Review Article

Management and treatment algorithm of airway complications after anterior cervical spine surgery: systematic review

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Background: Airway-related complications are rare after cervical spine surgery but can be devastating and compromise a successful outcome. The objective of this systematic review is to provide an overview of the management of airway complications after anterior cervical spine surgery (ACSS) and propose a treatment algorithm for approaching the patient with a compromised airway.

Methods: A literature search was conducted in PubMed and adapted for use in other databases, including the Cochrane Register of Controlled Trials, Cochrane Library Health Technology Assessment Database, Embase, and the National Health Service (NHS) Economic Evaluation Database.

Results: A total of 117 papers received a full text review. Thirty-seven studies were categorized as "management" and included. An additional four references were extracted from other references for a total of 41 studies.

Conclusions: Most of the available evidence on airway compromise after ACSS is level III or IV. Similarly, most available evidence on the management of acute airway complications comes from case reports or anecdotal publications. There are currently no methods in place to stratify the risk of airway complications in patients undergoing these guidelines on the management of these complications when they occur. This review is focused on practice, including management of such complications with a proposed treatment algorithm.

Keywords: Anterior cervical spine surgery (ACSS); airway obstruction; difficult airway; postoperative hematoma; emergency airway

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Introduction

Anterior cervical spine surgery (ACSS) is a common surgical procedure performed for many cervical spinal pathologies. Airway-related complications are rare but can be devastating and compromise a successful outcome. The current article reviews strategies for treating patients at risk of such for airway complications following ACSS. The etiology and risk factors for airway compromise after ACSS will not be discussed in this review, as there have been recent reviews covering these topics, including the differences and importance of the timing of findings of a patient who is experiencing such

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a complication (1,2). Ultimately, this systematic review aims to equip the spine surgeon and anesthesiologist with the knowledge to deal with these complications and provide the most up-to-date practice guidelines. Although a full discussion of the anesthetic management of difficult airways is beyond the scope of this review, the authors provide surgeons with the evidence supporting various techniques and instruments to manage airway loss after ACSS.

The review begins with a brief overview of the relevant airway anatomy and protocols for preventing reintubation or airway crises. This will be followed by an overview on the management of difficult airways and difficult extubation. There will then be a discussion on the treatment strategies to manage an obstructed airway and how to approach the most common etiologies for airway obstruction. Finally, the authors present their proposed treatment algorithm for managing airway complications in patients undergoing ACSS.

We systematically reviewed the literature for papers on this topic and separated them into three categories according to the whether the content of the paper involved etiology, risk factors, or management. Due to the vast amount of information on this topic, the etiology and risk factors categories are not included in this review. We present this article in accordance with the PRISMA reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-23-32/rc).

Highlight box

Key findings

- Consider overnight intubation for anterior-posterior (A-P) fusions with presence of risk factors for airway compromise. A postoperative cuff leak test and/or lateral radiograph may aid in assessing readiness for extubation.
- Difficult airway management strategies: awake intubation, use of stylets, rigid laryngoscope blades, and fiberoptic intubation. The Bullard laryngoscope and rigid video stylets may be useful adjuncts for intubating patients with difficult airways.
- Devices such as pediatric airway exchange catheters (PAEC) should be considered for patients at risk of difficult extubation because they can facilitate unplanned reintubation.
- In the setting of the "can't intubate, can't ventilate" patient, an emergent cricothyroidotomy or tracheostomy should be performed.

What is known and what is new?

- The supraglottic region of the laryngopharynx is most susceptible to compression due to edema or hematoma. Volumes of 20 mL in the retropharyngeal space has been demonstrated to cause deviation of the trachea and esophagus.
- In cases of upper airway obstruction, nasal airways are preferred.
- There is a lack of high-level evidence supporting any specific management or prevention for airway complications in patients undergoing anterior cervical spine surgery (ACSS).
- The authors have proposed a novel algorithm for approaching a patient with possible airway compromise after ACSS.

What is the implication, and what should change now?

- Airway-related complications after ACSS are rare but can be devastating and compromise a successful outcome.
- Future work is needed to validate the new proposed algorithm and to further optimize the treatment of these patients when an airway complication may occur.

Methods

A systematic search was conducted on PubMed. The search was then adapted for the following databases: Embase, National Health Service (NHS) Economic Evaluation Database, Cochrane Register of Controlled Trials, and the Cochrane Library Health Technology Assessment database. The search terms included a combination of keywords and controlled vocabularies: "airway complications", "respiratory difficulty", "intubation", "airway obstruction", "anterior cervical spine surgery", "anterior cervical discectomy", "anterior cervical fusion", and "anterior corpectomy". The date range was from 1 January 1990 to 21 December 2021. The full search strategy is provided in the Appendix. Studies were imported into the Covidence platform (Veritas Heal th Innovation Ltd; Melbourne, Australia), where duplicates were excluded and the screening process was completed by three of the authors (Y.K., L.F.C., and L.B.). First, all titles and abstracts were screened, followed by a full text review. All disagreements were resolved through an independent review by all of the authors. Any remaining disagreements after this secondary review were resolved through discussion after another full-text review. The selected studies included systematic reviews, meta-analyses, randomized controlled trials (RCTs), prospective cohort studies, retrospective cohort studies, case series, and case reports.

