Q statistic $\chi^2 = 3.49$, $p = 0.321$; $I^2 = 14.1\%$), and the funnel plot exhibited moderate symmetry (Egger $t = 1.96$, $p = 0.189$) (Fig. 2). The placement success rate for NCRIC was consistently low across all clinicians. The pooled success rate was 65.8% (CI = 42.3%–83.5%) (Fig. 7); the highest success rate was in a small study among physicians in which the success rate was 76.9% (CI = 47.8%–92.4%).

Surgical Cricothyrotomy

Eighteen studies reported SCRIC attempts in 485 patients.[9–12,24,38,49–60] The quality scores ranged from 1



EOA-EGTA (all patients, all clinicians)

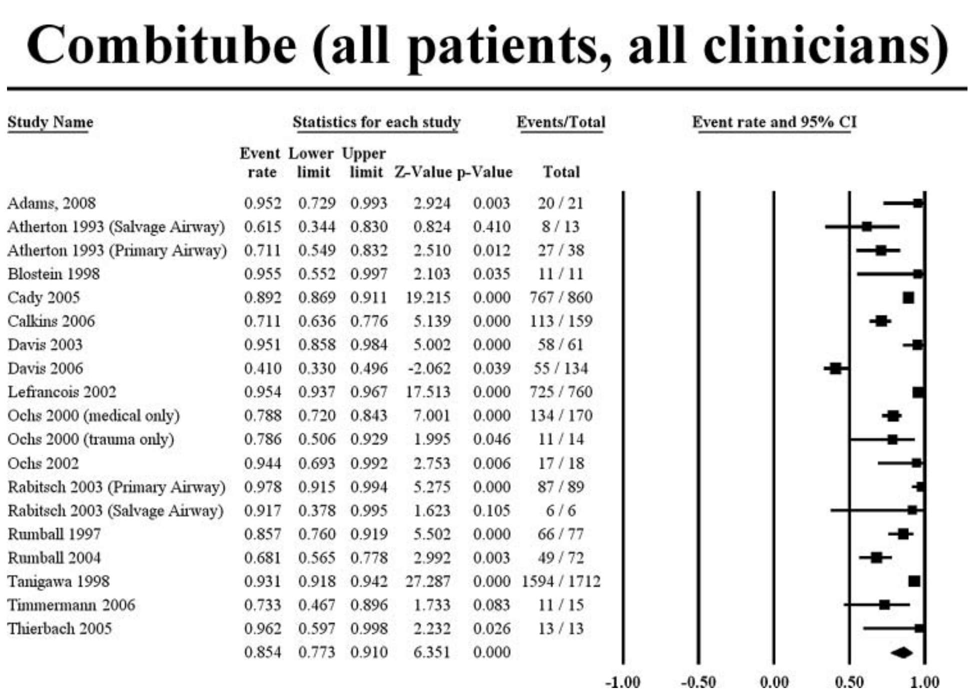
Study Name	Event rate	Lower limit	Upper limit	Z-Value	p-Value	Total
Bass 1982 [15]	0.880	0.800	0.931	6.475	0.000	88 / 100
Berdeen 1981 [16]	0.958	0.918	0.979	8.666	0.000	183 / 191
Donen 1983 [17]	0.947	0.915	0.967	11.195	0.000	284 / 300
Goldenberg 1986 (EGTA) [18]	0.922	0.837	0.965	5.812	0.000	71 / 77
Goldenberg 1986 (EOA) [18]	0.944	0.887	0.973	7.261	0.000	118 / 125
Hankins 1993 [19]	0.867	0.818	0.904	9.857	0.000	208 / 240
Reines 1988 [20]	0.963	0.779	0.995	3.197	0.001	26 / 27
Shea 1985 [21]	0.950	0.906	0.974	8.591	0.000	170 / 179
Tanigawa 1998 [22]	0.918	0.893	0.937	16.152	0.000	545 / 594
Summary Effect	**0.926**	**0.901**	**0.945**	**15.481**	**0.000**	**1693/1833**

FIGURE 3. Forest plot of esophageal obturator airway–esophageal gastric tube airway (EOA-EGTA) insertion. CI = confidence interval.

to 7, with a mean of 3.21 (±1.72). Details of the SCRIC studies are shown in Appendix 7. Substantial heterogeneity existed among the SCRIC studies (Q statistic $\chi^2 = 31.62$, $p = 0.017$; $I^2 = 46.2\%$), and the funnel plot exhibited moderate asymmetry (Egger t = 2.62, p = 0.018) (Fig. 2). The pooled success rate was 90.5% (CI = 84.8%–94.2%) across all patients and clinicians (Fig. 8). Ground paramedics and nonphysician air medical crews had similar success rates (90.8% vs. 90.9%); the physician SCRIC success rate was 97.1% (CI = 66.4%–99.8%).

DISCUSSION

Alternative airway devices are prominent in current prehospital airway management practice, with a widely held belief that AAD placement is easier than OETI placement. Yet, the data regarding prehospital AAD are limited; most AAD studies are small and focus on a single device, making it difficult to generalize the results. This meta-analysis is one of the first efforts to explore AAD insertion success across these many smaller studies. Overall, we found the pooled AAD



Combitube (all patients, all clinicians)

Study Name	Event rate	Lower limit	Upper limit	Z-Value	p-Value	Events/Total
Adams, 2008	0.952	0.729	0.993	2.924	0.003	20 / 21
Atherton 1993 (Salvage Airway)	0.615	0.344	0.830	0.824	0.410	8 / 13
Atherton 1993 (Primary Airway)	0.711	0.549	0.832	2.510	0.012	27 / 38
Blostein 1998	0.955	0.552	0.997	2.103	0.035	11 / 11
Cady 2005	0.892	0.869	0.911	19.215	0.000	767 / 860
Calkins 2006	0.711	0.636	0.776	5.139	0.000	113 / 159
Davis 2003	0.951	0.858	0.984	5.002	0.000	58 / 61
Davis 2006	0.410	0.330	0.496	-2.062	0.039	55 / 134
Lefrancois 2002	0.954	0.937	0.967	17.513	0.000	725 / 760
Ochs 2000 (medical only)	0.788	0.720	0.843	7.001	0.000	134 / 170
Ochs 2000 (trauma only)	0.786	0.506	0.929	1.995	0.046	11 / 14
Ochs 2002	0.944	0.693	0.992	2.753	0.006	17 / 18
Rabitsch 2003 (Primary Airway)	0.978	0.915	0.994	5.275	0.000	87 / 89
Rabitsch 2003 (Salvage Airway)	0.917	0.378	0.995	1.623	0.105	6 / 6
Rumball 1997	0.857	0.760	0.919	5.502	0.000	66 / 77
Rumball 2004	0.681	0.565	0.778	2.992	0.003	49 / 72
Tanigawa 1998	0.931	0.918	0.942	27.287	0.000	1594 / 1712
Timmermann 2006	0.733	0.467	0.896	1.733	0.083	11 / 15
Thierbach 2005	0.962	0.597	0.998	2.232	0.026	13 / 13
	0.854	0.773	0.910	6.351	0.000	

FIGURE 4. Forest plot of esophageal-tracheal Combitube insertion. CI = confidence interval.

