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Aducanumab Produced a Clinically Meaningful Benefit in Association With Amyloid Lowering

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Management of traumatic laryngotracheal separation: Case series and review

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Laryngotracheal injuries are rare, with a reported incidence of 1 in 4,491 trauma admissions.[1] In the setting of laryngotracheal separation injuries, complete or even partial separation of the airway can be rapidly fatal. However, if adequate oxygenation and ventilation are still able to occur, injuries can go unrecognized during initial resuscitation efforts. Following complete laryngotracheal separation, an intact sheath of peritracheal fascia may allow a conscious patient to breathe and may even enable ventilation.[2] As a result, laryngotracheal separation injuries can be a diagnostic challenge when airway injury is not evident at presentation, especially in the setting of blunt injury. Symptoms and examination findings may include dyspnea, dysphonia, dysphagia, odynophagia, pain, hemoptysis, stridor, ecchymosis, and crepitus. Imaging is not always possible because of the acuity of the injury, but when obtained, radiographic studies can demonstrate subcutaneous emphysema, laryngotracheal fractures, and abnormal separation of laryngotracheal structures.[3] Survival after laryngotracheal separation injuries relies on expedient and proper airway management. With a documented occurrence of less than 1% of neck injuries, most surgeons' experience with laryngotracheal injuries is limited.[4] In these circumstances, competence in emergency airway management is vital, as mishandling of the airway can rapidly lead to decompensation.

Given the infrequent occurrence of laryngotracheal injuries, there are currently no formal guidelines for the approach to management. The body of literature to date has consisted almost exclusively of case reports and recommendations on management based on expert opinion.[2] We aim to describe six previously unreported cases of laryngotracheal separation, including airway management and reconstruction and review the current body of literature relating to laryngotracheal separation injuries.

PATIENTS AND METHODS

Retrospective chart review was performed during a 10-year period at a single tertiary care level one trauma center. Cases of laryngotracheal separation injuries that underwent surgical repair by the otolaryngology service were identified. The clinical records of patients with traumatic laryngotracheal separation between July 2011 and December 2020 were accessed through the electronic medical record at the University Medical Center of Southern Nevada. Demographics, symptoms, and treatment details were reviewed for each patient. In addition, a comprehensive review of the literature was conducted in relation to the management of traumatic laryngotracheal separation injuries.

RESULTS

The six patients identified via chart review ranged in age from 18 to 55 years. Only one patient was female, while the other five were male. Two patients were involved in motor vehicle collisions, one of which sustained a penetrating neck wound caused by metal shrapnel from airbag deployment and the other sustained a blunt injury. Another patient presented with a penetrating neck wound after being shot with a bean-bag round. The other three patients sustained blunt injuries caused by hanging and being punched in the neck. Presenting symptoms included aphonia, dysphonia, dyspnea, dysphagia, odynophagia, and neck pain. Physical examination findings included stridor, ecchymosis, edema, crepitus, and a neck wound with audible air escape. All but one of the patients were able to undergo a computed tomography or computed tomography angiography of the neck on presentation (Figs. 1 and 2). The otolaryngology service was emergently consulted in all cases. Flexible fiberoptic laryngoscopy was performed in the trauma bay for two of the six patients, whereas the other patients all required emergent trips to the operating room before laryngoscopy could be performed. Findings on laryngoscopy included endolaryngeal edema and hematoma, vocal cord paralysis, and subglottic foreign body.