Each included paper was grouped into one of the three aforementioned categories based on the content of the paper—etiology, risk factors, and management. These were determined by all authors and any disagreements resolved after discussion and majority vote.

Results

The reviewed papers were categorized as follows: 39 as

etiology, 42 as risk factors, and 37 as management. Of these, 28 qualified for two categories and two papers into all three categories. Five of the included papers were review articles. Each paper was assessed and evaluated for risk of bias utilizing previously published tools depending on the study types. For example, Cochrane Risk of Bias Tool was utilized for RCTs (3). The Risk of Bias in Non-randomized Studies - of Interventions (ROBINS-I) tool was used to evaluate non-randomized studies (4), Assessment of Multiple Systematic Reviews 2 (AMSTAR 2) measurement tool was used for reviews (5). Finally, case series and case reports were assessed utilizing the Methodological Quality and Synthesis of Case Series and Case Reports tool (6). The assessment results can be found in *Tables 1-4*.

Table 1 Prospective, randomized studies (Cochrane Risk of Bias Assessment Tool)

Study	Study design (level of evidence)	Category	Patient number (n)	Average age, years [SD]	Bias risk assessment					
					Selection bias	Performance bias	Detection bias	Attrition bias	Reporting bias	Overall risk of bias
Audu P 2006 (7)	Prospective randomized study (II)	Risk factors, etiology	100	47 [11]	Low	Low	Low	Low	Low	Low
Brück S 2015 (8)	Prospective, randomized, blinded (II)	Management	56	58 [12]	Low	Low	Low	High	Low	Low
Cohn AI 1995 (9)	Prospective randomized study (III)	Management	17	NA	Low	High	High	Low	Unclear	High
Dutta K 2020 (10)	RCT (I)	Management	46	33 [12]	Low	Low	Low	Low	Low	Low
Hans P 2008 (11)	Randomized, prospective, double-blind (I)	Risk factors, etiology	34	47 [9]	Low	Low	Low	N/A	Low	Low
Nam K 2019 (12)	RCT (I)	Management	21	59 [10]	Low	High	Low	Low	Low	Low

SD, standard deviation; NA, not available; RCT, randomized controlled trial.

Discussion

Review of anatomy

Working knowledge of the airway is critical for understanding obstructive pathology. The epiglottis separates the oropharynx from the laryngopharynx (at C4). The laryngopharynx has three main components: the supraglottic, glottic, and subglottic regions. The supraglottic region includes the epiglottis, aryepiglottic folds, arytenoids, and ventricular folds (false cords). The glottis includes the true vocal cords, which have a larger diameter posteriorly, making posterior lesions more obstructive. The subglottic region is distal to the vocal cord and includes the trachea. While susceptible to edema, the glottic and subglottic regions are protected from compression by the thyroid cartilage, cricoid cartilage, and tracheal rings, which are rigid and resist collapse due to inward pressure. However, the supraglottic region is soft and vulnerable to compression (28).

The retropharyngeal space can only accommodate a small amount of fluid before causing deviations in vital structures, such as the esophagus and trachea. In a cadaveric study, Glinski *et al.* demonstrated that a volume of 20 mL (mean pressure 2.39 mmHg) was sufficient to cause tracheal deviation but 39 mL of fluid was required to visualize neck contour changes on clinical examination (44). This is significant as the amount of fluid (i.e., from a hematoma) required to cause clinically identifiable changes is nearly double that required to cause deviation of vital structures.

Protocols to prevent reintubation/airway crisis

Guidelines for determining the risk of postoperative

Table 2 Non-randomized studies (ROBINS-I)