Laryngeal Mask Airway (all patients, all clinicians)

Study Name	Event rate	Lower limit	Upper limit	Z-Value	p-Value	Total
Dimitriou 2006[37]	0.987	0.822	0.999	3.033	0.002	38 / 38
Germann 2009[38]	0.962	0.597	0.998	2.232	0.026	13 / 13
Hein 2008[39]	0.738	0.665	0.799	5.827	0.000	121 / 164
Martin 1999[40]	0.941	0.680	0.992	2.690	0.007	16 / 17
McCall 2008[41]	0.923	0.812	0.971	4.775	0.000	48 / 52
Murray 2002[42]	0.643	0.586	0.697	4.746	0.000	182 / 283
Nickel 2008[43]	0.971	0.664	0.998	2.436	0.015	17 / 17
Pattinson 2004[44]	0.871	0.771	0.932	5.359	0.000	61 / 70
Rumball 1997[23]	0.731	0.640	0.807	4.616	0.000	79 / 108
Tanigawa 1998[22]	0.896	0.884	0.906	36.091	0.000	2701 / 3016
Tentillier 2008[45]	0.956	0.839	0.989	4.241	0.000	43 / 45
Timmermann 2006[35]	0.889	0.500	0.985	1.961	0.050	8 / 9
Summary Effect	**0.874**	**0.790**	**0.928**	**6.162**	**0.000**	**3327/3832**

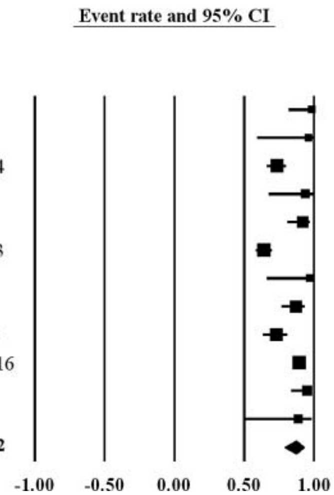


FIGURE 5. Forest plot of laryngeal mask airway insertion. CI = confidence interval.

placement success rates for most devices to be lower than expected.

Our study has many interesting observations. First, we found the pooled placement success rates for ETC and LMA, arguably the most common AADs, to be similar but unimpressive, with nonphysician placement success rates of 83.0% and 82.7%, respectively. Surprisingly, these success rates are lower than the overall pooled OETI success rate of 86.3% reported in a previous meta-analysis.[6] While these AADs might offer potential advantages over OETI in terms of reduced training requirements, or perhaps fewer or less severe complications, they should not be expected to provide higher airway management success rates than OETI. Where ETC or LMA is used as the primary airway management device (to the exclusion of OETI), practitioners should anticipate up to a 17% failure rate, underscoring the need for additional contingency airway measures. Where ETC and LMA are used as backup devices for unsuccessful OETI attempts, medical directors and EMS professionals alike must recognize that these devices are not 100% fail-safe.

Surprisingly, we found a higher nonphysician placement success rate (92.6%) for EOA and EGTA than for ETC and LMA. These were the earliest prehospital AADs, but because of reported complications and evidence that the devices are not superior to effectively performed bag–valve–mask (BVM) ventilations,[17,19,61–63] they have largely fallen into disfavor and now are rarely used. The available studies for these devices are relatively old, of marginal methodologic quality, and not directly comparable to those of contemporary AADs; these data do not support a return to the EOA and EGTA.

The most recently developed AAD is the King LT, which has achieved wide popularity in EMS because of its perceived ease of insertion. In our meta-analysis, the King LT was the AAD with the most promising success rate (96.5%). However, this estimate is based

King Airway (all patients, all clinicians)

Study Name	Event rate	Lower limit	Upper limit	Z-Value	p-Value	Total
Guyette 2007[46]	0.981	0.764	0.999	2.781	0.005	27 / 27
Kette 2005[47]	0.833	0.657	0.929	3.285	0.001	25 / 30
Wiese 2009[8]	0.995	0.920	1.000	3.681	0.000	93 / 93
Summary Effect	**0.965**	**0.712**	**0.997**	**2.698**	**0.007**	**145/150**

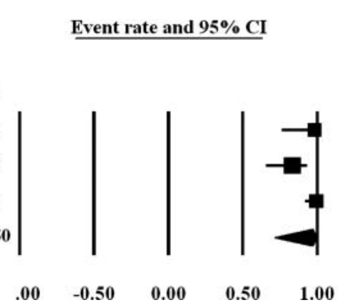


FIGURE 6. Forest plot of King LT airway insertion. CI = confidence interval. PEC = *Prehospital Emergency Care*.

Needle Cricothyrotomy (all patients, all clinicians)

Study Name	Event rate	Lower limit	Upper limit	Z-Value	p-Value	Total
Bulger 2002 [12]	0.750	0.377	0.937	1.346	0.178	6 / 8
Leibovici 1997 [10]	0.769	0.478	0.924	1.829	0.067	10 / 13
Nakayama 1990 [48]	0.500	0.059	0.941	0.000	1.000	1 / 2
Warner 2009 [9]	0.250	0.034	0.762	-0.951	0.341	1 / 4
Summary Effect	**0.658**	**0.423**	**0.835**	**1.328**	**0.184**	**18/27**

Event rate and 95% CI

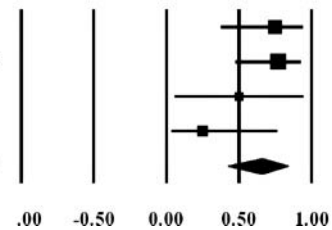


FIGURE 7. Forest plot of needle cricothyrotomy. CI = confidence interval.

on limited data. Because of the King LT's relatively recent introduction, only three studies reporting its use in the prehospital setting met our inclusion criteria, and all three suffered from small sample sizes. Subsequently, the CI around the pooled success rate is wide (71.2%–99.7%). Also, there were no reports of King LT use solely in trauma patients or exclusively as a rescue airway. Thus, additional King LT studies would help to improve the certainty of existing estimates, as well as define its utility among certain patient populations such as those suffering from traumatic injuries or failed OETI attempts.

Finally, our analysis affirms the limitations of NCRIC and SCRIC as prehospital airway procedures. We identified only four studies reporting the success rates of NCRIC. Regardless of patient circumstances or clinician credentials, the NCRIC success rate was ubiquitously low, ranging from 25.0% to 76.9%. The pooled results for the 18 SCRIC studies produced substantially higher success rates, although the success rate for all nonphysician clinicians was still only 90.4%. These percutaneous airways are infrequently performed in the prehospital setting,[9] and the lack of opportunity for skill maintenance likely exacerbates the difficulties associated with the procedures. Nonetheless, EMS systems that choose to incorporate a percutaneous airway procedure into their airway management protocols should recognize that the success rate of SCRIC far exceeds that of NCRIC.

