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Journal of Experimental Pathology Commentary

Identification of Laryngotracheal Stenosis During Weaning from Tracheostomy – A Clinical Conundrum

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Abstract

Laryngotracheal stenosis is an umbrella term for narrowing of the airway, which may occur at the level of the larynx, subglottic or trachea. Identification of laryngotracheal stenosis prior to decannulation poses a clinical conundrum. Subglottic stenosis is commonly reported as a symptom of laryngeal injury following endotracheal intubation. Readiness for tracheostomy decannulation varies between institutions, and lacks international consensus. Detection of laryngotracheal stenosis prior to decannulation typically involves invasive visualization of the airway using nasendoscopy or exposure to radiation for computerized tomography. Ultrasound is a non-invasive bedside diagnostic tool, available in most intensive care units and its portable nature promotes wider clinical utilization. Ultrasonography is employed to identify abnormal physiology, assist clinical examination and decision making and is well established for point of care lung assessment and echocardiography. There is increasing interest in ultrasound development for diagnostic and monitoring purposes, due to its safety, lack of radiation, rapid application, and real-time dynamic feedback. This narrative explores the consideration of laryngeal ultrasound in the context of tracheostomy weaning, a modality that has a promising role in detecting subglottic stenosis.

Keywords: Tracheostomy, Decannulation, Subglottic stenosis, Ultrasound, Laryngotracheal Stenosis, Laryngeal Injury

Glossary of Terms:

Decannulation: The process of removal of the tracheostomy tube.

Subglottic stenosis: Narrowing of the airway below the vocal cords.

Suprastomal: Above the tracheostomy stoma.

Tracheostomy: Medical procedure to create an opening at the trachea to allow for ventilation or airway patency.

Introduction

Tracheostomy insertion is a common procedure used to support weaning from mechanical ventilation or following head and neck surgery. Resolution of the clinical need for tracheostomy is followed by a process of tracheostomy weaning and subsequent decannulation. The method of establishing readiness for tracheostomy decannulation varies between country and institution and appears to be determined by expert opinion or institutional protocols [1] rather than a universally agreed approach [2]. The published literature supporting this clinically important decision consists of observational studies, case series and questionnaires, but is not supported by randomized controlled trials [2,3]. Consequently, international and inter-institutional differences in tracheostomy decannulation criteria exist.

These criteria can be insufficient to detect the presence of suprastomal pathology as described previously [4], although this complication occurs infrequently compared to the number of patients who can be successfully decannulated using recognized decannulation criteria [5]. This narrative explores the rationale underlying the components

of tracheostomy weaning and discusses diagnostic complexities in relation to identifying laryngotracheal stenosis. The reported incidence of stenosis varies between 0.6-21% and therefore warrants consideration when evaluating readiness for decannulation [6]. We discuss the emerging technique of laryngeal ultrasound, which has the potential to positively contribute to the assessment of tracheostomy decannulation readiness.

Tracheostomy Weaning

The first consideration for tracheostomy weaning readiness is resolution of the initial reason for tracheostomy placement [7]. For example, in the case of tracheostomy placement for head and neck surgical procedures it is prudent to ensure post-operative swelling has resolved before initiating tracheostomy weaning. Where a tracheostomy has been placed to support weaning from mechanical ventilation for respiratory insufficiency, ventilator liberation is not a pre-requisite for initiation of tracheostomy weaning. Successful tracheostomy cuff deflation and one-way valve use are possible during ventilator dependence with known benefits to communication, quality of life and lung recruitment [8,9] although full exploration of these benefits are outside the scope of this commentary.

The first formal stage of Tracheostomy weaning is establishing tolerance to cuff deflation [10]. While cuff deflation does increase airflow through the upper airway, tolerance to cuff deflation is usually determined by the patient's ability to manage their oral secretion load. Cuff deflation induced upper airway flow may improve upper airway sensation and elicit an increased frequency of swallow. Intolerance to cuff deflation (excessive coughing, desaturation and hypoxia) may be related to respiratory insufficiency, an ineffective swallow or a high burden of oropharyngeal secretions. Tolerance to cuff deflation can be improved through repeated exposure, swallow rehabilitation and the use of pharmacological agents to reduce the oral secretion burden [11].