Study					Pre-intervention		At intervention	Post-intervention				Overall risk of bias
Author, year	Design	Category	Patient/ cohort number (n)	Average patient age, years (if listed)	Bias due to confounding	Bias in selection of participants into the study	Bias in classification of interventions	Bias due to deviations from intended interventions	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of the reported result	Low/ moderate/ serious/ critical
Apfelbaum RI 2000 (13)	Cadaver/ retrospective	Risk factors, etiology	900	49.5	Critical	Moderate	Serious	Low	Serious	Moderate	Moderate	Serious
Dosemeci L 2004 (14)	Prospective observational	Management	36	52.6	Serious	Serious	Low	Low	Moderate	Moderate	Moderate	Moderate
Epstein NE 2001 (15)	Observational	Management	58	56	Critical	Serious	Moderate	Low	Serious	Serious	Critical	Serious
Jung A 2010 (16)	Prospective, observational	Risk factors	242	51.3	Critical	Serious	Moderate	Critical	Moderate	Moderate	Serious	Serious
Kim M 2017 (17)	Retrospective cohort	Risk factors, management	538	52	Serious	Serious	Low	Low	Moderate	Low	Low	Moderate
Kim M 2018 (18)	Retrospective cohort	Risk factors, management	400	53.6	Serious	Moderate	Serious	Moderate	Moderate	Serious	Critical	Serious
Kim SW 2017 (19)	Prospective observational	Etiology, management	160	54.2	Serious	Moderate	Low	Low	Moderate	Serious	Moderate	Moderate
Manninen PH 2007 (20)	Prospective, observational, cohort	Management	327	51	Critical	Moderate	Moderate	Critical	Critical	Serious	Serious	Critical
Nagoshi N 2017 (21)	Retrospective, cohort	Management	8,887	49.9	Serious	Serious	Low	Moderate	Critical	Serious	Moderate	Serious
Siemionow K 2014 (22)	Retrospective	Risk factors, management	35	60	Serious	Critical	Moderate	Moderate	Critical	Serious	Serious	Critical
Song KJ 2017 (23)	Retrospective	Risk factors, etiology	785	62	Serious	Serious	Low	Low	Serious	Serious	Moderate	Serious
Terao Y 2004 (24)	Retrospective	Risk factors, management	170	58.4	Critical	Critical	Moderate	Serious	Moderate	Serious	Moderate	Critical

ROBINS-I, Risk of bias in non-randomized studies - of interventions.

Table 3 Reviews (AMSTAR 2)

AMSTAR 2 (5)	Bonhomme 2009 (25)	Bribriesco 2018 (26)	Cheung 2014 (27)	Eskander 2019 (28)	Palumbo 2012 (29)	Palumbo 2013 (30)	Umobong 2018 (31)
Did the research questions and inclusion criteria include the components of PICO?	No	No	No	No	No	No	No
Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did it justify any significant deviations from the protocol?	No	No	No	No	No	No	No
Did authors explain their selection of the study designs for inclusion in the review?	No	No	No	No	No	No	No
Did authors use a comprehensive literature search strategy?	No	No	No	No	No	No	No
Did authors perform study selection in duplicate?	No	No	No	No	No	No	No
Did authors perform data extraction in duplicate?	No	No	No	No	No	No	No
Did authors provide a list of excluded studies and justify the exclusion?	No	No	No	No	No	No	No
Did authors describe the included studies in adequate detail?	No	No	Yes	Yes	Yes	No	Yes
Did authors use a satisfactory technique for assessing the RoB in individual studies that were included in the review?	No	No	No	No	No	No	No
Did the authors report on the sources of funding for the studies included in the review?	No	No	No	No	No	No	No
If meta-analysis was performed, did authors assess the potential impact of RoB in individual studies on the results of the meta-analysis or other evidence synthesis?	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Did authors account for RoB in individual studies when interpreting/discussing results of review?	No	No	No	No	No	No	No
Did authors provide satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?	No	No	Yes	Yes	Yes	No	Yes
If they performed quantitative synthesis did authors carry out an adequate investigation of publication bias and discuss its likely impact on the results of the review?	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Did authors report any potential sources of COI, including any funding they received for conducting the review?	No	No	Yes	Yes	Yes	Yes	No

AMSTAR, A MeaSurement Tool to Assess systematic Reviews; PICO, Population Intervention, Comparator group, Outcome; RoB, risk of bias; COI, conflict of interest; N/A, not applicable.

airway complications do not exist yet. Surgical and anesthetic judgement must be employed perioperatively to make rational decisions regarding airway care (30). However, several protocols have been suggested for airway management during high-risk anterior cervical procedures.

Epstein *et al.* studied a protocol to prevent reintubation in 58 complicated, multi-level (≥3), anterior-posterior (A-P) cervical fusions lasting 10 hours with a high estimated blood loss (average transfusion of 2.6 units of packed red blood cells). All patients were prophylactically left intubated overnight and underwent fiberoptic visualization of vocal cords and tracheal swelling with assessment for a cuff leak by an anesthesiologist prior to extubation [cuff leaks are exhibited by deflating the endotracheal tube (ETT) balloon

Table 4 Case reports and case series (Methodological Quality and Synthesis of Case Series and Case Reports)