Surgical Cricothyrotomy (all patients, all clinicians)

Study Name	Event rate	Lower limit	Upper limit	Z-Value	p-Value	Total
Adams 2008 [24]	0.765	0.514	0.909	2.061	0.039	13 / 17
Bair 2003 [49]	0.682	0.466	0.840	1.665	0.096	15 / 22
Boyle 1993 [50]	0.986	0.904	0.998	4.189	0.000	68 / 69
Brofeldt 1998 [51]	0.964	0.616	0.998	2.289	0.022	14 / 14
Brown 2001 [52]	0.833	0.194	0.990	1.039	0.299	3 / 3
Bulger 2002 [12]	0.980	0.749	0.999	2.724	0.006	25 / 25
Cook 1991 [53]	0.985	0.903	0.998	4.174	0.000	67 / 68
Fortune 1997 [54]	0.875	0.760	0.939	4.816	0.000	49 / 56
Gerich 1998 [55]	0.944	0.495	0.997	1.947	0.052	9 / 9
Germann 2009 [38]	0.929	0.423	0.996	1.748	0.081	7 / 7
Jacobson 1996 [56]	0.940	0.830	0.981	4.621	0.000	47 / 50
Leibovici 1997 [10]	0.971	0.664	0.998	2.436	0.015	17 / 17
Marcolini 2004 [57]	0.885	0.778	0.944	5.086	0.000	54 / 61
McIntosh 2008 [58]	0.971	0.664	0.998	2.436	0.015	17 / 17
Miklus 1989 [59]	0.976	0.713	0.999	2.594	0.009	21 / 21
Robinson 2001 [11]	0.625	0.285	0.875	0.699	0.484	5 / 8
Thomas 1999 [60]	0.900	0.533	0.986	2.084	0.037	9 / 10
Warner 2009 [9]	0.909	0.561	0.987	2.195	0.028	10 / 11
Summary Effect	**0.905**	**0.848**	**0.942**	**8.215**	**0.000**	**450/485**

Event rate and 95% CI

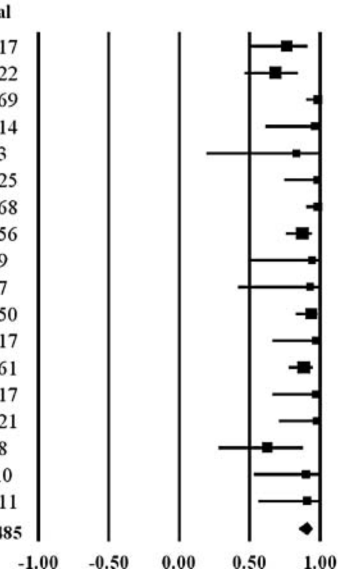


FIGURE 8. Forest plot of surgical cricothyrotomy. CI = confidence interval.

LIMITATIONS

This study has several noteworthy limitations. Primarily, we evaluated only placement success rates; we did not systematically explore the ability of each of the devices to provide effective ventilations, nor did we evaluate the complication rates of each device. In essence, the overarching goal of our study was limited to providing a pooled estimate of successful placement for each airway device across a variety of patient characteristics, clinical settings, and clinicians. There is, however, some evidence that AADs can provide adequate ventilation. In the only prehospital evaluation of ventilation with the PTLA, Bartlett et al. found arterial blood gas (ABG) measurements comparable to those for OETI.[64] For ETC, several crossover and comparative studies have demonstrated ABG measurements that equal or exceed those of OETI when the ETC is properly placed.[29,65,66] Data are limited on the ventilatory effectiveness of the prehospital use of the LMA, which was first described in 1983 by Brain as an alternative to OETI for surgical patients.[67] Martin et al.[40] reported the use of the LMA as a rescue airway in 16 patients treated by an air medical crew after failed intubation attempts. Although the authors concluded that the LMA was an effective temporary airway, the partial pressure of oxygen in arterial blood (PaO_2) was below 80 mmHg in five patients (31%), the saturation of peripheral oxygen (SpO_2) was less than 90% in three patients (19%), and the partial pressure of carbon dioxide in arterial blood ($PaCO_2$) was greater than 50 mmHg in two patients (13%). To date, there are no published evaluations of the ability of the King LT to provide effective ventilations.

The strength of our results is tempered by the quality of the body of published works with respect to prehospital airway control. Based on our criteria, quality scores showed considerable variation, and the overall quality of studies was poor. Over one-third of the studies were retrospective and descriptive in nature, some were not designed specifically for evaluating airway success rates, and oftentimes successful placement was self-reported by the clinician based only on clinical criteria such as breath sounds and chest rise. Few studies used capnography or capnometry to verify placement or had placement confirmed by the emergency department physician, and an upward bias of success rates has been suggested when successful placement is self-reported and based solely on clinical assessment.[6] Unfortunately, we were unable to conduct a sensitivity analysis using only the highest-quality studies because of the small total number of included studies.

We also recognize the lack of recency of some of our data. Some of the included studies were over 30 years old and likely represent an epoch of EMS history in which training and medical oversight differed significantly from those of present times. Additionally, most of the devices were not used during the same time periods, further complicating direct comparisons. Consequently, the validity of our findings is subject to history-maturation effects.

We were not able to control for experience in airway management, which has been demonstrated to have a substantial impact on the rate of successful placement of endotracheal tubes by prehospital providers, and likely has a similar effect on AAD placement.[68] In addition, we did not control for any differences in training between international prehospital clinicians and their U.S. counterparts.

Finally, our results must also be interpreted recognizing the limitations of meta-analysis as a statistical technique, which we have reviewed previously.[6] An advantage of the meta-analysis methodology is to combine underpowered studies to increase the sample size and confidence in the resulting pooled effect. However, for some of our subgroup analyses, the total number of patients was small even after pooling, leading to wide CIs. Furthermore, for some analyses, a few studies represented a disproportionately large segment of the pooled data. In addition, study selection bias is a frequent problem of meta-analysis and is further compounded by the inherent bias against publication of studies with negative results. In the absence of publication bias, the funnel plot should demonstrate a symmetrical distribution of studies within the funnel. As demonstrated by the asymmetrical funnel plot, our meta-analysis suffered from publication bias in the SCRIC analysis.

Another limitation of meta-analysis is statistical heterogeneity. In a homogeneous distribution, the dispersion of success rates around the pooled estimate differs only by sampling error. A significant Q-statistic rejects this assumption, indicating that the dispersion of success rates is associated with differences in study characteristics as well as sampling error. With the exception of SCRIC, we discovered significant heterogeneity in the selected studies for all airway techniques when examined collectively across all clinicians and patient groups. In addition, the I^2 statistic, which ranges between 0% and 100% and measures the amount of inconsistency across studies, was high in several analyses, indicating considerable between-study variation.