If cuff deflation is tolerated, the next stage of tracheostomy weaning is the application of a one-way valve or speaking valve [10] which forces expiratory airflow via the suprastomal tracheal segment, glottic opening and upper airway, promoting voice production. Evaluation of vocal quality during one-way valve application indicate that the suprastomal anatomical segments have sufficient space to allow airflow during expiration. One-way valves may also contribute to an increase in positive subglottic tracheal pressure [9] which in turn elicits improved expiratory glottic airflow. Intolerance to one-way valve application is suggestive of compromised suprastomal expiratory flow and can be caused for a variety of reasons. For example, the tracheostomy tube itself may be too large and impede expiratory upper airway airflow when a one-way valve is applied. Simply downsizing the tracheostomy tube may improve upper airway expiratory airflow and promote tolerance to one-way valve application. If intolerance to one-way valve application persists, further evaluation in relation to laryngotracheal stenosis should be considered.

For patients with defined tolerance to both cuff deflation and one way valve application, the final step in the process of decannulation is assessing the ability to manage pulmonary secretions. Cough strength and/or effectiveness is therefore an important factor to consider when evaluating readiness for tracheostomy decannulation. Clinicians participating in an international survey [12] rated effective cough as one of the most important determinants ascertainment for decannulation. A clinical consensus statement from an expert panel also included cough effectiveness in the determination of readiness for decannulation [13]. Cough strength can be determined subjectively by clinical teams experienced in observing and rating cough in patients with Tracheostomy, however subjectivity in the assessment of cough effectiveness can lead to conflicting opinion regarding decisions to decannulate, which may lead to premature or delayed decannulation [14]. Cough strength can be determined objectively by measuring peak expiratory flow generation during a cough attempt. Cough Peak Flow (CPF) measurement in the patient with tracheostomy has received some attention in the literature due to its potential to be able to predict decannulation success in populations with neuromuscular impairment [15,16]. Since the most common reason for decannulation failure is secretion retention or management [17], establishing safe and objective criteria for cough strength in patients with Tracheostomy prior to decannulation appears warranted [18,19].

There are few reports in the literature regarding the frequency of decannulation compared to total tracheostomy numbers within specific patient cohorts. One German study reported a 57% incidence of decannulation in a neurological population [20] but did not report outcomes for the remaining patients. Similarly, there are few descriptions in the literature regarding the physiological rationale underlying steps within the tracheostomy weaning process or acceptable rates of decannulation failure. Clinical impressions of acceptable failure rates in an international survey ranged between 1% and 20% [12]. It would appear that standardized multi-professional tracheostomy decannulation criteria, alongside a robust understanding of the physiological changes driven by these criteria will allow clinicians to determine decannulation readiness with a relatively low rate of failure.

While no international consensus for tracheostomy decannulation exists, the steps outlined above represent key components to evaluating readiness for decannulation.

In the small cohorts who do not meet the established decannulation criteria, further evaluation of the upper airway and consideration of laryngotracheal stenosis may be pertinent.

Laryngotracheal Stenosis

Laryngotracheal stenosis is an umbrella term for narrowing of the airway, which may occur at the level of the larynx, subglottis or trachea. Stenosis may be idiopathic, iatrogenic, autoimmune or traumatic in origin [21], although for this narrative we focus on subglottic stenosis arising from prolonged endotracheal intubation or tracheostomy. The subglottic space is defined as the area at the level of the cricoid, between the inferior margin of the vocal cords to the lower border of the cricoid cartilage. Subglottic stenosis occurs when a firm, fibrous scar forms [22]. It poses a treatment challenge to specialists, primarily due to the potential for regrowth of granulation tissue at the site of intervention [23]. Iatrogenic subglottic stenosis may be caused by mucosal ischemia and ulceration produced by an endotracheal tube [22]. The endotracheal tube sits in a vulnerable anatomical region for laryngeal function. As the endotracheal tube is inserted, it passes the arytenoid cartilages and cricoarytenoid joints and through the vocal folds; all regions which are susceptible to trauma and residual laryngeal complications, such as dysphagia, dysphonia and laryngeal pathology [24]. Subglottic stenosis is commonly reported as a symptom of laryngeal injury, with the prevalence of subglottic stenosis reported as high as 13% [25]. Prolonged duration of intubation appears to be a risk factor for subglottic stenosis, with a reported incidence of 2% for those intubated between three and five days, and 5% for those intubated between six and ten days [24].