Reference	Study type	Selection[a]	Ascertainment		Causality				Reporting
		"High" or "Low" risk	Exposure adequately ascertained?	Outcome adequately ascertained?	Other alternative causes ruled out?	Was there challenge/ rechallenge phenomenon?	Was there a dose-response effect?	Follow-up long enough for outcomes to occur?	Sufficient details for others to replicate or make inferences?
Antoine 2010 (32)	Case report	Low	N/A	Yes	No	N/A	N/A	No	Yes
Chang 2021 (33)	Case report	Low	Yes	Yes	Yes	N/A	N/A	Yes	Yes
Gwinnutt 1992 (34)	Case report	Low	Yes	Yes	No	N/A	N/A	No	Yes
Inoue 2011 (35)	Case report	High	No	Yes	No	N/A	N/A	Yes	Yes
Joshi 2012 (36)	Case report	High	No	No	No	N/A	N/A	Yes	Yes
Kim 2011 (37)	Case report	Low	Yes	No	No	N/A	N/A	No	No
Manski 1998 (38)	Case report	Low	No	Yes	No	N/A	N/A	No	No
Paradells 2014 (39)	Case series	High	No	Yes	No	N/A	N/A	No	No
Penberthy 1998 (40)	Case report	Low	Yes	Yes	Yes	N/A	N/A	No	Yes
Roy 1999 (41)	Case report	High	No	No	Yes	N/A	N/A	No	No
Schoenhage 2006 (42)	Case report	High	No	Yes	Yes	N/A	N/A	No	Yes
Thompson 2010 (43)	Case report	High	Yes	Yes	Yes	N/A	N/A	No	–

[a], Does the patient(s) represent(s) the whole experience of the investigator (center) or is the selection method unclear to the extent that other patients with similar presentation may not have been reported? N/A, not applicable.

and listening for air leakage; if the airway is collapsed and swollen, no cuff leak will be evident]. Extubation was delayed if there was no cuff leak or if the patient showed signs of residual swelling on fiberoptic bronchoscopy. Forty patients were successfully extubated on day 1, followed by 5, 3, 2, 2, and 3 on postoperative days 2–7, respectively; the remaining three patients required an elective tracheostomy on postoperative day 7. Operative time greater than 10 hours, weight greater than 220 lbs, transfusion of >4 units, prior anterior neck surgery, 4-level operations, and asthma were risk factors for prolonged intubation and tracheostomy. Only one case required emergent reintubation (15).

Kim *et al.* established protocol to leave patients intubated overnight if they demonstrated any significant patient or operative risk factors for airway compromise. A lateral radiograph was obtained immediately after surgery and at 12 hours postoperatively; if swelling increased from preoperative measurements more than 250% at C2 or 150% at C5, the patient was left intubated for another 12 hours. If the X-ray measurements were below these cut-offs and the patient had a positive cuff leak, they were extubated. If the patient could not be extubated, a second check was performed 12 hours later. Patients who remained without cuff leak after 7 days underwent tracheostomy. The use of this protocol resulted in a significantly reduced incidence of postoperative airway complications. Notably, all patients without risk factors, radiographic or clinical evidence of prevertebral soft tissue swelling, were extubated immediately without complications (17).

Other techniques that may prevent airway compromise include atraumatic placement of the ETT (45) on the first attempt and limited retraction of the soft tissues intraoperatively (30). Moreover, extubation should only be performed when qualified practitioners are available in the event of failed extubation or the need for immediate reintubation (30). Releasing the pressure from the ETT cuff and examining for cuff leak can be a useful way to determine the appropriateness of extubation (30).

Combined A-P cervical fusions carry an increased risk of airway complications and should be considered for overnight intubation (24). Some authors suggest considering staging while others have not found significant differences in reintubation rates between single- and two-stage A-P cases (22).

Finally, patients with suspected unilateral vocal cord

Table 5 Specialized equipment of portable storage unit for difficult airway

Rigid laryngoscope blades of various designs and sizes
Video laryngoscope
Tracheal tubes of assorted sizes
Tracheal tube guides (e.g., semirigid stylets, ventilating tube-changer, light wands, forceps)
Supraglottic airways
Flexible fiberoptic intubation equipment
Equipment suitable for emergency invasive airway access
Exhaled carbon dioxide detector

palsy, defined as current or past symptoms of hoarseness, thyroidectomy, carotid endarterectomy, ligation of patent ductus arteriosus, repair of a complex congenital cardiac anomaly, thoracic aortic aneurysm, or anterior cervical discectomy and fusion (ACDF), should be evaluated preoperatively by an ear, nose, and throat (ENT) specialist. Failure to do so can result in bilateral vocal cord paralysis leading to airway compromise (38).

Difficult airway

The American Society of Anesthesiologists (ASA) has developed guidelines for the management of difficult airways (defined as difficulty with mask ventilation, supraglottic intubation, tracheal intubation, or both) (46). While a full discussion on difficult airways is beyond the scope of this review, the salient points and evidence supporting certain methods of airway management in cervical spine surgery are presented below.

Airway evaluation in the elective setting begins with a history of risk factors for a difficult airway (obstructive sleep apnea, history of snoring, mediastinal mass, subglottic stenosis, ankylosing spondylitis, cervical spondylosis, Down syndrome, Treacher Collins syndrome, tonsillar hypertrophy, or a history of difficult intubation). An anesthesiologist should then examine the patient for structural factors that could make tracheal intubation difficult, including poor visibility of the uvula, short thyromental distance, shape of the palate, maxillary incisor protrusion, short neck, and limited cervical range of motion. Preoperative preparation includes a storage unit containing specialized equipment (*Table 5*), an assigned assistant who is available to help the primary anesthesiologist, face mask preoxygenation equipment, and supplemental oxygen delivery systems. The patient is preoxygenated and supplemental oxygen delivered throughout the intubation attempt. Strategies for managing a difficult airway include awake intubation, the use of intubating stylets or tube changers, rigid laryngoscopic blades, and fiberoptic bronchoscope (FOB) intubation. Once tracheal intubation is performed, it should be confirmed using capnography (46).