CONCLUSIONS

As more EMS systems embrace AADs, either as rescue airways or as primary airways in lieu of OETI, it is important to have a clear appreciation for the true success rates of these devices across a variety of patient characteristics and clinical settings. Through a meta-analysis of published prehospital airway data, we generated pooled estimates of prehospital AADs and percutaneous airway procedural success rates. Clearly, AADs are not a panacea for the difficulties of prehospital airway management. The King LT had the highest placement success rate, at 96.5%, but this pooled success rate is based on limited data. More data are available for the ETC and LMA, which had collective success rates of 83.0% and 82.7%, respectively. Surprisingly, this is lower than the pooled success rate estimate of 86.3% for OETI reported in an earlier meta-analysis, emphasizing that ETC and LMA are not fail-safe airway devices. NCRIC has a low rate of success, with approximately one in three attempts resulting in failure; SCRIC has a much higher success rate (90.5%) and should be considered the preferred technique for establishing a prehospital percutaneous rescue airway.

References

1. Winchell RJ, Hoyt DB. Endotracheal intubation in the field improves survival in patients with severe head injury. Trauma Research and Education Foundation of San Diego. Arch Surg. 1997;132:592–7.
2. Suominen P, Baillie C, Kivioja A, Ohman J, Olkkola KT. Intubation and survival in severe paediatric blunt head injury. Eur J Emerg Med. 2000;7(1):3–7.
3. Gausche M, Lewis RJ, Stratton SJ, et al. Effect of out-of-hospital pediatric endotracheal intubation on survival and neurological outcome: a controlled clinical trial. JAMA. 2000;283:783–90.
4. Davis DP, Hoyt DB, Ochs M, et al. The effect of paramedic rapid sequence intubation on outcome in patients with severe traumatic brain injury. J Trauma. 2003;54:444–53.
5. Wang HE, Yealy DM. Out-of-hospital endotracheal intubation: where are we? Ann Emerg Med. 2006;47:532–41.
6. Hubble M, Brown LH, Wilfong DA, Hertelendy A, Benner RW, Richards ME. A meta-analysis of prehospital airway control techniques, part I: orotracheal and nasotracheal intubation success rates. Prehosp Emerg Care. 2010;14:377–401.
7. Rumball C, Macdonald D, Barber P, Wong H, Smecher C. Endotracheal intubation and esophageal tracheal Combitube insertion by regular ambulance attendants: a comparative trial. Prehosp Emerg Care. 2004;8:15–22.
8. Wiese CH, Semmel T, Muller JU, Bahr J, Ocker H, Graf BM. The use of the laryngeal tube disposable (LT-D) by paramedics during out-of-hospital resuscitation—an observational study concerning ERC guidelines 2005. Resuscitation. 2009;80:194–8.
9. Warner KJ, Sharar SR, Copass MK, Bulger EM. Prehospital management of the difficult airway: a prospective cohort study. J Emerg Med. 2009;36:257–65.
10. Leibovici D, Fredman B, Gofrit ON, Shemer J, Blumenfeld A, Shapira SC. Prehospital cricothyroidotomy by physicians. Am J Emerg Med. 1997;15:91–3.
11. Robinson KJ, Katz R, Jacobs LM. A 12-year experience with prehospital cricothyrotomies. Air Med J. 2001;20(6):27–30.
12. Bulger EM, Copass MK, Maier RV, Larsen J, Knowles J, Jurkovich GJ. An analysis of advanced prehospital airway management. J Emerg Med. 2002;23:183–9.
13. Moher D, Cook DJ, Eastwood S, Olkin I, Rennie D, Stroup DF. Improving the quality of reports of meta-analyses of randomised controlled trials: the QUOROM statement. Quality of Reporting of Meta-analyses. Lancet. 1999;354:1896–900.
14. Borenstein M, Hedges L, Higgins JP, Rothstein HR. Introduction to Meta-Analysis. West Sussex, UK: John Wiley & Sons, Ltd., 2009.
15. Bass RR, Allison EJ Jr, Hunt RC. The esophageal obturator airway: a reassessment of use by paramedics. Ann Emerg Med. 1982;11:358–60.
16. Berdeen TN. One-year experience with the tracheo-esophageal airway. Ann Emerg Med. 1981;10:25–7.
17. Donen N, Tweed WA, Dashfsky S, Guttormson B. The esophageal obturator airway: an appraisal. Can Anaesth Soc J. 1983;30:194–200.
18. Goldenberg IF, Campion BC, Siebold CM, McBride JW, Long LA. Esophageal gastric tube airway vs endotracheal tube in prehospital cardiopulmonary arrest. Chest. 1986;90:90–6.
19. Hankins DG, Carruthers N, Frascone RJ, Long LA, Campion BC. Complication rates for the esophageal obturator airway and endotracheal tube in the prehospital setting. Prehosp Disaster Med. 1993;8:117–21.
20. Reines HD, Bartlett RL, Chudy NE, Kiragu KR, McKnew MA. Is advanced life support appropriate for victims of motor vehicle accidents: the South Carolina Highway Trauma Project. J Trauma. 1988;28:563–70.
21. Shea SR, MacDonald JR, Gruzinski G. Prehospital endotracheal tube airway or esophageal gastric tube airway: a critical comparison. Ann Emerg Med. 1985;14:102–12.
22. Tanigawa K, Shigematsu A. Choice of airway devices for 12,020 cases of nontraumatic cardiac arrest in Japan. Prehosp Emerg Care. 1998;2:96–100.
23. Rumball CJ, MacDonald D. The PTL, Combitube, laryngeal mask, and oral airway: a randomized prehospital comparative study of ventilatory device effectiveness and cost–effectiveness in 470 cases of cardiorespiratory arrest. Prehosp Emerg Care. 1997;1:1–10.
24. Adams BD, Cuniowski PA, Muck A, De Lorenzo RA. Registry of emergency airways arriving at combat hospitals. J Trauma. 2008;64:1548–54.
25. Atherton GL, Johnson JC. Ability of paramedics to use the Combitube in prehospital cardiac arrest. Ann Emerg Med. 1993;22:1263–8.
26. Blostein PA, Koestner AJ, Hoak S. Failed rapid sequence intubation in trauma patients: esophageal tracheal Combitube is a useful adjunct. J Trauma. 1998;44:534–7.
27. Cady CE, Pirrallo RG. The effect of Combitube use on paramedic experience in endotracheal intubation. Am J Emerg Med. 2005;23:868–71.
28. Calkins TR, Miller K, Langdorf MI. Success and complication rates with prehospital placement of an esophageal-tracheal Combitube as a rescue airway. Prehosp Disaster Med. 2006;21 (2 suppl 2):97–100.
29. Davis DP, Valentine C, Ochs M, Vilke GM, Hoyt DB. The Combitube as a salvage airway device for paramedic rapid sequence intubation. Ann Emerg Med. 2003;42:697–704.
30. Davis DP, Fisher R, Buono C, et al. Predictors of intubation success and therapeutic value of paramedic airway management in a large, urban EMS system. Prehosp Emerg Care. 2006;10:356–62.
31. Lefrancois DP, Dufour DG. Use of the esophageal tracheal combitube by basic emergency medical technicians. Resuscitation. 2002;52:77–83.
32. Ochs M, Vilke GM, Chan TC, Moats T, Buchanan J. Successful prehospital airway management by EMT-Ds using the Combitube. Prehosp Emerg Care. 2000;4:333–7.
33. Ochs M, Davis D, Hoyt D, Bailey D, Marshall L, Rosen P. Paramedic-performed rapid sequence intubation of patients with severe head injuries. Ann Emerg Med. 2002;40:159–67.
34. Rabitsch W, Schellongowski P, Staudinger T, et al. Comparison of a conventional tracheal airway with the Combitube in an