Half of the patients underwent initial neck exploration in the operating room under general anesthesia. The other three patients were intubated with the use of flexible fiberoptic laryngobronchoscopy. During neck exploration, three patients were found to have complete traumatic separations between the cricoid cartilage and trachea. Two patients had a complete separation between the thyroid cartilage and cricoid cartilage, and one patient had a partial separation between the thyroid and cricoid cartilages with additional comminuted fractures involving the laryngeal framework. The majority of laryngotracheal repairs were performed with polypropylene suture; however, miniplates and screws were also used in one patient. All sutures were placed submucosally, hugging the inner perichondrium of the larynx and

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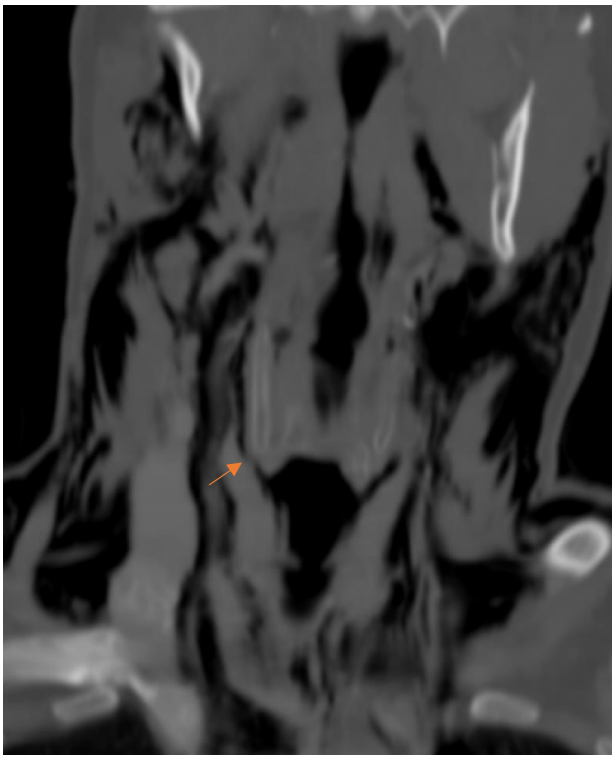

Figure 1. Thin cut coronal computed tomography of a 55-year-old hanging victim through the level of the cricothyroid notch demonstrating complete separation of the more distal trachea from the cricoid cartilage. The arrow demonstrates the inferior border of the lateral cricoid cartilage.

trachea to avoid mucosal disruption and introduction of a foreign substance into the airway lumen. Knots were tied extraluminally to avoid disruption of the intraluminal healing process. A fenestrated tracheostomy was performed in all patients. In five of the six patients, this was placed distal to the area of repair; however, in one patient, it was placed through the area of injury and repair, as there was missing cartilage in that region.

The five patients who followed up after their repairs were successfully decannulated and eating regular diets by mouth at 3 months after their injury. None required further procedures. There were no instances of repair dehiscence or surgical site infection. All patients had mild dysphonia compared with their preinjury state; however, only one patient had a persistent significantly hoarse voice. The patient with significant hoarseness had sustained injury to the recurrent laryngeal nerve with unilateral vocal cord paralysis at the time of the laryngotracheal separation event. No patients desired further procedures to improve their voice.

DISCUSSION

Trauma resulting in laryngotracheal separation is rare, and most patients die before hospital arrival secondary to airway compromise.[5] Because of its rarity, only a small number of case reports have been published describing the treatment and outcomes of patients who survive these injuries. Laryngotracheal injuries are graded I to V, with grade I representing minor hematoma or laceration without detectable fracture, up to a grade V complete separation.[3] Minor injuries can be managed conservatively, but unstable airways and displaced fractures mandate surgical exploration and repair. If significant injury is recognized during primary evaluation, blind orotracheal intubation should be avoided to prevent further tracheal damage.[1] Even videolaryngoscopy may not be sufficient, as visualization of the distal portion of injury through the vocal cords may not be possible. Patients who do make it to a hospital necessitate prompt diagnosis and treatment to optimize their chance for survival.