Manninen *et al.* prospectively studied anesthesiologists' preferred method for intubation of patients undergoing cervical spine surgery. They noted that awake FOB was preferentially chosen for trauma, myelopathy, and spinal stenosis. However, they failed to find a correlation between the method of intubation (awake FOB, asleep FOB, or asleep while using other devices, such as trachlight and Glidescope®) and postoperative airway complications (20). Video laryngoscopy (e.g., McGrath laryngoscope) is another alternative to a fiberoptic scope, which has been found to produce less upper cervical spine movement (10).

Minimizing trauma to the airway and providing inline stabilization are critical for preventing airway complications during ACSS. The Glidescope® has been found to increase successful first attempt tracheal intubation and decrease intubation time (8). However, this tool may be associated with higher mean arterial pressures 2 min after intubation, as well as larger C2–5 Cobb angle changes than other intubation methods. Thus, it may be less suitable for cases with cardiovascular or cerebrovascular risk factors, or in cases of spinal cord injury where movement of the cervical spine is contraindicated.

Other intubation instruments such as the Bullard laryngoscope have been shown to decrease the time to intubation and reduce neck motion during the procedure (9). Additional advantages of the Bullard laryngoscope include portability, decreased cost, and increased device durability. A rigid video-stylet (e.g., Optiscope®) is another good option for intubating ACSS patients, especially after traumatic injuries, since it has been found to produce less movement at the upper and subaxial cervical spine than the video laryngoscope (12).

Difficult extubation

There are currently no guidelines for assessing the risk of difficult extubation (46). The ASA recommends considering awake extubation and establishing a plan for airway management in patients unable to maintain adequate ventilation before attempting extubation. They

also recommend using a device, such as a stylet, which can serve as a guide for expedited reintubation should the need arise (46). The PAEC can also be used as a stylet with a 4-mm external diameter hollow conduit by inserting it into the ETT prior to extubation. Oxygen can be delivered through the catheter at the desired flow rate. In the event of respiratory failure, an ETT can be reinserted using a catheter as a guide. Dosemeci *et al.* demonstrated that leaving a PAEC in place during complicated maxillofacial or major neck surgery facilitated reintubation in situations that would otherwise have been difficult, if not impossible, with direct laryngoscopy. PAEC may also facilitate direct laryngoscopy, but the two methods are not mutually exclusive (14). In addition, Antoine *et al.* wrote about a difficult extubation following a standard C5-C7 ACDF where the patient required extubation over an airway catheter. They reported that the airway catheter could provide oxygen to the patient and maintain a conduit for emergent reintubation. The airway catheter was left in place until the patient followed commands. Eventually, the patient was diagnosed with compression of the airway by the innominate artery and tracheomalacia (32). Another advantage of PAEC is that it allows those who have difficult reintubations to be extubated earlier and with less apprehension, possibly avoiding the costs and complications associated with prolonged tracheal intubation (14). This may be particularly useful in cases where laryngeal edema makes reintubation much more difficult or to avoid the need for tracheostomy, especially in cases of diffuse idiopathic skeletal hyperostosis (DISH) where preoperative laryngeal edema is common and may be exacerbated by surgery (37). These patients can have airways that are additionally compromised by anterior displacement of the airway, restricted cervical movement, and limited oropharyngeal space (43). Finally, fiberoptic bronchoscopy may be used intraoperatively and postoperatively to compare compression in the areas of the pharynx prone to swelling (aryepiglottic and vestibular folds). If serious swelling is present, this practice can help prevent extubation.

The obstructed airway

The obstructed airway is particularly important due to its lethality (47). It should be noted that urgent intubation of obstructed airways is not straightforward and is a high-risk procedure with potentially devastating complications, such as anoxic brain injury, cardiac arrest, and death. The goals of managing an obstructed airway are to maintain oxygenation and hemodynamic function (31). A common answer to the obstructed airway is awake fiberoptic intubation, but this has also been associated with serious complications (47). Obstructions are generally classified by anatomical location: laryngeal (or upper airway obstruction), mid-tracheal obstruction, and lower tracheal obstruction. The majority of obstructed airways in ACSS occur within 24 h but can occur in a delayed fashion postoperatively (21). Timing may suggest the cause of the obstruction; for example, those occurring within 12–72 hours postoperatively are most commonly due to hematoma or pharyngeal edema (29,30). While hematoma may occur at any point after surgery, delayed causes of obstruction are more commonly attributed to cerebrospinal fluid (CSF) collection or infection (29).