urban emergency medical services system run by physicians. Resuscitation. 2003;57:27–32.
35. Timmermann A, Eich C, Russo SG, et al. Prehospital airway management: a prospective evaluation of anaesthesia trained emergency physicians. Resuscitation. 2006;70:179–85.
36. Thierbach AR, Piepho T, Maybauer M. The EasyTube for airway management in emergencies. Prehosp Emerg Care. 2005;9:445–8.
37. Dimitriou V, Voyagis GS, Grosomanidis V, Brimacombe J. Feasibility of flexible lightwand-guided tracheal intubation with the intubating laryngeal mask during out-of-hospital cardiopulmonary resuscitation by an emergency physician. Eur J Anaesthesiol. 2006;23:76–9.
38. Germann CA, Baumann MR, Kendall KM, Strout TD, McGraw K. Performance of endotracheal intubation and rescue techniques by emergency services personnel in an air medical service. Prehosp Emerg Care. 2009;13:44–9.
39. Hein C, Owen H, Plummer J. A 12-month audit of laryngeal mask airway (LMA) use in a South Australian ambulance service. Resuscitation. 2008;79:219–24.
40. Martin SE, Ochsner MG, Jarman RH, Agudelo WE, Davis FE. Use of the laryngeal mask airway in air transport when intubation fails. J Trauma. 1999;47:352–7.
41. McCall MJ, Reeves M, Skinner M, Ginifer C, Myles P, Dalwood N. Paramedic tracheal intubation using the intubating laryngeal mask airway. Prehosp Emerg Care. 2008;12:30–4.
42. Murray MJ, Vermeulen MJ, Morrison LJ, Waite T. Evaluation of prehospital insertion of the laryngeal mask airway by primary care paramedics with only classroom mannequin training. Can J Emeg Med. 2002;4:338–43.
43. Nickel EA, Timmermann A, Roessler M, Cremer S, Russo SG. Out-of-hospital airway management with the LMA CTrach—a prospective evaluation. Resuscitation. 2008;79:212–8.
44. Pattinson K, Todd I, Thomas J, Wyse M. A two year review of laryngeal mask airway use by the Warwickshire ambulance service. Emerg Med J. 2004;21:397–8.
45. Tentillier E, Heydenreich C, Cros AM, Schmitt V, Dindart JM, Thicoïpé M. Use of the intubating laryngeal mask airway in emergency pre-hospital difficult intubation. Resuscitation. 2008;77:30–4.
46. Guyette FX, Wang H, Cole JS. King airway use by air medical providers. Prehosp Emerg Care. 2007;11:473–6.
47. Kette F, Reffo I, Giordani G, et al. The use of laryngeal tube by nurses in out-of-hospital emergencies: preliminary experience. Resuscitation. 2005;66:21–5.
48. Nakayama DK, Gardner MJ, Rowe MI. Emergency endotracheal intubation in pediatric trauma. Ann Surg. 1990;211:218–23.
49. Bair AE, Panacek EA, Wisner DH, Bales R, Sakles JC. Cricothyrotomy: a 5-year experience at one institution. J Emerg Med. 2003;24:151–6.
50. Boyle MF, Hatton D, Sheets C. Surgical cricothyrotomy performed by air ambulance flight nurses: a 5-year experience. J Emerg Med. 1993;11:41–5.
51. Brofeldt BT, Osborn ML, Sackles J, Panacek E. Evaluation of the rapid four-step cricothyrotomy technique:an interim report. Air Med J. 1998;17:127–30.
52. Brown J, Thomas F. What happens with failed blind nasal tracheal intubations? Air Med J. 2001;20(2):13–6.
53. Cook S, Dawson R, Falcone RE. Prehospital cricothyrotomy in air medical transport: outcome. J Air Med Transp. 1991;10(12):7–9,12.
54. Fortune JB, Judkins DG, Scanzaroli D, McLeod KB, Johnson SB. Efficacy of prehospital surgical cricothyrotomy in trauma patients. J Trauma. 1997;42:832–6; discussion 837–8.
55. Gerich TG, Schmidt U, Hubrich V, Lobenhoffer HP, Tscherne H. Prehospital airway management in the acutely injured patient: the role of surgical cricothyrotomy revisited. J Trauma. 1998;45:312–4.
56. Jacobson LE, Gomez GA, Sobieray RJ, Rodman GH, Solotkin KC, Misinski ME. Surgical cricothyroidotomy in trauma patients: analysis of its use by paramedics in the field. J Trauma. 1996;41:15–20.
57. Marcolini EG, Burton JH, Bradshaw JR, Baumann MR. A standing-order protocol for cricothyrotomy in prehospital emergency patients. Prehosp Emerg Care. 2004;8:23–8.
58. McIntosh SE, Swanson ER, Barton ED. Cricothyrotomy in air medical transport. J Trauma. 2008;64:1543–7.
59. Miklus RM, Elliott C, Snow N. Surgical cricothyrotomy in the field: experience of a helicopter transport team. J Trauma. 1989;29:506–8.
60. Thomas SH, Harrison T, Wedel SK. Flight crew airway management in four settings: a six-year review. Prehosp Emerg Care. 1999;3:310–5.
61. Gertler JP, Cameron DE, Shea K, Baker CC. The esophageal obturator airway: obturator or obtundator? J Trauma. 1985;25:424–6.
62. Smith JP, Bodai BI, Aubourg R, Ward RE. A field evaluation of the esophageal obturator airway. J Trauma. 1983;23:317–21.
63. Smith JP, Bodai BI, Seifkin A, Palder S, Thomas V. The esophageal obturator airway. A review. JAMA. 1983;250:1081–4.
64. Bartlett RL, Martin SD, McMahon JM Jr, Schafermeyer RW, Vukich DJ, Hornung CA. A field comparison of the pharyngeotracheal lumen airway and the endotracheal tube. J Trauma. 1992;32:280–4.
65. Frass M, Frenzer R, Rauscha F, Schuster E, Glogar D. Ventilation with the esophageal tracheal Combitube in cardiopulmonary resuscitation. Promptness and effectiveness. Chest. 1988;93:781–4.
66. Frass M, Frenzer R, Zdrahal F, Hoflehner G, Porges P, Lackner F. The esophageal tracheal Combitube: preliminary results with a new airway for CPR. Ann Emerg Med. 1987;16:768–72.
67. Brain AI. The laryngeal mask—a new concept in airway management. Br J Anaesth. 1983;55:801–5.
68. Fullerton J, Roberts KJ, Wyse M. Can experienced paramedics perform tracheal intubation at cardiac arrests? Five years experience of a regional air ambulance service in the UK. Resuscitation. 2009;80–1342-5.