It would be remiss to discuss subglottic stenosis within the context of tracheostomy without referencing the significant increased need for mechanical ventilation and subsequent tracheostomy as a result of the Covid-19 Pandemic. Over the past twelve months in the United Kingdom, there have been 421,603 patients admitted to hospital with Covid-19. Among those hospitalized with Covid-19, up to one quarter required intensive care admission for severe respiratory disease [26]. During the United Kingdom's second wave, the number of patients receiving mechanical ventilation peaked at 4,077 on the 24th of January 2021. Typically, tracheostomy is performed between days seven to ten of endotracheal intubation [27]. An emerging, distinctive characteristic of the Covid-19 cohort is the duration of ventilator reliance, up to twenty days and beyond [28]. Interim reports from COVIDTrach, a UK multi-center cohort study evaluating the outcomes of tracheostomy in patients with Covid-19 receiving mechanical ventilation, found the number of days from intubation to tracheostomy ranged from 0-35 days [29]. The need for a high level of suspicion for laryngotracheal stenosis following prolonged intubation and tracheostomy has been highlighted in this cohort [30].

Detecting subglottic stenosis prior to decannulation remains a clinical conundrum and there is a paucity of evidence for a universally accepted method of determining the presence of this pathology. Persistent intolerance to one-way valve application in the tracheostomy weaning process may elicit the need for direct visualization of the larynx by nasendoscopy to determine glottic and upper airway competency. Direct visualization of the larynx may identify subglottic stenosis, however the level to which the scope must pass to visualize this pathology requires sedation and may not always be possible during bedside evaluation. With 13.2% of tracheostomized patients reported to have laryngeal lesions, evidence from literature synthesis suggests that nasendoscopy may result in more successful decannulation, although scoping to the level of the glottis does not identify subglottic pathology [31,32].

Thomas et al., 2020 [4] discuss the use of 'capping' or 'corking', as another technique to detect incompetence of the supra-stomal trachea by completely obstructing the *in-situ* tracheostomy tube. Capping the tracheostomy tube forces the patient to use the upper airway for both inspiratory and expiratory flow and experience normalized airway pressure changes during the respiratory cycle. Unlike the one-way valve, capping elicits an inspiratory negative pressure change within supra-stomal anatomical segments. These inspiratory negative pressures may be sufficient to overcome the structural integrity of incompetent or narrowed supra-stomal segments due to the collapsing pressures generated. Inability to tolerate capping may be indicative of laryngotracheal pathology although the tracheostomy tube itself may "splint" the suprastomal tracheal segment during these negative pressure swings and mask potential complications [4]. While "capping" is discussed in the literature, the purpose, timing and duration of applying a tracheostomy cap lacks consensus and guidelines. Standardized "capping" protocols have been developed by individual centers, but a larger sample size is required to test efficacy and determine which cohort benefits from this additional step in the decannulation process [33,34].

Clinical Applicability of Laryngeal Ultrasound

Given the absence of consensus on ways in which subglottic incompetence can be identified in patients with tracheostomy, clinicians must remain cognizant of the potential for failed decannulation due to this risk factor and explore additional diagnostic methods to detect its presence where there is a clinical concern.

Laryngeal ultrasound has been discussed as an exploratory non-invasive clinical tool for identifying laryngeal and supra-stomal abnormalities and could be explored in the process of tracheostomy decannulation. Ultrasound (US) is a non-invasive bedside diagnostic tool, available in most intensive care units [35], although its portable nature promotes wider clinical utilization. Ultrasonography is employed to identify abnormal physiology, assist clinical examination and decision making [36] and is well established for point of care lung assessment [37] and echocardiography [38]. There is increasing interest in ultrasound development for diagnostic and monitoring purposes, due to its safety, lack of radiation, rapid application, and real-time dynamic feedback [39].

Clinicians specializing in the upper airway currently utilize a range of invasive instrumental diagnostics (nasendoscopy; laryngoscopy; flexible endoscopic evaluation of swallowing; endoscopic evaluation of the larynx; and video fluoroscopic swallowing studies) to promote objective assessment of the biomechanics, pathology and anatomical structures involved in swallowing and laryngeal function [40-43]. The Covid-19 global pandemic challenged clinician's abilities to complete instrumental assessments, secondary to the risk of completing aerosol generating procedures affecting transmissibility of the disease [44-46]. This challenge has encouraged clinicians to explore alternative approaches to clinical care, including developments in laryngeal ultrasound.