Upper airway obstruction

The upper airway, or pharyngeal airway (higher than C4) is susceptible to compression from swelling and hematoma following ACSS (19). Mason and Fielder's guidance on obstructed airways in patients with head and neck tumors translates well to ACSS patients (47). The upper airway includes the pharynx and supraglottic, epiglottic, and subglottic areas. Stridor is a common sign of airway compromise, which occurs when >50% of the airway diameter is obstructed. In this setting, oral airways should be avoided during induction of light anesthesia, as this could lead to total collapse of the airway secondary to laryngeal spasm and coughing. Instead, a nasal airway is preferred to prevent the opposition of the soft palate to the posterior pharyngeal wall. Similarly, awake fiberoptic intubation may be dangerous because spontaneous and complete occlusion of the airway is possible. If the decision is made to proceed with laryngoscopy, only one or two attempts should be made, as continued attempts may result in complete obstruction. If the anatomy is too tenuous, a tracheostomy should be performed by a skilled ENT provider. A provider able to perform tracheostomy should always be available to help maintain the airway in the setting of the "can't intubate, can't ventilate" patient (47,48). Emergent front-of-neck access may be obtained using either a standard open approach or a cannula technique (48). In contrast, obstruction caused by lower tracheal lesions may be best managed with fiberoptic intubation as tracheostomy may not be an option.

Hematoma

Hematomas generally affect the upper airway and can

cause tracheal deviation (35). Awake intubation may be attempted in such situations. Gwinnutt *et al.* reported a case of hematoma resulting in upper airway obstruction managed with inhalation induction of anesthesia; however, several attempts were required to attain successful intubation using a Macintosh laryngoscope (34). Notably, in cases of hematoma, venous drainage may be impaired in the cranial and facial systems. This can result in severe swelling of the tongue, retropharyngeal soft tissue, and the nasal mucosa. Inoue *et al.* reported a case of attempted nasal fiberoptic intubation in this situation, which resulted in massive epistaxis and thus should be avoided (35). A forceful intubation prior to hematoma evacuation should also be avoided (33). Song *et al.* proposed an algorithm for the management of postoperative hematomas, which involves immediate evacuation of the hematoma and hemostasis if any of the following are present: cyanosis, respiratory stridor, patient panic or anxiety, or lack of improvement after close observation. They recommend cricothyroidotomy for patients with cyanosis and unsuccessful re-intubation due to swelling and possible adhesion of the vocal cords in the postoperative period (23).

Palumbo *et al.* (29) detail a systematic approach to managing postoperative hematoma after ACSS:

- Early multidisciplinary recruitment in this process is essential (Spine Surgery, Anesthesiology, and ENT). The operating room (OR) staff should be alerted, and a tracheostomy tray should be prepared.
- A rapid bedside assessment should be performed, including evaluation of vital signs, particularly oxygen saturation, and examination of the neck/wound for an expanding hematoma or swelling.
- Supplemental oxygen via nonrebreather should be administered immediately, followed by an assessment of the severity of airway compromise. Therefore, sedation should be minimized.
  - Noncritical airway compromise occurs with partial obstruction, which is not life-threatening. Vital signs are normal, and there may be mild dyspnea or stridor.
    - The patient is transferred to the OR.
    - Awake FOB intubation is attempted.
    - If this fails, the hematoma should be evacuated while maintaining bag mask ventilation.
    - An attempt at intubation should be made. If this fails, a surgical airway is used.
  - Critical airway compromise occurs with near-total obstruction. Vitals may be altered and the patient may appear panicked and anxious.
    - Treatment is initiated at bedside.
    - If bag mask ventilation was inadequate, awake fiberoptic intubation was attempted. This may be very difficult, if not impossible, for a patient experiencing respiratory distress. If awake FOB intubation cannot be performed, bedside hematoma removal should be considered. If the patient cannot be intubated, emergent tracheostomy or cricothyrotomy should be performed (40,41).

Following evacuation of the hematoma, the patient should undergo a detailed history for any evidence of a clotting disorder, bleeding disorder, or anticoagulation use as recurrent hematomas are possible (39). A coagulation lab panel should be ordered with hematology consultation if there are any abnormalities.

Implant failure and graft extrusion

Implant failure and anterior graft extrusion may result in airway compromise and unanticipated difficulty in reintubation. Joshi reported a case of a 65-year-old female with plate failure and graft extrusion in which a TruView laryngoscope, which allows for anterior visualization through the use of a prism, was used following induction of anesthesia. However, the larynx could not be identified and they switched to a Macintosh blade and performed the intubation using a stylet (36). In these situations, it is important to anticipate anterior displacement of the airway due to implant failure. Schoenhage *et al.* reported two cases of difficulty with endotracheal intubation secondary to protrusion of the cervical hardware. These protrusions were eventually navigated with FOB, but resulted in unanticipated difficulty. It is necessary for the spine surgeon to discuss possible obstructions with the anesthesiologist prior to induction as this situation can rapidly deteriorate into a "can't intubate, can't ventilate" situation (42). These patients should either have a preoperative tracheostomy or an ENT should be prepared to perform an emergency airway.