APPENDIX 1. Characteristics of Esophageal Obturator Airway–Esophageal Gastric Tube Airway Studies

First Author, Year*	Type of Design	Clinician	Air Medical Team	Patient Mix	Setting	Verification	Verification Type	Pediatric	Cardiac Arrest	Drug Assist	Rescue Airway	Sample Size	Quality Score
Bass, 1982 (EOA)[15]	P	P	N	NS	G	P	A	N	NS	NS	N	100	5
Berdeen, 1981 (EOA)[16]	P	E	N	NS	G	P	NS	NS	NS	NS	N	191	4
Donen, 1983 (EOA)[17]	P	E	N	M	G	P	A	N	Y	N	NS	300	6
Goldenberg, 1986 (EGTA)[18]	P	P	N	NT	G	P	NS	N	Y	N	M	77	7
Goldenberg, 1986 (EOA)[18]	P	P	N	NT	G	P	NS	N	Y	N	M	125	7
Hankins, 1993 (EOA/EGTA)[19]	P	P/E	N	NT	G	M	A	N	Y	NS	NS	240	5
Reines, 1988 (EOA)[20]	R	P/E	N	T	G	P	NS	NS	NS	NS	NS	27	2
Shea 1985 (primary EGTA)[21]	P	P	N	NT	G	P	NS	N	Y	N	N	179	8
Tanigawa 1998 (EOA)[22]	R	I/P	N	NT	G	P	NS	NS	Y	N	NS	594	6

*For complete reference citations, see the reference list.
Key: Type of Design: B = before–after; P = prospective; R = retrospective. Clinician: E = emergency medical technician; I = international; MD = physician; N = nurse; NS = not stated; P = paramedic; PA = physician assistant; RN = registered nurse. Air Medical Team: M = mixed; N = clinician not a member of air medical team; NS = not stated; Y = clinician member of air medical team. Patient Mix: M = mixed; NS = not stated; NT = nontrauma; T = trauma. Setting: A = air ambulance; G = ground ambulance; M = mixed; NS = not stated. Verification: ED = emergency department; M = mixed; NS = not stated; P = practitioner. Verification Type: A = clinical assessment such as breath sounds and chest rise; C = single objective criterion such as colorimetric carbon dioxide (CO_2) detector, end-tidal carbon dioxide ($ETCO_2$), saturation of peripheral oxygen (SpO_2), or esophageal detector device (EDD); M = multiple objective criteria such as CO_2 detector, $ETCO_2$, EDD, SpO_2, etc.; NS = not stated. Pediatric: M = mixed pediatric and adult; N = non–drug-facilitated, non-RSI; NS = not stated; Y = yes. Cardiac Arrest: M = mixture of arrest and nonarrest patients; N = no; NS = not stated; Y = yes. Drug Assist: D = drug-facilitated; M = mixture of rapid-sequence intubation (RSI), non-RSI, drug-facilitated, non–drug-facilitated; N = no; NS = not stated; R = RSI; Y = yes. Rescue Airway: M = mixture of rescue and primary airway; N = no; NS = not stated; Y = yes.
EOA = esophageal obturator airway; EGTA = esophageal gastric tube airway.

APPENDIX 2. Characteristics of Pharyngeotracheal Lumen Airway Studies

First Author, Year*	Type of Design	Clinician	Air Medical Team	Patient Mix	Setting	Verification	Verification Type	Pediatric	Cardiac Arrest	Drug Assist	Rescue Airway	Sample Size	Quality Score
Rumball, 1997[23]	P	I/E	N	M	G	ED	NS	NS	M	NS	Y	117	6

*For complete reference citations, see the reference list.
Key: Type of Design: B = before–after; P = prospective; R = retrospective. Clinician: E = emergency medical technician; I = international; MD = physician; N = nurse; NS = not stated; P = paramedic; PA = physician assistant; RN = registered nurse. Air Medical Team: M = mixed; N = clinician not a member of air medical team; NS = not stated; Y = clinician member of air medical team. Patient Mix: M = mixed; NS = not stated; NT = nontrauma; T = trauma. Setting: A = air ambulance; G = ground ambulance; M = mixed; NS = not stated. Verification: ED = emergency department; NS = not stated; P = practitioner. Verification Type: A = clinical assessment such as breath sounds and chest rise; C = single objective criterion such as colorimetric carbon dioxide (CO_2) detector, end-tidal carbon dioxide ($ETCO_2$), saturation of peripheral oxygen (SpO_2), or esophageal detector device (EDD); M = multiple objective criteria such as CO_2 detector, $ETCO_2$, EDD, SpO_2, etc.; NS = not stated. Pediatric: M = mixed pediatric and adult; N = non–drug-facilitated, non-RSI; NS = not stated; Y = yes. Cardiac Arrest: M = mixture of arrest and nonarrest patients; N = no; NS = not stated; Y = yes. Drug Assist: D = drug-facilitated; M = mixture of rapid-sequence intubation (RSI), non-RSI, drug-facilitated, non–drug-facilitated; N = no; NS = not stated; R = RSI; Y = yes. Rescue Airway: M = mixture of rescue and primary airway; N = no; NS = not stated; Y = yes.

APPENDIX 3. Characteristics of Esophageal-Tracheal Combitube Studies

First Author, Year*	Type of Design	Clinician	Air Medical Team	Patient Mix	Setting	Verification	Verification Type	Pediatric	Cardiac Arrest	Drug Assist	Rescue Airway	Sample Size	Quality Score
Adams, 2008[24]	P	P/MD/PA/ CRNA	Y	M	M	ED	M	NS	M	NS	M	21	3
Atherton, 1993 (rescue airway)[25]	P	P	N	M	G	P	NS	NS	Y	N	Y	13	6
Atherton, 1993 (primary airway)[25]	P	P	N	M	G	P	NS	NS	Y	N	N	38	6
Blostein, 1998[26]	P	N	Y	T	A	ED	A	N	N	N	Y	10	10
Cady, 2005[27]	B	E/P	N	M	G	P	A	N	M	N	NS	860	3
Calkins, 2006[28]	R	P	N	M	G	P	A	NS	M	N	Y	162	4
Davis, 2003[29]	P	P	N	T	G	P	M	N	N	R	Y	61	9
Davis, 2006[30]	P	P	N	M	G	P	O	NS	M	N	M	134	5
Lefrancois, 2002[31]	P	I/EMT	N	M	G	ED	M	N	Y	N	N	760	9
Ochs, 2000 (medical only)[32]	P	E	N	NT	G	ED	NS	N	Y	NS	Y	170	9
Ochs, 2000 (trauma only)[32]	P	E	N	T	G	ED	NS	N	Y	NS	Y	14	9
Ochs, 2002[33]	P	P	N	T	G	ED	M	NS	N	R	Y	18	9
Rabitsch, 2003 (primary airway)[34]	P	I/MD	N	NT	G	NS	NS	N	Y	N	N	89	8
Rabitsch, 2003 (rescue Combitube)[34]	P	I/MD	N	NT	G	NS	NS	N	Y	N	Y	5	8
Rumball, 1997[23]	P	I/E	N	M	G	ED	NS	NS	M	NS	Y	77	6
Rumball, 2004[7]	P	I/E	N	M	G	ED	NS	N	M	NS	NS	72	6
Tanigawa, 1998[22]	R	I/P	N	NT	G	P	NS	NS	Y	N	NS	1712	5
Timmermann, 2006[35]	P	I/MD	N	M	M	P	C	NS	M	NS	Y	15	4
Thierbach, 2005[36]	P	MD	N	M	G	P	M	NS	M	M	Y	12	5

*For complete reference citations, see the reference list.