One of the first reported cases of laryngotracheal separation injuries in the literature was by LeJeune[6] in 1978. Recommendations from his experience with two patients and prior expert experience[7,8] included immediate intubation in the field or transfer to a hospital within 4 to 10 minutes of the injury for emergent tracheostomy through the area of injury. Surgical repair then followed within 48 hours of the injury. Details of his recommended repair include creating a midline vertical incision from hyoid to sternum if needed, followed by placement of a new tracheostomy below the area of injury. The tracheostomy technique was not described. Exploration was then performed to identify any injury to the recurrent laryngeal nerves and esophagus. A soft splint was placed in the tracheal lumen, secured to the trachea with a stainless-steel wire, and tracheal mucosal repair was performed with absorbable suture. The laryngeal framework was then reapproximated with stainless steel suture.

Figure 2. Thin cut sagittal computed tomography of a 46-year-old male motor vehicle collision victim showing complete laryngotracheal separation. The distal tip of the endotracheal tube is at the most proximal portion of the distal airway segment.

A literature review was performed to identify reported cases of laryngotracheal separation injuries with an emphasis on treatment and outcomes. The level of detail provided concerning the specifics of the airway management and surgical techniques and reconstruction vary widely.[6,9–24] The results are summarized in Table 1. Management strategies have not unsurprisingly evolved throughout the years. In the early literature, the initial airway management consisted largely of blind orotracheal intubation attempts followed by tracheostomy. Surgical repair was then often delayed for several days. Repair techniques consisted of absorbable suture and stainless steel suture to perform laryngotracheal reconstruction over a temporary soft intraluminal stent.[6,9,10] More recently, there has been a shift toward fiberoptic intubation followed by tracheostomy. Surgical

TABLE 1. Literature Review

Study	Format	Cases/ Patients	Type of Injury	Treatment	Outcome
LeJeune, 1978[6]	Case report	2	Patient 1: partial separation Patient 2: complete separation	Patient 1: intubation, delayed repair over a stent with stainless steel and absorbable suture Patient 2: failed intubation, tracheostomy, delayed anastomosis over a stent with stainless steel and absorbable suture	Patient 1: tracheoesophageal fistula, subglottic stenosis not requiring a tracheostomy Patient 2: decannulation
Hermon et al., 1987[9]	Case report	1	Complete separation	Failed intubation, low tracheostomy with t-tube placement, anastomosis over t-tube with 3-0 polyglycolic acid suture	Tracheostomy dependence
Chen et al., 1993[10]	Case report	1	Complete separation	Failed intubation, awake tracheostomy, anastomosis with stainless steel suture over a stent	Tracheostomy dependent because of spinal injury
Offiah et al., 1997[11]	Case report	1	Complete separation	Tracheostomy, delayed laryngotracheal repair	Not available
Schweikh et al., 2001[12]	Case report	1	Complete separation	Failed intubation and cricothyroidotomy, neck exploration with placement of endotracheal tube into distal trachea	Cardiac arrest and brain death
Mazita and Sani, 2005[13]	Case report	2	Complete separation	Patient 1: Tracheostomy through defect, delayed cricotracheal anastomosis with absorbable suture and tracheostomy through the anastomosis Patient 2: Tracheostomy through defect, primary anastomosis with absorbable suture	Patient 1: Tracheostomy dependence because of paralyzed vocal cords Patient 2: Subglottic stenosis requiring tracheostomy followed by tracheal resection and anastomosis
Bernat et al., 2005[14]	Case report	1	Complete separation	Intubation through neck wound, tracheostomy, primary anastomosis with nonabsorbable monofilament suture over a stent	Decannulation
McCrystal and Bond, 2006[15]	Case report	1	Partial separation	Blind intubation, primary anastomosis with 2-0 nylon suture and 4-0 polyglycolic acid suture for mucosa, low tracheostomy	Decannulation
Ajmal et al., 2008[16]	Case report	1	Partial separation	Tracheostomy, delayed neck exploration and cricotracheal anastomosis with rib cartilage graft done over a t-tube	Removal of t-tube, dilation of subglottic stenosis
Smith et al., 2009[17]	Case report	1	Complete separation	Nasotracheal intubation, end tracheostomy with laryngeal repair over stent with polypropylene suture, delayed l aryngotracheal primary reconstruction with polypropylene suture over soft stent, tracheostomy	Tracheostomy dependence
Choi et al., 2012[18]	Case report	1	Complete separation	Tracheostomy, anastomosis with 4-0 polyglactin suture	Extubation
Sing et al., 2012[19]	Case report	1	Complete separation	Tracheostomy tube inserted through neck wound, primary tracheal anastomosis with tracheostomy	Tracheostomy dependence
Vivero et al., 2014[20]	Case report	1	Complete separation	Blind intubation, anastomosis over a stent with 2-0 polypropylene, low Bjork flap tracheostomy	Decannulation
Malliari et al., 2014[21]	Case report	1	Complete separation	Intubation, primary anastomosis over a t-tube	T-tube removed
Chatterjee et al., 2015[22]	Case report	1	Complete separation	Blind intubation, fiberoptic intubation, low tracheostomy, primary anastomosis	Tracheostomy dependence
Jitpakdee et al., 2016[23]	Case report	1	Complete separation	Awake tracheostomy, repeat tracheostomy distal to the injury, primary anastomosis over a stent with 3-0 polyglactin for mucosa and 4-0 polydioxanone for the cartilaginous framework	Tolerating capping trials
Humenansky et al., 2017[24]	Case report	1	Complete separation	Blind intubation, tracheostomy	Transferred for definitive repair