Performed using a sweeping motion across the midline, paramedian transverse, and longitudinal regions of the neck, utilizing frequencies of 7-18 MHz with a linear probe, laryngeal ultrasound allows identification of anatomical structures, and subtle but clinically important abnormalities that are not visible with other modalities [47]. These authors suggest that although laryngeal visualization is possible through varying thyroid cartilage thickness, optimization through the thyrohyoid and cricothyroid membranes enables hypoechoic views of the subglottic space, glottis and supraglottic anatomy.

The subglottic space is the narrowest aspect of the trachea and vulnerable to stenosis [22]. New clinical assessments of this anatomical area should demonstrate robust measurement properties in relation to established or proven techniques. There is emerging evidence of the reliability of subglottic airway ultrasound using a linear probe at 7-15MHz for airway diameter, when compared with magnetic resonance imaging [48]. Furthermore, ultrasound has been shown reliable in evaluating the nature, length and diameter of subglottic lesions, using a linear probe at 6-12MHz, when compared with endoscopy and computerized tomography [49]. Eicken et al., 2012 [50] highlights a significant loss of reverberation artifact seen on ultrasound in a normal subglottic space, and a narrowed air column width in a case of subglottic stenosis. Reduced air column width is further supported by Farghaly et al., 2020 [51] exploring early post-intubation ultrasound for tracheal stenosis, who report significantly reduced air column width, ratio and difference in comparison to ultrasound scans of patients without stenosis. Several authors [48,49,52] using a linear probe at 3.5-10 MHz, and an extended neck in supine, report that ultrasound can reveal intrinsic and extrinsic lesions, with potential to place compressional forces on the trachea, similar to the stenotic pathology encountered by Thomas et al., 2020 [4].

In addition to establishing upper airway patency prior to tracheostomy decannulation the ability to phonate is a critical clinical indicator of decannulation readiness. Comparable abnormalities of vocal cord pathology and movement are reported between laryngeal ultrasound and computerized tomography in patients with thyroid swelling [53], suggesting laryngeal ultrasound is valuable in the assessment of vocal cord palsy, particularly for those unable to tolerate laryngoscopy, or where it is otherwise contraindicated [47]. Although high body mass index (BMI) can impact visualization of vocal fold function [54], using laryngeal ultrasound to assess vocal fold function appears viable. Specificity, sensitivity and predictive values for vocal fold ultrasound remain variable within the literature, suggesting it could be utilized as a first line screening tool with secondary laryngoscopy for positive cases [43,55-58].

While there are currently no identified studies exploring laryngeal ultrasound in the context of tracheostomy weaning, the modality has a promising role in future areas of application. Some authors suggest there is scope for ultrasound to be used in the assessment of tracheal diameter to guide pediatric tracheostomy tube changes [59]. There are also developments using laryngeal ultrasound for the prediction of post extubation stridor using air column width and laryngeal oedema [60-63]. Future exploration of laryngeal ultrasound in the screening for laryngotracheal stenosis secondary to one way valve intolerance in patients with tracheostomy is urgently required.

Conclusion

Laryngeal ultrasound as a portable non-invasive tool has the potential to support identification of supra-stomal airway narrowing and vocal cord function which may influence clinical reasoning toward tracheostomy decannulation. Laryngeal ultrasound is an emerging technique which has yet to be fully validated across multiple patient cohorts and diagnostic groups. Future studies should evaluate its ability to reliably detect upper airway pathology by comparison against traditional and

well-established diagnostic tools. Further consideration of the protocol for utilizing ultrasound in this cohort, focusing on the ideal imaging method for evaluation of laryngeal structures requires multidisciplinary team collaboration. Advancing scope of practice for Allied Health Professionals in the United Kingdom may provide a vehicle for progressing laryngeal ultrasound methods and frameworks within standard clinical practice.

The recent worldwide Covid-19 pandemic has demonstrated the need to identify alternatives to high-risk aerosol generating procedures, such as endoscopy, which often require multiple staff involvement and specialist environments. Further development of this emerging technique may mitigate these risks, and concomitantly add a different dimension to existing diagnostic tools.

Conflicts of Interest

There are no conflicts of interest declared in the preparation of this narrative.

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