Key: Type of Design: B = before–after; P = prospective; R = retrospective. Clinician: CRNA = certified registered nurse anesthetist; E = emergency medical technician; EMT = emergency medical technician; I = international; MD = physician; N = nurse; NS = not stated; P = paramedic; PA = physician assistant; RN = registered nurse. Air Medical Team: M = mixed; N = clinician not a member of air medical team; NS = not stated; Y = clinician member of air medical team. Patient Mix: M = mixed; NS = not stated; NT = nontrauma; T = trauma. Setting: A = air ambulance; G = ground ambulance; M = mixed; NS = not stated. Verification: ED = emergency department; NS = not stated; P = practitioner. Verification Type: A = clinical assessment such as breath sounds and chest rise; C = single objective criterion such as colorimetric carbon dioxide (CO_2) detector, end-tidal carbon dioxide ($ETCO_2$), saturation of peripheral oxygen (SpO_2), or esophageal detector device (EDD); M = multiple objective criteria such as CO_2 detector, $ETCO_2$, EDD, SpO_2, etc.; NS = not stated. Pediatric: M = mixed pediatric and adult; N = non–drug-facilitated, non-RSI; NS = not stated; Y = yes. Cardiac Arrest: M = mixture of arrest and nonarrest patients; N = no; NS = not stated; Y = yes. Drug Assist: D = drug-facilitated; M = mixture of rapid-sequence intubation (RSI), non-RSI, drug-facilitated, non–drug-facilitated; N = no; NS = not stated; R = RSI; Y = yes. Rescue Airway: M = mixture of rescue and primary airway; N = no; NS = not stated; Y = yes.

APPENDIX 4. Characteristics of Layrngeal Mask Airway Studies

First Author, Year*	Type of Design	Clinician	Air Medical Team	Patient Mix	Setting	Verification	Verification Type	Pediatric	Cardiac Arrest	Drug Assist	Rescue Airway	Sample Size	Quality Score
Dimitriou, 2006[37]	P	MD	N	M	G	P	NS	N	Y	N	NS	37	6
Germann, 2009[38]	R	P/N	Y	M	A	P	M	M	NS	M	Y	12	4
Hein, 2008[39]	P	I/P	N	M	G	P	NS	NS	M	NS	NS	164	3
Martin, 1999[40]	P	NS	Y	M	A	P	M	M	NS	NS	Y	17	5
McCall, 2008[41]	P	P	N	NS	G	P	NS	N	M	N	M	52	5
Murray, 2002[42]	P	I/P	N	NT	G	P	A	N	Y	N	N	283	8
Nickel, 2008[43]	P	I/MD	Y	M	M	P	NS	N	M	NS	NS	16	3
Pattinson, 2004[44]	R	I/P	N	M	G	NS	NS	NS	M	NS	M	70	2
Rumball, 1997[23]	P	I/E	N	M	G	ED	NS	Y	M	NS	Y	108	7
Tanigawa, 1998[22]	R	I/P	N	NT	G	P	NS	NS	Y	N	NS	3016	5
Tentillier, 2008[45]	P	I/MD	N	M	G	P	M	NS	M	M	M	45	5
Timmermann, 2006[35]	P	I/MD	N	M	M	P	C	NS	M	NS	Y	9	4

*For complete reference citations, see the reference list.

Key: Type of Design: B = before–after; P = prospective; R = retrospective. Clinician: E = emergency medical technician; I = international; MD = physician; N = nurse; NS = not stated; P = paramedic; PA = physician assistant; RN = registered nurse. Air Medical Team: M = mixed; N = clinician not a member of air medical team; NS = not stated; Y = clinician member of air medical team. Patient Mix: M = mixed; NS = not stated; NT = nontrauma; T = trauma. Setting: A = air ambulance; G = ground ambulance; M = mixed; NS = not stated. Verification: ED = emergency department; NS = not stated; P = practitioner. Verification Type: A = clinical assessment such as breath sounds and chest rise; C = single objective criterion such as colorimetric carbon dioxide (CO_2) detector, end-tidal carbon dioxide ($ETCO_2$), saturation of peripheral oxygen (SpO_2), or esophageal detector device (EDD); M = multiple objective criteria such as CO_2 detector, $ETCO_2$, EDD, SpO_2, etc.; NS = not stated. Pediatric: M = mixed pediatric and adult; N = non–drug-facilitated, non-RSI; NS = not stated; Y = yes. Cardiac Arrest: M = mixture of arrest and nonarrest patients; N = no; NS = not stated; Y = yes. Drug Assist: D = drug-facilitated; M = mixture of rapid-sequence intubation (RSI), non-RSI, drug-facilitated, non–drug-facilitated; N = no; NS = not stated; R = RSI; Y = yes. Rescue Airway: M = mixture of rescue and primary airway; N = no; NS = not stated; Y = yes.

APPENDIX 5. Characteristics of King LT Airway Studies

First Author, Year*	Type of Design	Clinician	Air Medical Team	Patient Mix	Setting	Verification	Verification Type	Pediatric	Cardiac Arrest	Drug Assist	Rescue Airway	Sample Size	Quality Score
Guyette, 2007[46]	R	N/P	N	M	A	P	M	N	M	NS	M	26	3
Kette, 2005[47]	P	I/N	N	M	G	P	A	N	Y	NS	N	30	6
Wiese, 2009[8]	P	I/P	N	NS	G	P	A	N	Y	N	N	92	7

*For complete reference citations, see the reference list.
Key: Type of Design: B = before–after; P = prospective; R = retrospective. Clinician: E = emergency medical technician; I = international; MD = physician; N = nurse; NS = not stated; P = paramedic; PA = physician assistant; RN = registered nurse. Air Medical Team: M = mixed; N = clinician not a member of air medical team; NS = not stated; Y = clinician member of air medical team. Patient Mix: M = mixed; NS = not stated; NT = nontrauma; T = trauma. Setting: A = air ambulance; G = ground ambulance; M = mixed; NS = not stated. Verification: ED = emergency department; NS = not stated; P = practitioner. Verification Type: A = clinical assessment such as breath sounds and chest rise; C = single objective criterion such as colorimetric carbon dioxide (CO_2) detector, end-tidal carbon dioxide ($ETCO_2$), saturation of peripheral oxygen (SpO_2), or esophageal detector device (EDD); M = multiple objective criteria such as CO_2 detector, $ETCO_2$, EDD, SpO_2, etc.; NS = not stated. Pediatric: M = mixed pediatric and adult; N = non–drug-facilitated, non-RSI; NS = not stated; Y = yes. Cardiac Arrest: M = mixture of arrest and nonarrest patients; N = no; NS = not stated; Y = yes. Drug Assist: D = drug-facilitated; M = mixture of rapid-sequence intubation (RSI), non-RSI, drug-facilitated, non–drug-facilitated; N = no; NS = not stated; R = RSI; Y = yes. Rescue Airway: M = mixture of rescue and primary airway; N = no; NS = not stated; Y = yes.