repair is usually immediate when possible and consists of the use of absorbable and/or nonabsorbable suture based on surgeon preference. An intraluminal stent is still used when deemed necessary as dictated by the specifics of each injury. The creation of a tracheostomy is not universal but is frequently done.[17,22,23]

Although the details of each of our cases varied, the airway management and repair techniques used were similar. The decision for initial airway management in these patients should revolve around performing the safest possible intervention to obtain a stable airway in each situation. In all circumstances, the safest method is always to obtain a secure airway while the patient is still spontaneously breathing when possible. In the setting of laryngotracheal separation injuries, these options would include surgical exploration of the anterior neck under local anesthesia or awake fiberoptic intubation. In the setting of surgical exploration under local anesthesia, this is performed similarly to an awake tracheostomy that may be performed for obstructive laryngeal lesions. The anterior neck is infiltrated with local anesthesia, 1% lidocaine with 1:100,000 epinephrine in our cases, and the neck wound is explored down to the trachea. In the setting of blunt injury, the anterior neck is opened and dissected down to the anterior trachea. An endotracheal tube can then be placed through the area of injury or guided into the distal trachea during orotracheal intubation. Care should be taken to only dissect tissue that is necessary for obtaining the airway and reconstructing the area of injury to avoid unnecessary damage to important surrounding neurovascular structures.

Awake fiberoptic intubation can also be performed with the use of videolaryngobronchoscopy. This allows for visualization of the distal tracheal segment and guidance of the endotracheal tube into that distal segment, preventing the possibility of extratracheal intubation that can occur with blind intubation. Blind intubation also carries the risk of further damaging the already existing area of injury. Topical laryngeal anesthetic should be used cautiously, as this can potentially exacerbate a patient's respiratory distress. When awake fiberoptic intubation is not successful, emergency tracheostomy is preferable to cricothyroidotomy, as a cricothyroidotomy may be performed through an area of injury in an unstable segment.

Primary reapproximation of the trachea to the larynx in our cases was performed with 2-0 or 0 polypropylene sutures with tapered needles. When possible, areas of injury were sutured to the cricoid cartilage because of its stability. Posterior membranous tracheal mucosal injuries were repaired with 3-0 polyglactin suture. A fenestrated tracheostomy was placed below the repair in every case but one. In contrast to planned tracheal resections, in which placement of a tracheostomy is generally avoided, traumatic separations can often require a different management strategy. In our experience, these patients do require a tracheostomy secondary to extensive global edema and inflammation of the airway. A tracheal window was created by removing the anterior portion of one tracheal ring. The skin edges of the tracheostomy stoma were sewn to the tracheal window with 2-0 polyglactin sutures with tapered needles. In each case, the fenestrations were conservative, approximating closely a size 6 Shiley (Medtronic, Minneapolis, MN) tracheostomy tube, which is used routinely by our service. An illustration of the fenestrated tracheostomy technique is shown in Figure 3.