CSF leak

If CSF leak is the suspected cause of obstruction, a computed tomography (CT) myelogram may be obtained to confirm the diagnosis, assuming that the patient is not in respiratory distress. Subsequently, the CSF leak should be evacuated, and the dural tear repaired as recurrent CSF

fluid collection may cause secondary obstruction (40).

Emergency airway access

An emergent surgical airway, or a cricothyroidotomy, should be established in the "can't intubate, can't oxygenate" scenario. Both spine surgeons and anesthesiologists should be familiar with the basic techniques to provide this life-saving procedure if necessary. The tracheal cartilage corresponds to laryngeal prominence and is a key landmark. The cricothyroid membrane is a finger breadth below this point and indicates a region of the airway below the vocal cords. Surgical placement of airways in or above the vocal cords can lead to significant morbidity. In the setting of a previous anterior cervical approach, the surgical incision should be extended to the midline (if horizontal). The cricothyroid membrane is then identified between the cricoid cartilage and tracheal cartilage and repeatedly confirmed by palpation. The airway should be stabilized by the non-dominant hand, and a horizontal incision is made in the membrane close to the cricoid cartilage. The incision is then dilated using a hemostat forcep followed by insertion of a tracheostomy tube (6 cm) and inflation (26). Tracheostomy involves creating an opening in the anterior tracheal wall and is used for airway access. The procedure can be performed percutaneously or as an open procedure (27).

Proposed airway management algorithm

(I) Assess for preoperative airway risk factors.
  (i) It is critical to assess for risk factors preoperatively and incorporate these risks into the preoperative surgical discussion and informed consent process. These risk factors are discussed separately in previously published reviews (1,2).
  (ii) Prepare for intubation: have an assistant available as well as adequate airway adjuncts [laryngeal mask airway (LMA), FOB, Glidescope®].
  (iii) Preoxygenate patient and provide supplemental oxygen throughout the intubation process.
  (iv) If possible, atraumatic intubation on the first attempt by a senior anesthesia provider would be ideal.
  (v) Consider awake intubation for expected difficult airways.
  (vi) Consider the use of an advanced intubation technique with FOB, lighted stylet, or video-assisted laryngoscopy.
  (vii) Tracheostomy should be available in situations where a difficult tracheal intubation is anticipated.

(II) Plan for the unexpected: pre-operative ENT examination if vocal cord paralysis is suspected—such as with previous neck surgery. Adjust the approach accordingly.
  (i) Spinal surgeons should evaluate any anticipated anterior airway displacement secondary to deformity or hardware complications and discuss the possibilities and challenges with the anesthesiologist. Patients should be counseled of possible airway complications in these situations as well as the need for possible tracheostomy.
  (ii) Techniques to limit neck movement in trauma patients undergoing cervical spine surgery (25):
    ❖ Apply cricoid pressure using a two-hand technique to limit cervical spine motion: one hand on the back of the neck and another on the cricoid.
    ❖ Direct laryngoscopy with manual in-line traction and stabilization.
    ❖ Use of helpful devices, such as stylets, with alternative airways available, such as levering laryngoscopes, fiberoptic laryngoscopes, video laryngoscopes, or other imaging devices.
    ❖ Failure to intubate may necessitate alternative methods such as establishing a LMA. However, these devices may exert pressure against the vertebrae and lead to posterior displacement of the cervical spine, which is not ideal in cases of trauma, instability, or severe stenosis.
    ❖ Extreme emergencies—retrograde tracheal intubation or emergent cricothyroidotomy.

(III) Assess for intraoperative risk factors: blood loss >300 mL, operative time >5 h, >3 level operation, combined A-P cervical surgery.
  (i) Lateral radiographs may be obtained to assess swelling prior to extubation.
  (ii) If positive, leave the patient intubated for 12 additional hours and perform the cuff leak test (see below).
  (iii) Use propofol for maintenance of anesthesia (as opposed to sevoflurane) (11).

(IV) Assess for cuff leak.
  (i) A cuff leak test should be performed in patients with more than one risk factor for airway compromise after ACSS or in those who fail an extubation attempt.
  (ii) If positive, attempt extubation when appropriate

personnel are available. Consider leaving the airway catheter for another 12–24 hours.

(iii) If negative, obtain lateral radiograph or perform FOB to evaluate for swelling.
- ❖ If significant swelling on lateral radiograph or FOB, keep the patient intubated and recheck in 12 hours.
- ❖ If there was significant swelling but a cuff leak test failed, keep the patient intubated and recheck in 12 hours.

(iv) Tracheostomy should be considered in patients who remain intubated on postoperative day 7 due to failed cuff leak tests and/or multiple extubation attempts.

(V) Managing the obstructed airway.

(i) When a patient develops signs (e.g., stridor) or symptoms (panic) of airway obstruction in the acute postoperative period, an immediate bedside assessment should be performed with the delivery of oxygen via nonrebreather and constant monitoring of vital signs.