APPENDIX 6. Characteristics of Needle Cricothyrotomy Studies

First Author, Year*	Type of Design	Clinician	Air Medical Team	Patient Mix	Setting	Verification	Verification Type	Pediatric	Cardiac Arrest	Drug Assist	Rescue Airway	Sample Size	Quality Score
Bulger, 2002[12]	R	P	N	M	G	P	NS	NS	M	NS	NS	8	2
Leibovici, 1997[10]	R	I/MD	Y	M	NS	P	A	N	NS	NS	M	13	2
Nakayama, 1990[48]	R	NS	NS	T	NS	NS	NS	Y	NS	NS	Y	2	3
Warner, 2009[9]	P	P	N	M	G	P	M	M	M	M	Y	4	5

*For complete reference citations, see the reference list.
Key: Type of Design: B = before–after; P = prospective; R = retrospective. Clinician: E = emergency medical technician; I = international; MD = physician; N = nurse; NS = not stated; P = paramedic; PA = physician assistant; RN = registered nurse. Air Medical Team: M = mixed; N = clinician not a member of air medical team; NS = not stated; Y = clinician member of air medical team. Patient Mix: M = mixed; NS = not stated; NT = nontrauma; T = trauma. Setting: A = air ambulance; G = ground ambulance; M = mixed; NS = not stated. Verification: ED = emergency department; NS = not stated; P = practitioner. Verification Type: A = clinical assessment such as breath sounds and chest rise; C = single objective criterion such as colorimetric carbon dioxide (CO_2) detector, end-tidal carbon dioxide ($ETCO_2$), saturation of peripheral oxygen (SpO_2), or esophageal detector device (EDD); M = multiple objective criteria such as CO_2 detector, $ETCO_2$, EDD, SpO_2, etc.; NS = not stated. Pediatric: M = mixed pediatric and adult; N = non–drug-facilitated, non-RSI; NS = not stated; Y = yes. Cardiac Arrest: M = mixture of arrest and nonarrest patients; N = no; NS = not stated; Y = yes. Drug Assist: D = drug-facilitated; M = mixture of rapid-sequence intubation (RSI), non-RSI, drug-facilitated, non–drug-facilitated; N = no; NS = not stated; R = RSI; Y = yes. Rescue Airway: M = mixture of rescue and primary airway; N = no; NS = not stated; Y = yes.

APPENDIX 7. Characteristics of Surgical Cricothyrotomy Studies

First Author, Year*	Type of Design	Clinician	Air Medical Team	Patient Mix	Setting	Verification	Verification Type	Pediatric	Cardiac Arrest	Drug Assist	Rescue Airway	Sample Size	Quality Score
Adams, 2008[24]	P	P/MD/PA/ CRNA	Y	M	M	ED	M	NS	M	NS	M	17	3
Bair, 2003[49]	R	N	Y	M	A	NS	NS	NS	NS	NS	M	22	2
Boyle, 1993[50]	R	N	Y	M	A	P	A	M	NS	NS	Y	69	3
Brofeldt, 1998[51]	P	N/MD	Y	NS	A	NS	NS	NS	NS	NS	NS	13	2
Brown, 2001[52]	R	P/N	Y	M	A	P	NS	M	N	M	Y	2	3
Bulger, 2002[12]	R	P	N	M	G	P	NS	NS	M	NS	NS	24	2
Cook, 1991[53]	R	P/N	Y	T	M	P	NS	NS	NS	NS	M	68	1
Fortune, 1997[54]	R	P	N	NS	G	P	NS	NS	M	NS	NS	56	2
Gerich, 1998[55]	P	I/MD/P	Y	T	A	ED	M	NS	M	M	M	8	5
Germann, 2009[38]	R	P/N	Y	M	A	P	M	N	NS	M	Y	6	5
Jacobson, 1996[56]	R	P	N	T	G	NS	NS	N	M	N	M	50	5
Leibovici, 1997[10]	R	I/MD	N	M	NS	P	A	N	NS	NS	M	16	2
Marcolini, 2004[57]	R	P	Y	M	G	ED	NS	N	M	Y	Y	61	7
McIntosh, 2008[58]	R	N/P	Y	M	A	P	NS	NS	NS	M	M	16	1
Miklus, 1989[59]	R	N/MD	Y	M	A	NS	NS	M	M	NS	Y	20	2
Robinson, 2001[11]	R	N/RT	Y	T	A	P	A	NS	M	N	Y	8	4
Thomas, 1999[60]	R	N/P	Y	M	M	ED	NS	NS	NS	NS	M	10	2
Warner, 2009[9]	P	P	N	M	G	P	M	M	M	M	Y	11	6

*For complete reference citations, see the reference list.
Key: Type of Design: B = before–after; P = prospective; R = retrospective. Clinician: CRNA = certified registered nurse anesthetist; E = emergency medical technician; I = international; MD = physician; N = nurse; NS = not stated; P = paramedic; PA = physician assistant; RN = registered nurse; RT = respiratory therapist. Air Medical Team: M = mixed; N = clinician not a member of air medical team; NS = not stated; Y = clinician member of air medical team. Patient Mix: M = mixed; NS = not stated; NT = nontrauma; T = trauma. Setting: A = air ambulance; G = ground ambulance; M = mixed; NS = not stated. Verification: ED = emergency department; NS = not stated; P = practitioner. Verification Type: A = clinical assessment such as breath sounds and chest rise; C = single objective criterion such as colorimetric carbon dioxide (CO_2) detector, end-tidal carbon dioxide ($ETCO_2$), saturation of peripheral oxygen (SpO_2), or esophageal detector device (EDD); M = multiple objective criteria such as CO_2 detector, $ETCO_2$, EDD, SpO_2, etc.; NS = not stated. Pediatric: M = mixed pediatric and adult; N = non–drug-facilitated, non-RSI; NS = not stated; Y = yes. Cardiac Arrest: M = mixture of arrest and nonarrest patients; N = no; NS = not stated; Y = yes. Drug Assist: D = drug-facilitated; M = mixture of rapid-sequence intubation (RSI), non-RSI, drug-facilitated, non–drug-facilitated; N = no; NS = not stated; R = RSI; Y = yes. Rescue Airway: M = mixture of rescue and primary airway; N = no; NS = not stated; Y = yes.