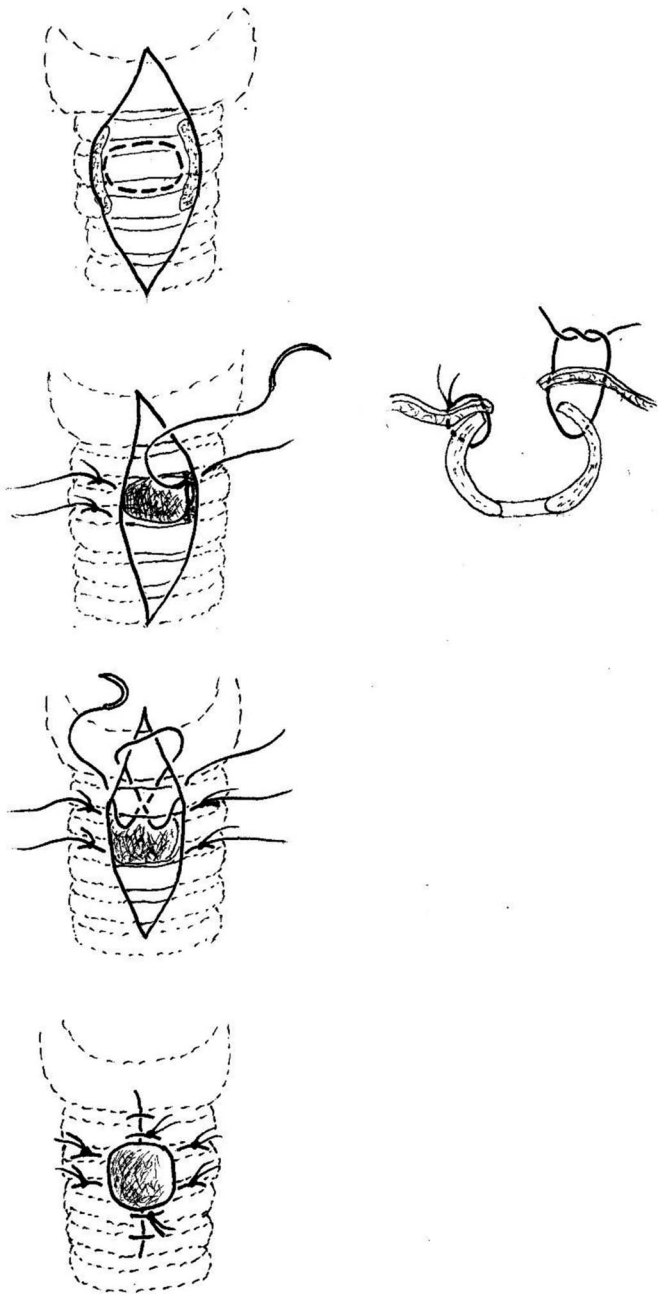

Figure 3. Illustration of the fenestrated tracheostomy technique. The skin edges are sewn down to the trachea laterally, and an "X" suture is placed superiorly and inferiorly to bring the skin edges together and also flush with the trachea. Of note, sutures are not displayed as being placed submucosally; however, in practice, they should be.

Tracheostomy fenestration was preferred in our patients for several reasons. It allows for the complete separation of the stoma site from the surrounding tissues, as the stomal skin is sewn tightly and circumferentially to the anterior tracheal wall. This prevents surrounding neck tissues and the area of repair from being chronically bathed in secretions, theoretically lowering the chance of infection. This technique also provides an extremely safe airway in the immediate postoperative period.