(ii) Alert the appropriate multidisciplinary staff—spine surgeon, anesthesiologist, on-call ENT, respiratory therapist, OR staff—for an emergency trip to the OR.

(iii) In patients with obvious neck swelling, hematoma should be suspected, and bag mask ventilation should be initiated.
- ❖ Abnormal vital signs and panic should be considered critical:
  - ◆ If bag mask ventilation is inadequate, attempt awake fiberoptic intubation.
  - ◆ If this fails, evacuate the hematoma at the bedside, and then re-attempt awake fiberoptic intubation.
  - ◆ If this fails, perform an emergent surgical airway.
  - ◆ Once an airway is secured, the surgical wound and hematoma should be addressed in the OR (i.e., re-evaluation for hemostasis).
- ❖ Normal vital signs without panic should be considered non-critical:
  - ◆ Bring patient to OR in an urgent fashion.
  - ◆ Attempt awake fiberoptic intubation.
  - ◆ If this fails, attempt to evacuate hematoma under bag mask ventilation.
  - ◆ Repeat awake fiberoptic intubation.
  - ◆ If this fails, consider a surgical airway.

(iv) When hematoma is not suspected, perform immediate bedside lateral cervical spine X-ray.
- ❖ Severe soft tissue swelling/edema present.
  - ◆ Insert nasal airway.
  - ◆ Attempt intubation with gentle laryngoscopy.
  - ◆ If this fails, transfer patient to OR for a surgical airway.
- ❖ Graft extrusion suspected.
  - ◆ Transfer patients to the OR for revision surgery if able to maintain stable vital signs with oxygen therapy.
  - ◆ If this fails, provide bag mask ventilation while transferring patient to OR.
  - ◆ If this fails, insert nasal airway and attempt laryngoscopic intubation in OR.
  - ◆ If this fails, proceed with the surgical airway and revision surgery when the patient is hemodynamically stable.
- ❖ CSF leak suspected.
  - ◆ This rarely presents acutely.
  - ◆ If able to maintain oxygenation via nonrebreather, obtain CT myelogram.
  - ◆ If positive, proceed with revision surgery when patient is hemodynamically stable.

(VI) Postoperative monitoring: patients should be instructed to self-monitor for up to 2 weeks and given instructions on possible airway complications and signs of eminent airway collapse, such as stridor, swelling, shortness of breath, or an increase in anxiety associated with any of the aforementioned.

Conclusions

This review summarizes the most recent and relevant literature regarding management of airway complications after ACSS. Currently, the literature lacks high-level evidence (I or II) supporting any specific management or prevention strategy for patients undergoing these surgeries. The authors aim to provide guidelines based on the available literature on airway compromise in ACSS. The following are additional recommendations outside of this proposed algorithm based on our systematic review.

Additional recommendations/guidelines

(I) Intraoperative: deflation of the ETT after retractor placement. Subsequent ETT re-inflation to the just-sealed pressure. Repeat if the retractor position is changed or with noted elevation in cuff pressure (13,16).
(II) Postoperative: delayed (>24 hours) extubation in patients with risk factors for unplanned reintubation even without clinical signs of respiratory distress, but extubation as quickly as safe in patients without risk factors (18). The following are the risk factors for airway complications.
    (i) Medical comorbidities or functional dependence.
    (ii) Patients with DISH or ossification of the posterior longitudinal ligament (OPLL).
    (iii) Trauma.
    (iv) Combined A-P surgery.
    (v) Operative time >5 hours.
    (vi) Estimated blood loss >300 mL.
    (vii) Revision surgery.

When encountering a difficult airway, it is preferable to use a Glidescope®, although a Bullard laryngoscope may provide faster intubation, whereas a rigid video-stylet may cause less motion across the cervical spine. Any spine surgeon or anesthesiologist taking care of ACSS patients should be equipped to perform an emergency airway in the setting of the acute loss of an airway. This study has several limitations. As previously mentioned, the available literature on this topic is mostly anecdotal, retrospective, small series and opinion based studies. Therefore, the proposed algorithm was formulated as the opinion of the authors based on the available evidence. Some of the recommendations are controversial, such as deflation of the ETT after retractor placement with reinflation and pressure adjustment. Although we reference studies supporting this practice (16,18), others have found it does not affect the incidence of postoperative vocal fold immobility (7).

Despite the presented studies, there remains a paucity of evidence to fully support these recommendations. Future studies are needed to provide high-level evidence that spine surgeons and anesthesiologists can rely on to make clinical decisions and to create evidence-based practice guidelines. Ideally, some of the provided recommendations could be evaluated with RCTs; however, considering the danger to patients, this may pose an ethical challenge. With the recent development and use of artificial intelligence algorithms for medical research, we hope that future studies can use machine learning from large databases to understand the most important etiological and risk factors for airway complications after ACSS while establishing sound management protocols.

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