There is no stomal tract that provides the possibility of collapse when the tracheostomy tube is changed or in the case of accidental decannulation. We routinely change our tracheostomy tubes on postoperative day one as a result (Fig. 4). The patient is also able to easily replace the tube on their own, as the cutaneous stoma enters directly into the trachea. Once decannulated, the stoma often closes spontaneously as with other tracheostomy methods; however, some do require surgical closure in our experience. In our five cases with postoperative follow up, all patient's stomas closed spontaneously.

Because of its rarity, there have been no standardized methods for repair of such injuries. Suspicion of injury must be high, and once recognized, definitive repair should be performed in an expedited fashion. The larynx and trachea should be reapproximated and secured in a manner that reduces stress and tension on the repair. Nonabsorbable sutures were the preferred manner of achieving this in our cohort. As the stability of the laryngotracheal apparatus is permanently weakened by these injuries, the use of nonabsorbable suture provides permanent structural support that ensures stability throughout the healing period and afterward. The choice of polypropylene suture was dictated by its monofilament nature that has been shown to have fair tensile strength and minimal tissue reactivity. Miniplates may also be used to stabilize associated cartilage fractures; however, their use is limited by several factors. They should generally only be used when there are relatively large segments of cartilage that need to be reapproximated, which can accommodate the bulk of the miniplate. In addition, ossified cartilage may further fracture when drilled or when placing a screw. A miniplate was only used in our series in a young patient with large segments of fractured cartilage. Polypropylene suture allows for reapproximation of smaller segments of fractured cartilage. It can also be used in instances of ossified cartilage. Threading the needle through ossified cartilage can also fracture the cartilage; however, the suture can be looped around entire segments of cartilage to achieve reapproximation. Care must be taken when tying the suture to not create overlap of separated segments but still achieve close reapproximation.

Figure 4. Fenestrated tracheostomy visualized on postoperative day one during tube exchange.

To our knowledge, this is the largest case series reported that presents both surgical technique and long-term outcomes on multiple patients. All patients who maintained follow-up were successfully decannulated by 3 months and eating regular diets. None of the patients required further procedures. We believe this to be at least partially related to early surgical intervention, lack of unnecessary tissue dissection, securing a safe airway, effective reconstruction of the airway, and the fenestrated tracheostomy technique. Outcomes of this case series suggest that these techniques can be implemented for life-sustaining measures while also carrying the potential to result in good voice quality and freedom from long-term tracheostomy dependence.

Although this study represents the largest series of laryngotracheal separation injury management reported to date, it remains limited by the still small number of patients included. Future studies would benefit from inclusion of a larger number of patients, although this is inherently difficult because of the rarity of these injuries and the high mortality. In addition, this represents a single institution study with management dictated by the two senior authors (R.C.W. and M.N.). Future studies would benefit from multi-institutional data, which could help overcome the low patient numbers and afford the opportunity to compare different management strategies.

CONCLUSION

Laryngotracheal separation injuries are often fatal and require prompt evaluation and surgical intervention. Initial airway management is paramount, as mishandling it can quickly lead to respiratory decompensation. Our series demonstrates that repair and subsequently good outcomes can successfully be achieved in a single-stage fashion. This is done by using conservative tissue dissection, effective airway reconstruction, and placing a fenestrated tracheostomy.

AUTHORSHIP

N.H.R., Y.K., and J.B.K. contributed in the literature search. N.H.R., J.B.K., A.G.S., M.N., and R.C.W. contributed in the study design. N.H.R., Y.K., and J.B.K. contributed in the data collection. N.H.R., Y.K., J.B.K., A.G.S., M.N., and R.C.W. contributed in the data analysis. N.H.R., Y.K., J.B.K., A.G.S., M.N., and R.C.W. contributed in the data interpretation. N.H.R., Y.K., J.B.K., A.G.S., M.N., and R.C.W. contributed in the writing. N.H.R., Y.K., J.B.K., A.G.S., M.N., and R.C.W. contributed in the critical revision.

DISCLOSURE

The authors declare no conflicts of interest.

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